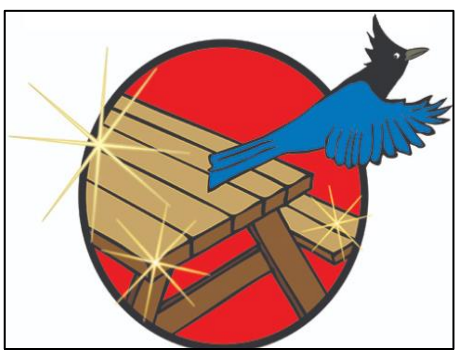

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Compensatory Mitigation Strategy for Marbled Murrelets Impacted by Operation of the Humboldt Wind Project

Project #3980

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Executive Summary

The marbled murrelet (*Brachyramphus marmoratus*) is a federally threatened and state endangered seabird that flies between the ocean and inland sites used for nesting. In southern Humboldt County, development of a wind energy facility has been proposed by Humboldt Wind, LLC. (hereafter the Project), which would construct a line (or string) of turbines along the top of Bear River Ridge and Monument Ridge. There is potential for murrelets crossing these ridges to encounter wind turbines associated with this Project as they transit to and from inland nesting habitat. The most precautionary estimate of risk to marbled murrelets over the 30-year life of the Project was estimated to be 7.77 adults by a probabilistic collision risk model, after accounting for interannual variability in inland transits over the 30 years.

The Project is estimated to result in the loss of individual murrelets but will not take or compromise existing nesting habitat. As such, the risk to murrelets associated with this Project will be temporary, existing only when turbines are operational. Herein, a compensatory mitigation strategy is proposed that will fully replace the 7.77 adult murrelets predicted to collide with turbines over the 30-year Project period as well as create additional murrelets. Calculations used maximally conservative inputs with the intention of estimating replacement. This mitigation strategy is estimated to produce substantially more breeding adults than will be lost; replacement of adult murrelets is likely projected to be between 6 and 12 times greater than loss depending on scenario and assumptions. Because the production of adult murrelets over 30 years will likely exceed take by 6-12 times, the strategy proposed herein will ensure full mitigation of Project related losses much earlier than the 30-year life of the Project. Any uncertainty in assumptions used to estimate replacement should be accommodated by estimates of replacement exceeding take.

Murrelet populations throughout the Pacific Northwest became threatened due to population declines resulting from extensive losses of suitable nesting habitat; only 4% of coastal old-growth forest remains in California relative to what was historically available. For most threatened or endangered species, mitigation strategies usually consist of the generation or protection of habitat. Marbled murrelets typically nest in mature and old-growth trees (redwoods or Douglas fir in California) that have developed branches large enough to support nesting, which requires a minimum of more than two centuries, and often longer, to achieve. As such, the generation of old-growth forest able to support murrelet nesting would minimally require 6-7 times the duration of the proposed Project; little benefit to murrelets would occur for 200-500 years while the trees were developing adequate structure to support murrelet nesting. Almost all remnant murrelet nesting habitat has been protected in California through designation as national, state, and county parks or preserves. There are also no willing sellers of additional land with old growth in Humboldt County.

Therefore, mitigation strategies have focused on reduction of predation hazards to murrelets in existing publicly owned parks. A primary goal of parks is to provide people with opportunities for "enjoyment, education, and inspiration" (NPS 2019), "high-quality recreation" (California State Parks 2019), including "camping, picnicking, swimming, fishing, boating, beachcombing, clamming, hiking, bicycling and wildlife viewing" (Humboldt County 2019). An inadvertent consequence of incorporating the majority of remnant murrelet nesting habitat into areas shared with human recreation is the concomitant increase in the availability of anthropogenic foods and subsequent attraction of synanthropic species into these areas, including corvids (Family Corvidae; includes jays, ravens, crows and magpies). Unfortunately, nest predation by corvids (especially Steller's jays and common ravens) has caused substantial reproductive loss to murrelets to the extent of threatening their ability to successfully produce chicks in remaining old-growth habitat. Thus, increased abundance and activity of corvids in these coastal old-growth forests has degraded quality of the remaining murrelet nesting habitat. Notably, the murrelet nesting season greatly overlaps the time of year when human use of these areas is greatest (April-September), which further compounds the risk that corvids pose to nesting murrelets.

Failure of murrelet nests due to predation by corvids is currently the greatest threat to murrelets in California (perhaps with the exception of climate change and the predicted vulnerabilities and loss of old-growth forests in coastal areas of California; DellaSalla et al. 2015, DellaSalla 2017). Efforts to reduce current levels of predation have been identified as essential to maintaining a viable murrelet population in California. In recognition of the severity of the situation for murrelets, all major parks in coastal old-growth forests throughout California have prioritized actions that eliminate sources of anthropogenic foods and effectively minimize corvid attraction to murrelet nesting habitat so as to reduce human-induced take caused by recreation in murrelet nesting habitat.

Anthropogenic food not only attracts corvids to these areas, it also increases reproductive success and survivorship of these individuals, thereby increasing the local abundance of corvids. Increases in corvid abundance are known to increase nest predation rates for a variety of bird species, including murrelets. The suite of actions needed to effectively ensure that park visitors are able and willing to keep recreational areas overlapping murrelet habitat "crumb clean" to minimize corvid use of parks is referred to as "comprehensive corvid management". Comprehensive corvid management requires the installation of bear-proof food lockers, garbage bins, and recycling bins; food catchment devices under water spigots; educational signage; active visitor education; and enforcement of corvid management practices throughout the murrelet nesting period.

Successful implementation of comprehensive corvid management is beyond the budget capacity of most parks despite it being a major cause of poor reproductive success of a federally threatened and state endangered species. In recognition of this problem, natural resource trustee agencies (California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, National Park Service) and Trustee Councils overseeing the restoration funds to replace murrelets lost in oil spills have made substantial financial contributions throughout central and northern California to facilitate corvid management initiatives and ensure resources needed to implement range-wide corvid management over the past 15 years.

One of the last remaining parks containing coastal old-growth forest in California but lacking comprehensive corvid management is Van Duzen County Park (VDCP) in southern Humboldt County near the location of the proposed Project. VDCP contains many trees capable of supporting nesting by murrelets. VDCP also attracts many visitors throughout the murrelet nesting season due to its proximity to population centers, its scenic old-growth setting, the readily accessible swimming holes, and relatively low-cost camping.

Herein, a strategy is proposed to fully replace and provide a net benefit to murrelets by implementing comprehensive corvid management at VDCP. Efforts to eliminate anthropogenic foods to corvids will directly benefit murrelets nesting in or near VDCP by minimizing predation risk posed by corvids. Furthermore, murrelets nesting in nearby parks (e.g., Cheatham Grove, Grizzly Creek State Park, Humboldt Redwoods State Park, and Headwaters Forest Reserve) will also benefit because corvids subsidized by foods at campgrounds are in better condition and are able to produce more young. Thus, VDCP serves as a "source" of corvids where newly produced juveniles disperse into the broader landscape and increase predation risk for murrelets nesting in nearby forests, compromising a wider landscape.

Habitat acquisition in California was not a viable option for murrelets as almost all remaining stands of old-growth forest in California have either been protected or are possessed by landowners unwilling to sell. Furthermore, while habitat creation is essential for the population to return to historical levels, this takes many times longer than the duration of the Project. Importantly, despite habitat protection, murrelets have continued to decline due to nest predation such that some old-growth forests structurally capable of supporting murrelet nests currently support relatively little nesting by murrelets. Thus, increasing nest survivorship is essential for murrelets to persist in the habitat that remains, and this can only be accomplished by reducing the frequency of nest predation in that remaining habitat. This approach both repairs an existing problem and is intended to maintain a viable breeding population of marbled murrelets through the temporal period required for maturation of additional (acquired) forest habitat to achieve breeding habitat for the species.

Improvements in the survivorship of murrelet nests are virtually impossible to directly measure due to the difficulty of locating a nest and reliance on correlational links are required. This need to indirectly assess murrelet nest success is required for any mitigation strategy that would be beneficial to murrelets, whether the proposed actions are to acquire or create additional habitat or to improve the quality of remaining protected habitat, although both approaches that have been supported by the resource agencies. Steller's jays are incidental nest predators and, as such, the chance that they will encounter murrelet nests as they search for primary food sources (fruit and insects) in the forest canopy is random and varies in proportion to their abundance. Thus, the loss of nests due to predation would decrease proportionally in response to relative reductions in predators. This proportional relationship can be used to infer improvements in the survivorship of murrelet nests for various levels of predator reductions. Reductions in the abundance of Steller's jays and other corvids in VDCP will be quantified to assess efficacy of mitigation actions in providing a net benefit to murrelets.

Specifically, this Project will consider reduction in Steller's jays, the primary predator of murrelet nests in northern California, as indicative that mitigation efforts will mitigate Project losses and provide a net benefit to murrelets. A 32% reduction of corvids has been reported as a minimum reduction elsewhere and this reduction would provide full compensatory mitigation plus 21.6 to 53.2 additional murrelets (depending on assumptions). However, based on outcomes of analogous actions in other parks throughout California, it is expected that reductions will probably be at least 50%, which will conservatively provide 6 to 12 times more murrelets than will be lost due to the Project. However, the minimum potential effectiveness target will be 32% and this will be the minimum target of the mitigation. However, a 50% reduction will be considered the likely evidence-based outcome. Consequently both the 32% and the more likely 50% corvid reductions are reported here to identify the minimum target used in the effectiveness assessment but also the more likely outcome based on evidence from other parks, respectively.

The target reduction will be monitored with standardized point-count surveys. Point counts have been used elsewhere to quantify corvid reductions conducted and will be used here before the first year of active corvid management in order to establish a baseline. These surveys will be repeated at 2, 4, 6, 8, and 10 years after initiation of corvid management. If the target reduction is not met within 6 years, additional measures used elsewhere to reduce corvid predation of murrelet nests such as conditioned aversion will be used to further improve the likelihood that murrelets can nest successfully in and around VDCP.

Ultimately, actions proposed for mitigation will facilitate the production and survival of additional adult murrelets in southern Humboldt County. Based on a 50% reduction in the abundance of Steller's jays (and other corvids) and the resulting increase in nest survival are estimated to conservatively produce between 47.6 and 96.8 additional breeding adults over 30 years. This represents a complete mitigation of take as well as a production of an extra 40 to 89 breeding adults, and the goal of complete replacement would be met within 5 to 10 years of achieving the 50% reduction, with continued benefits thereafter.

In addition to minimizing the take that occurs annually by allowing human recreation in murrelet nesting habitat without comprehensive actions to minimize anthropogenic feeding of murrelet nest predators, there are additional benefits to murrelets that have not been quantified by the proposed mitigation that should be considered in the overall assessment of net benefits to murrelets. Installation of a renewable energy facility in Humboldt County will minimize the reliance on petroleum-based energy generation. For murrelets, oil spills in Humboldt Bay have killed hundreds of adult murrelets since 1997, which is orders of magnitude greater than the take estimated for the Humboldt Wind Project. Furthermore, shifting to energy sources that do not release carbon into the atmosphere is essential to minimize climate change which, given the observed and projected warming trend, threatens to shift the range of coastal redwood forests northward. For murrelets, any additional loss of habitat that could result from climate change should be considered catastrophic due to the extraordinary amount of time needed to for forests to mature enough to support nesting by murrelets.

Table of Contents

Tables

Figures

List of Preparers

Richard T. Golightly, Ph.D.
Stephanie R. Schneider, M.S.
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Section 1.0 Introduction

The marbled murrelet (*Brachyramphus marmoratus*, hereafter "murrelet") is a small seabird found along the Pacific Coast of western North America, ranging from central California to northern Alaska (Carter and Erickson 1992, Piatt and Naslund 1995). This species was listed as Federally Threatened in 1992 (Federal Register 57 FR 45328) and State Endangered in California in 1992 (USFWS 1997). Unlike other seabirds that nest on offshore rocks and islands, murrelets typically nest on large branches of old-growth and late-successional coniferous trees up to 37 km inland from the ocean in California (Carter and Erickson 1988, Patton and Ralph 1990). Murrelets do not build nest structures; rather they lay and a single egg on large, flat tree branches with natural depressions or moss, lichen, and tree litter. In northern California, redwoods (*Sequoia sempervirens*) are the most common conifer available for nesting, although they also nest in Douglas fir (*Pseudotsuga menziesii*; Golightly et al. 2009).

Humboldt Wind, LLC. has proposed to build a wind energy facility in southern Humboldt County, CA (hereafter "Project") which is within the range of the murrelet. In the case of murrelets, the turbines will not directly damage or degrade murrelet nesting habitat; however, the turbines do represent a collision risk hazard for individuals crossing Bear River Ridge or Monument Ridge in the vicinity of the Project. Under the assumptions of the maximum turbine size and rotational speed, the greatest collision risk assessment conservatively estimated that 7.77 adult murrelets would be removed from the population over the 30-year life of the Project.

Herein, a strategy to fully replace and provide a net benefit to murrelets to mitigate losses associated with the Project is described and the expected magnitude of replacement is estimated. Developing a mitigation strategy that will result in a net benefit to murrelets within the 30-year life of the Project is challenging because traditional mitigation actions, specifically the creation and protection of essential nesting habitat, is not a readily available option for murrelet mitigation. In California, less than 4% of the coastal old-growth habitat historically available to murrelets for nesting remains (Noss 2000). This extensive habitat loss due to harvesting of old-growth forests throughout the Pacific Northwest led to the decline and eventual listing of murrelets in California, Oregon, and Washington (USFWS 1997). Murrelets nest in forests that are a minimum of 200 years old, as the branch characteristics needed to support nesting are not available in younger forests (Hamer and Nelson 1995, Plissner et al. 2015); note that redwoods take considerably longer to attain characteristics needed to support murrelet nesting relative to Douglas fir and many murrelet nest trees are much older (500^{+} years). The rate of loss of coastal old growth forests has slowed and, in some areas, halted (Raphael et al. 2016); in California, almost all remaining patches of old-growth coastal forest have been protected by incorporation into national, state, and county parks or preserves (Golightly and Gabriel 2009). Therefore, there is little additional habitat available to protect. The creation of additional habitat from stands that are now young, while ultimately beneficial for supporting a larger murrelet population in the long-term, fails to address the short-term needs of murrelets. Addressing the immediate issues threatening murrelet survival will ensure a surviving population that can benefit from any efforts to create additional breeding habitat in the future.

Although murrelet nesting habitat has become increasingly protected from harvest through the designation as federal, state, and county parks, the quality of these areas has been degraded and this degradation compromises the viability of the remaining murrelet population (Peery and Henry 2010). A major goal of parks is to provide people with opportunities for "enjoyment, education, and inspiration" (NPS 2019), "high-quality recreation" (California State Parks 2019), including "camping, picnicking, swimming, fishing, boating, beachcombing, clamming, hiking, bicycling and wildlife viewing" (Humboldt County 2019). An inadvertent consequence of incorporating the majority of remnant murrelet nesting habitat into areas designed for human recreation is a concomitant increase in the availability of anthropogenic foods and subsequent attraction of synanthropic species into these areas, including corvids (Family Corvidae includes jays, ravens, crows, magpies, and nutcrackers). Notably, the murrelet nesting season greatly overlaps the time of year with the greatest human use of parks (April-September; S.E. McAllister & Associates 2019) and murrelet nest failure due to corvid predation is so frequent it inhibits the production of new juveniles and threatens population viability (Peery and Henry 2010).

It is well established that recreation by humans in wild landscapes changes the use of these areas by various corvid species (Wallen et al. 1999, George et al. 2001, Bensen 2008, NPS 2010, Walker and Marzluff 2015, Goldenberg et al. 2016, West et al. 2016). Corvids are attracted to the accessibility of anthropogenic foods at campgrounds, picnic areas, and along hiking trails throughout these coastal old-growth forests. The resulting increases in corvid abundance have been well documented at protected old-growth forests near the Project; Steller's jays (*Cyanocitta stelleri*) were 3 to 6 times more abundant in and around areas where anthropogenic foods were easily accessed at Redwood National and State Parks (Wallen et al. 1999, George et al. 2001, Bensen 2008, NPS 2010).

Murrelet nests may be depredated by various types of corvids (Luginbuhl et al. 2001, Marzluff and Neatherlin 2006, Hébert and Golightly 2007, Malt and Lank 2009, Golightly and Schneider 2009, 2011); In northern California, Steller's jays are implicated as the primary predator of murrelet nests and to a lesser extent common ravens (*Corvus corax*; Golightly and Schneider 2009, 2011). At Redwood National and State Parks, nest failure due to corvid predation was 71.4% (Golightly and Schneider 2011) and an analysis of all studies reporting corvid-specific nest failure rates suggests that nest loss due to corvids could be as high as 90.9% with Steller's jay accounting for 69.7% of all losses due to corvids (Singer et al. 1991, Luginbuhl et al. 2001, Marzluff and Neatherlin 2006, Hébert and Golightly 2007, Malt and Lank 2009, Golightly and Schneider 2011). Demographic studies from central California also corroborate a nest predation rate of 69% with the primary predator identified as corvids (Peery et al. 2004a, Peery and Henry 2010). Actions that reduce current levels of predation are essential to murrelet recovery. Eliminating all sources of anthropogenic foods available to Steller's jays and other corvids in coastal old-growth forests is essential to improving the quality of murrelet habitat throughout California to maintain viability of the murrelet population here; in central California parks, it was calculated that a 40% reduction in corvids could improve murrelet nesting success enough to halt and reverse the continued population decline (Peery and Henry 2010).

In recognition of the severity of the situation for murrelets, all major parks in coastal old-growth forests throughout the state of California have prioritized actions that eliminate sources of anthropogenic foods and effectively minimize corvid attraction to murrelet nesting habitat. The suite of actions needed to effectively guarantee that park visitors are able and willing to keep murrelet habitats "crumb clean" to minimize corvid use of parks are collectively referred to as "corvid management." Comprehensive corvid management requires the installation of bear-proof food lockers, garbage bins, recycling bins, food catchment devices under water spigots, educational signage, and active visitor education, and enforcement throughout the murrelet nesting period.

Although it has been widely recognized that the co-occurrence of human recreation and murrelet nesting habitats has potential to cause significant impacts that compromise murrelet recovery, we are unaware of any discussion of permits being sought or issued to cover the impacts caused by these parks to murrelets. However, predation on murrelets by corvids in Redwood National and State Parks was recognized to have potential to have a significant negative impact on the federally listed murrelet population which resulted in a biological opinion from the USFWS in 2007 that required a trails plan with corvid management and monitoring (NPS 2008). Another example of the recognition of this problem regarding the California Environmental Quality Act comes from the Final Environmental Impact Report (FEIR) for the General Management Plan at a central California park (California Department of Parks and Recreation 2013). The new General Management Plan resulted in considerable public debate that included a call to remove campgrounds from murrelet nesting habitat as a means of protecting murrelets from corvids (Audubon California 2013). The FEIR had a finding of "significant and unavoidable impact", and a settlement agreement was reached with parties that sued to address corvid impacts to murrelets (California Department of Parks and Recreation 2013). In the settlement agreement the park agreed to several management activities including immediate implementation of the "crumb clean campaign", trash management and, where possible, relocating camping and picnic facilities out of murrelet nest habitat.

Unfortunately, successful implementation of a comprehensive corvid management strategy is beyond the general financial capacity of most parks. Recognizing this limitation, natural resource trustee agencies (California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, National Park Service) have made substantial efforts to facilitate corvid management initiatives within their jurisdiction and prioritized major funding from several sources including oil spill restoration funds to ensure adequate resources to accomplish this task. These restoration funds were specifically directed to mitigate the loss of hundreds of murrelets resulting from oil spills in California (see damage assessments for the Command, Luckenbach, Kure, Stuyvesant, and Cosco Busan oil spills; CDFW 2019a, 2019b, 2019c, 2019d, 2019e and Society for Ecological Restoration 2019). Implementing comprehensive corvid management in murrelet nesting habitat as a means to mitigate losses was the most consistent and coordinated action taken by the Trustee Councils overseeing the oil spill restoration funds.

Over the past 20 years, almost all parks in California with habitat suitable for murrelet nesting have implemented programs intended to minimize feeding of corvids through changes in infrastructure, park practices, and visitor outreach including most parks in Humboldt County (e.g., Humboldt Redwoods State Park, Grizzly Creek State Park, Headwaters Forest, and Redwood National and State Parks). Parks that have implemented a corvid management strategy have substantially reduced the abundance and density of corvids, thereby reducing the likelihood of nest failure for murrelets. Evidence corroborating this assertion comes from four parks containing murrelet nesting habitat in central California (Big Basin Redwoods State Park, Portola Redwoods State Park, Butano State Park, and San Mateo County Memorial Park); in these parks' jay abundance has been successfully reduced by minimizing food accessibility (Suddjian 2009, Halbert and Singer 2017).

Unfortunately, one park managed by Humboldt County, Van Duzen County Park (VDCP), has not received support to develop a corvid management plan or resources to fix infrastructure despite containing murrelet nesting habitat. VDCP attracts many people throughout the murrelet nesting season due to its proximity to population centers, its scenic old-growth setting, the readily accessible swimming holes, and relatively low-cost camping. In 2018, corvids were reported in surveys at VDCP at 15 of 16 survey stations (S.E. McAllister & Associates 2019).

This lack of corvid management at VDCP compromises murrelets nesting here and at all other nearby locations that have already implemented corvid management practices; it is likely that the corvids concentrating around sources of anthropogenic food in VDCP have territories extending beyond the boundaries of VDCP into nearby old-growth forests (Scarpignato and George 2013, Goldenberg et al. 2016, West et al. 2016, West and Peery 2017); forests influenced by corvid abundance beyond VDCP include those neighboring VDCP (e.g.: Cheatham Grove and Keller Flats) and other forests within traveling distance of corvids such as Humboldt Redwoods State Park, Headwaters Forest Reserve, and Grizzly Creek State Park. By establishing the kind of corvid management practices implemented by other parks, nesting habitat in and adjacent to VDCP can be enhanced, resulting in the production of new murrelets that would not occur without the aid of corvid management. In addition, corvid management in VDCP should also benefit murrelets nesting outside, the park.

Given the logic presented above, development and implementation of a corvid management plan for VDCP that minimizes to the maximum extent practical, accessibility of anthropogenic foods to corvids as a means of reducing their abundance to increase murrelet nest survival throughout VDCP is proposed to both replace and provide a net benefit to murrelets. To estimate the expected benefit of this mitigation strategy to murrelets, the production of reproductively capable adult murrelets resulting from predator reductions throughout VDCP was calculated using a deterministic model of replacement. Inputs and assumptions used to quantify the production of new adult murrelets were based on the scientific literature and, when a range of values were possible, values were selected to be overly conservative so that the outcome represented a conservative estimate of what is expected. As such, the estimate of replacement provides a realistic minimum estimate of the net cumulative benefit to be expected for the proposed actions over the 30-year life of the Project. These calculations include the adjacent Cheatham Grove (California State Parks) as a reduction of predator abundance in VDCP that will also improve the quality of this adjacent grove in terms of increased reproduction by murrelets.

This strategy report incorporates the first two of the five bullet points below, in accordance with Mitigation Measure 3.5-2c: Implement Compensatory Mitigation to Offset Operational Impacts on Marbled Murrelets from the Draft EIR. The subsequent three bullets will be addressed prior to mitigation implementation.

• A description of how predator management will be implemented at Van Duzen County Park to reduce the abundance and concentration of corvids (Steller's jays and ravens)
• A plan to assess the effectiveness of the predator management and outreach campaign, and a reporting plan to describe the results.
• A work plan for collaborating with land managers of adjoining parcels and nearby reserves to facilitate comprehensive predator and visitor management in areas adjacent to Van Duzen County Park.
• A funding plan detailing the costs associated with implementation of the plan for the life of the project, and a description of endowment that will fund ongoing predator management, visitor outreach, and monitoring.
• A schedule for mitigation implementation and reporting.

1.1 Proposed mitigation

1.1.1 Location of mitigation

VDCP is located approximately 5.7 miles (9.2 km) north of the Project's turbines and contains approximately 135 acres (54.6 ha) of suitable murrelet nesting habitat. Murrelet habitat encompassed by VDCP is in four groves separated by short distances from each other along the Van Duzen River. Although not part of VDCP, an additional 90 acres (36.4 ha) of old-growth forest suitable for murrelet nesting known as Cheatham Grove is separated from VDCP by an elbow of the Van Duzen River; this grove is 85 m distant from the eastern extent of VDCP at the closest point. Although Cheatham Grove is managed by California State Parks, this grove is virtually contiguous with VDCP and lacks outreach and enforcement of corvid management goals. Importantly, murrelets and corvids are unaware of the jurisdictional differences in these five adjacent groves of old-growth forest. Thus, corvids attracted by visitors to VDCP likely inhibit the survival of murrelet nests throughout this entire area. Hereafter, these affected forests are collectively referred to the as the Van Duzen River Complex (VDRC) and this entire area 225-acre (91 ha) area is considered for purposes of calculating replacement.

Across the river from VDRC are additional stands of older second-growth known as Keller Flats; this area may also be capable of supporting nesting by murrelets (S.E. McAllister & Associates 2019). Corvids could easily travel between groves within VDRC and Keller Flats and, as such, the quality of Keller Flats would also benefit by comprehensive corvid management within VDRC. The two nearest stands on Keller Flats total approximately 108 acres (43.7 ha) and, although these lands were not included in replacement calculations, they could increase the area of benefit by 48% and, thus, in the event that murrelets do nest in this stand the production of new murrelets would increase estimates of replacement beyond those reported here.

Behaviors indicative of nesting (Evans Mack et al. 2003) have been reported at VDCP and nearby Cheatham Grove (L. Roberts, pers. comm., S.E. McAllister & Associates 2019). In recent surveys commissioned by Humboldt County in 2018, murrelets were detected at all sites in VDCP and circling behaviors associated with nesting were observed multiple times at Cheatham Grove (S.E. McAllister & Associates 2019). Furthermore, in 2001, sub-canopy behaviors by murrelets were also observed at VDCP which is indicative "occupancy" according to the Pacific Seabird Group (PSG) Protocol that is relied on as a means of identifying forest stands that support activities associated with murrelet reproduction (Evans Mack et al. 2003). Importantly, the PSG Protocol does not limit the time for which a stand is classified as occupied following the observation of behaviors indicative of occupancy; "although it is possible for murrelet presence/probable absence in forest stands to change through time, we recommend that occupied stands should be treated as occupied indefinitely" (Evans-Mack et al. 2003). Although sub-canopy behavior used to classify stands as occupied were not detected in VDCP during the 2018 surveys, other behaviors including circling and diving flights were both observed from survey stations in VDCP in 2018. The PSG Protocol specifically notes that "circling and other above-canopy flights, such as dives, indicate possible occupancy of a site (reviewed by Nelson and Hamer 1995). These behaviors are a red flag that should prompt additional survey effort to observe subcanopy activity" (Evans Mack et al. 2003). Although the PSG Protocol requires two years of initial survey (unless positive results occur in the first year) to classify a stand as unoccupied, a 19-year effort to survey murrelets by the Humboldt Redwood Company (see HRC 2019) following methods established by the PSG Protocol provides evidence that two years is not always sufficient to detect behaviors indicative of occupancy when re-examining a stand for occupancy; based on HRC data, an average of 2.9 and maximum of 13 years can elapse between subsequent detections of occupied behavior at a given site (see Table 1 in HRC 2019). Consequently, based on the PSG Protocol, both Cheatham Grove and VDCP should be considered occupied and regarded as capable of supporting nesting and reproductive activities of murrelets.

1.1.2 Proposed actions

VDCP has 57 individual campsites in a formal campground, a large group campground, a variety of river access points, trails, and picnic areas. Presently anthropogenic foods can be easily accessed by a variety of wildlife species, including corvids. Elimination of anthropogenic food sources available to corvids within VDRC would be achieved through three general actions: (1) comprehensive installation of animal-resistant hardware to minimizes accessibility of anthropogenic foods to jays and other wildlife, (2) development of an interpretive outreach program to educate park visitors about the detriments of wildlife feeding, especially as it relates to murrelet survival (Marion et al. 2008, NPS 2008), and (3) formalizing 1 and 2 above in a written management plan.

Elimination of anthropogenic food sources available to corvids must be comprehensive, because even small quantities of food can provide energy substantial enough to concentrate individuals within otherwise high-quality murrelet habitat. Therefore, actions are proposed to minimize foods available to corvids in all areas of VDRC where visitors may make food available. Proposed management actions target Steller's jays but would also likely reduce raven abundance (Marzluff and Neatherlin 2006). Thus, the proposed mitigation will reduce the abundance corvids throughout VDRC by minimizing availability of anthropogenic foods throughout the park.

VDCP does have some bear-proof trash cans, but infrastructure needed achieve the comprehensive reductions in anthropogenic foods required for successful corvid management requires installation of additional bear-proof trash cans as well as various bear-proof food-storage and waste-control devices. In addition, VDCP lacks an overall corvid management plan and there is little outreach to educate visitors, as is common in other parks and preserves within old-growth forests. Specific infrastructure needs at VDCP include bear-proof food lockers, garbage bins, recycling bins at all at campgrounds, picnic areas, and points of interest. The number of trash and food storage devices needed throughout VDCP was determined in cooperation with Humboldt County Staff (Table 1). This bear-resistant hardware has a life expectancy of 20 to 30 years but could last much longer, even in the wet climate of northern California (BearSaver staff 2011, pers. comm). In addition to ensuring that all trash and food storage devices within VDCP are bear-resistant, grates with gravel catchments underneath all water spigots would be installed to restrict jay access to human food scraps commonly left by campers after washing food-covered items (i.e., pots and dishes) underneath these outdoor spigots (Table 1).

Furthermore, at VDRC park visitors will be encouraged to keep murrelet nesting habitats "crumb clean" by installing educational signage, implementing active visitor education, and enforcing corvid management practices throughout the murrelet nesting period over the 30-year life of the Project (Table 1). VDRC does not currently have a large-scale interpretive program designed to educate visitors about the impact of feeding jays and other wildlife species on the survival of murrelets and other bird species. Uneducated visitors are more likely to feed jays (and other wildlife), both directly and inadvertently, within VDRC. To promote visitor education, both passive and active techniques would be used. Passive techniques proposed include installing educational signs at each picnic table to remind visitors of the negative impacts of feeding wildlife, particularly Steller's jays and other corvids. Additional displays designed to educate visitors about the impacts of feeding wildlife would be installed at campgrounds and points of visitor concentration. Along with installation of hardware, an interpretation program that actively educates park visitors about the relationship between corvid feeding and murrelet survival would be developed and implemented to promote proper food handling practices throughout VDRC. Once the interpretive program is developed, the Project would provide funding for a part-time interpreter to educate visitors over the 30-year life of the Project.

Table 1. Infrastructure and interpretive elements to be provided to the Van Duzen River Complex for successful reduction in marbled murrelet nest predators as a strategy to replace individuals lost due to turbine operation associated with Humboldt Wind's proposed energy facility in Humboldt County, CA.

Mitigation element	Number [a]
Hardware installation at Van Duzen County Park	
Bear-proof food lockers	64
Additional bear-proof trash stations	6
Bear-proof recycling stations	10
Water faucet food grates	22
Corvid Management at Van Duzen River Complex	
Development of corvid management plan	1 year
Educational signage (initial and recurring)	30 years
Interpreter during peak visitor season (May to September)	30 years

[a] Infrastructure needs provided by the county in April 2019

Expected outcomes associated with the actions proposed to increase murrelet nesting success by reducing food availability and jay abundance are that 1) installing hardware and educating visitors would minimize food available to jays and other corvids, 2) minimizing food availability would successfully reduce jay abundance, and 3) reducing jay abundance would improve murrelet productivity. Mitigation actions proposed here are similar to actions implemented elsewhere in California to improve the quality of murrelet nesting habitat and increase murrelet reproductive success (CDFW 2019a, 2019b, 2019c, 2019e; USFWS et al. 2004). These actions have successfully reduced jay abundance elsewhere (Bensen 2008, Suddjian 2009, West et al. 2016, Halbert and Singer 2017, see Appendix A). To ensure compliance over time, reports will be produced annually and provided to Humboldt County (with copies to California Department of Fish and Wildlife and the US Fish and Wildlife Service). These reports will include state of the hardware in VDCP, notable outreach experiences including visitor contacts and activities, as well as results of post implementation corvid surveys and effectiveness monitoring (when conducted).

Due to the difficulty of finding murrelet nests, it is not possible to directly monitor murrelet productivity to assess the efficacy of any proposed mitigation actions. This is true for mitigation strategies that include habitat creation and acquisition as well as the habitat improvement mitigation strategy proposed herein. There are two aspects to the effectiveness of comprehensive corvid management, both of which have been demonstrated: (1) the degree to which proposed actions reduce corvid abundance in murrelet nesting habitat and (2) the degree to which these reductions will likely improve nesting success by murrelets. Predation is the primary cause of continued declines of murrelets (Peery and Henry 2010); a Population Viability Analysis for murrelets in central California (the population currently most vulnerable to extirpation) showed that a 40% reduction in corvid predation of murrelet nests would halt the current decline and allowing for a positive trajectory in population growth (Peery and Henry 2010). Although this latter part is challenging to directly quantify, the ratio of juveniles to adults observed at-sea in central California have increased since corvid management was widely implemented throughout the central California parks (Figure 1; Henry 2017).

Although measuring the juvenile to adult ratios at-sea are the most direct way to assess if murrelet nest survival has increased, this is still correlational and is easily confounded by additional factors that influence murrelet productivity such as poor ocean conditions and inability to provision chicks rather than solely reflecting nest loss due to predation (Henry 2017).

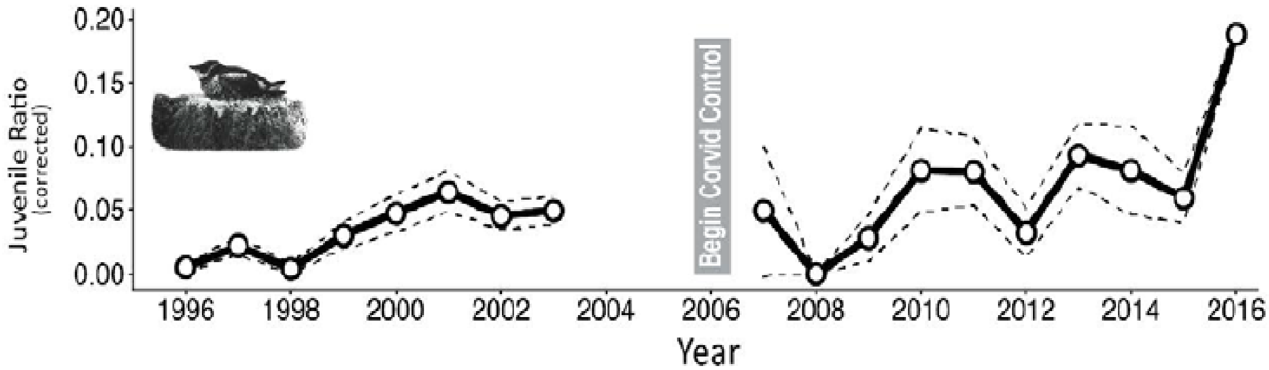

Figure 1. Trends in the juvenile to adult ratio of marbled murrelets observed in central California during at-sea surveys conducted prior to and following implementation of corvid management in old-growth nesting habitats. Dashed lines indicate the 95% confidence interval. This figure was originally produced by Henry (2017).

Section 2.0 Methods

2.1 Estimating replacement of adult murrelets

A conservative approach to projecting the cumulative production of new adult murrelets over the 30-year Project period was made to inform the decision-making process and to ensure that the proposed mitigation would produce a net benefit to murrelets. Because the radar surveys on which the collision risk assessment was based could not distinguish between juvenile, sub-adult, and adult murrelets, the most conservative approach was to assume that all take was of adult murrelets. A deterministic replacement model was created (Figure 2) to estimate the number of additional reproductively mature murrelets expected to result from reducing predation of murrelet nests throughout VDRC following implementation of comprehensive corvid management.

The cumulative production of reproductively mature murrelets within VDRC resulting from proposed mitigation actions were projected over a 30-year period using the following inputs:

(1) The lowest density of nesting that could occur in VDRC, which was a conservative method used to set the upper limit of replacement calculations;
(2) A modifier to reduce the number of nests currently present in VDRC relative to the conservative estimate of nest density established by point 1 so as to account for the current reality that murrelet nesting habitat associated with VDRC has been degraded by anthropogenic recreation and the resulting artificial elevation of corvid abundance;
(3) Evidence-based expectations regarding the reduction in corvid abundance at VDCP achievable by comprehensive corvid management;
(4) Literature-inferred expectations regarding reductions in nest predation and corresponding increases in murrelet nest survival following a reduction in corvid abundance;
(5) The probability of fledglings reaching sexual maturity (e.g., surviving to age 3).

This deterministic replacement model was specified to produce a range of conservative yet realistic estimates of the benefit of proposed mitigation actions to murrelets. Justification for each value used for inputs is detailed in Section 2.1.1 . Briefly, we assumed:

(1) A minimum potential nest density based on lowest density of active nests reported in the literature (1 nest per 8.23 acres; Manley 1999); it is likely that this assumption substantially underestimates the actual achievable nest density due to the fact that active nests have been located as close as 30 meters apart (Nelson and Wilson 2002, but see Plissner et al. 2015) and at greater density (Manley 1999);
(2) Two nest occupancy scenarios: one where only 33% of the potential murrelet nest-sites estimated to be present in VDRC are currently used (i.e., an effective nest density of 1 nest per 24.96 acres) and a second scenario where 0% of available nest are currently used in VDCP and only 33% of nest-sites are currently used in Cheatham Grove (i.e., an effective nest density of 1 nest per 62.44 acres).

(3) A range of evidence-based expectations regarding the achievable reduction in corvid abundance, from minimal to maximal, based on analogous efforts to reduce corvid abundance in parks central and northern California that contain murrelet nesting habitat;
(4) The minimum literature-based expectation in increases in nest survival of artificial murrelet nests and other avian species following reductions in corvid and predator abundance;
(5) The best available science regarding survival from fledging to adulthood;

Note that reproductive output of adult murrelets produced in excess of the lowest nest density reported for murrelets (and presumed nesting capacity of VDRC) were not included in estimates of replacement even though these additional birds would likely contribute to the additional production of adult murrelets.

2.1.1 Inputs and assumptions

2.1.1.1 Potential nest density that could be achieved in VDRC

Within any coastal old-growth forest, the number of branches possessing characteristics to support nesting by murrelets are limited. The number of suitable nest platforms theoretically sets the upper limit of a given habitat's potential to produce new murrelets. For VDRC, this value was estimated by multiplying the number of acres of old-growth (225 acres in VDRC) by a density of active nest-sites per acre. For purposes of this replacement calculator, the density of active nests achievable in VDRC was based on lowest density of nests reported by empirical studies, 1 active nest per 8.23 acres (reported as 0.3 nests per ha; Manley 1999). This calculation provides an estimate of the minimum achievable number of murrelet nests that could potentially occur in VDRC and was, thus, the most conservative estimate that could be used to calculate replacement.

The density of platforms able to support nesting by murrelets is a property of the forest and tree characteristics rather than murrelets, and if the habitat is able to support nesting at higher density (e.g., more than 1 platform every 8.23 acres) there is evidence that nesting could occur at much higher density than has been assumed herein; a recent habitat evaluation conducted for murrelets in VDRC noted that "all four stands within the VDCP complex exhibit…[an] abundance of large diameter branches and reiterated trunks" and the "effectively contiguous" Cheatham Grove supports "an abundance of large diameter branches, reiterated trunks, canopy gaps, and other characteristics that constitute suitable nesting habitat for marbled murrelets" (S.E. McAllister & Associates 2019). Thus, it is likely that the calculations for replacement underestimate the potential capacity of VDRC to support nesting murrelets in terms of the nest-site availability. Importantly, murrelets can nest at high density if the habitat will support it (Nelson and Wilson 2002, see Plissner et al. 2015, Manley 1999).

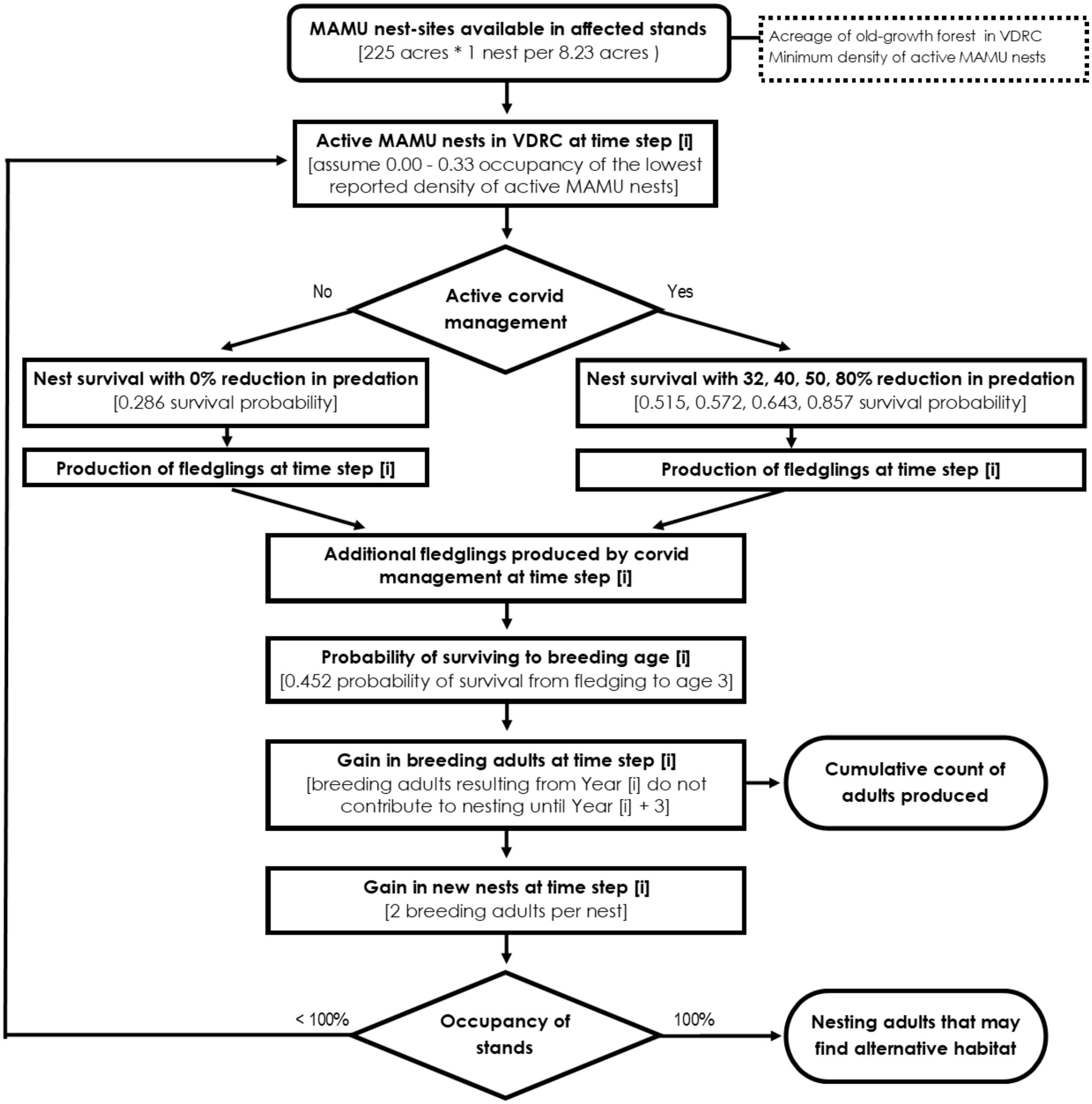

Figure 2. A flow diagram describing the structure of the model used to estimate replacement of adult marbled murrelets resulting from proposed mitigation actions at the Van Duzen River Complex (VDRC). In the context of this document, nest-site density is based on the lowest value reported in the scientific literature for murrelets (1 nest per 8.23 acres) and occupancy of those available nest-sites is defined as the proportion that are actively used; an occupancy of 0 indicates that none of the available nest-sites are actively used and an occupancy of 1 indicate all of the available nest-sites are actively used.

2.1.1.2 Proportion of potential nests that are currently used by murrelets in VDRC

Without extensive forest canopy surveys during the murrelet nesting season (e.g., tree climbing, which will cause disturbance if conducted during nesting and is incomplete and biased if conducted after the nesting season), it is not possible to empirically determine the proportion of actively used nest-sites within VDRC. While it is possible that all nest-sites are currently used each year and that the habitat in VDRC is 100% saturated, it seems more reasonable to presume that these stands are not currently 100% saturated, especially given the abundance of human recreation at the site. There are additional reasons to believe that the current number of nests in VDRC is lower than what would be expected if this habitat was optimal including: (1) old-growth in southern Humboldt County is likely undersaturated in general given that the population of murrelets detected on the ocean adjacent to this region is relatively small compared to what the inland old-growth habitats should be able to support; (2) although murrelets do exhibit strong fidelity to nest-sites, stands, and watersheds (Plissner et al. 2015), it is possible that individuals may attempt to nest elsewhere following frequent or repeated nest failure (Hedgren 1980, Harris et al. 1995, Lima 2009); and (3) alternative nesting habitat is within flight distance of VDRC and these sites have recently implemented corvid management to reduce corvid abundance; thus, nest failure due to predation should be lower in these nearby habitats.

To estimate the proportion of nests that are currently used by murrelets in VDRC, we assumed two scenarios: (1) a likely scenario, where all groves in VDRC are currently 33% occupied, and (2) a worst-case scenario, where VDCP is unoccupied (0%) and Cheatham Grove is 33% occupied. Assuming 33% occupancy in VDRC, the effective nest density used to calculate replacement started at 1 nest per 25 acres. In the worst-case scenario that considers VDCP to be unoccupied, the effective nest density used to calculate replacement started at 1 nest per 62.5 acres.

Although unlikely, we also calculate the number of breeding adults that could be produced in VDRC over a 30-year period if the all potential nest-sites available in VDRC are presently used and that this habitat remains saturated for the 30-year period. This represents the minimum number of murrelets that could be produced by this habitat if conditions were improved through reductions in nest predation, the primary factor limiting population growth for murrelets (Peery and Henry 2010). Because these calculations are based on the low reported nest density, this is almost certainly an underestimate of the actual capacity of this VDRC to produce murrelets.

For each 1-year time-step in the model starting at year 3, breeding adults resulting from nests initiated two years prior become mathematically recruited into the VDRC breeding population (with every two new adults forming one nest). The numbers of active nests in VDRC were allowed to increase in the model only to the point at which that habitat became saturated by attaining a nest density of 1 nest per 8.23 acres (the lowest density of murrelet nests reported; Manley 1999); if a greater nest density was possible, calculations would produce more new murrelets. When the number of nests calculated to be present reached the potential nest capacity calculated for VDRC by the model, the number of breeding adults resulting from nests in VDRC stopped increasing and was stable in subsequent time-steps. Individuals produced in excess of the capacity of VDRC may go on to nest elsewhere, but the potential reproductive output of these individuals were not counted for purposes of calculating replacement.

2.1.1.3 Justifiable expectations of predator reductions and increased nest success achievable from comprehensive corvid management in VDRC

Predation rates by corvids on murrelet nests were informed from studies within the redwood region of California. For purposes of replacement calculations, the current rate of nest loss to predation in the absence of corvid management was set at 71.4 %. This was the observed rate of nest predation by corvids at a nest in similar habitats (e.g., redwood forests) at Redwood National and State Parks, the nearest location to VDRC where predation rates by corvids have been quantified (Golightly and Schneider 2011). This corresponds to a nest survival rate of 28.6%.

Data from the scientific literature was compiled to justify (Appendix B) and set expectations for the effectiveness of corvid management actions (Appendix C) in terms of reducing the abundance of corvids, with a focus on Steller's jays. To summarize, we expect that Steller's jay abundance could be reduced according to the following four corvid reduction scenarios which would be reflected in the effectiveness of the mitigation:

(1) A minimum evidence-based scenario where abundance is reduced by 32%, which matches what was achieved in the first year of corvid management in central California parks (Suddjian 2009);
(2) A performance-based target scenario where abundance is reduced by 40%, assuming a 1:1 relationship between abundance and predation rate, and was identified as needed to maintain viable murrelet populations in central California (Peery and Henry 2010);
(3) A most likely evidence-based scenario where abundance is reduced by 50%, which is 4% lower than what was ultimately achieved by corvid management in central California parks (Suddjian 2009);
(4) A maximum evidence-based scenario where abundance is reduced by 80%, which approximates the differences in jay abundance documented in high-human-use areas relative to back-country areas of old-growth redwood forests of central and northern California (Benson 2008, Suddjian 2009, NPS 2010);

Data from the scientific literature was also compiled to justify and set expectations for the degree to which murrelet nest success could be improved following measurable reductions in predator abundance (Appendix C). Importantly, Steller's jays forage throughout the forest searching for food such as berries or insect prey and do not use a specialized search strategy to locate murrelet nests and, instead find nests incidentally (Vigallon and Marzluff 2005). Following Vigallon and Marzluff's (2005) conclusion that Steller's jay are incidental nest predators, encountering nests is a random event based on their abundance in an area and, as such, risk increases and decreases proportionally to jay abundance (linear relationship). To determine the proportional rate of increase following a unit of decrease, we calculated the degree to which a nest success increased for artificial murrelet following a 5% reduction in predator abundance. The survival of artificial murrelet nests increased by 1.145-1.208 times following a 5% reduction in Steller's jay and corvids, respectively (Malt and Lank 2009, Luginbuhl et al. 2001). Studies focused on other bird species produced comparable results, with the survival of nests increasing by 1.125-1.267 times following a 5% reduction in predator abundance (Appendix C).

For purposes of calculating replacement we used the lowest estimate of effectiveness and assumed that that nest success would increase 1.125 times following a 5% reduction in corvid abundance and where nest survival in the absence of corvid management was estimated to be 28.6%. Thus, for the most likely evidence-based scenario, a 50% reduction in predator abundance would cause the predation rate of 71.4% to be halved (71.4/2=35.7). This results in a 35.7% increase in nest survivorship. Thus, survivorship increased from 28.6% to 64.3% following a 50% reduction in predators. This is conservative as it assumes that one of every three nests will still fail due to predation even after the successful implementation of corvid management in VDRC.

2.1.1.4 Survival of fledglings to breeding adults

To estimate the production of new adult murrelets, the survival of fledglings to reproductive age had to be incorporated into the estimate. For murrelets, the age of sexual maturity is not precisely established, but the literature suggests that this occurs by age 2 or 3 (Beissinger and Nur 1997, Peery et al. 2006, Peery and Henry 2010); to be conservative, the calculations used here assumed that it takes 3 years to fully mature, although there may be individuals that breed as early as age 2. The mean expected survival rate for first-year murrelets was reported to be 0.605 (range: 0.580 to 0.634; Beissinger and Peery 2007). Survival of second-year murrelets has not been explicitly measured, but is assumed to approximate the adult survival rate of 0.864 (range: 0.829 to 0.905; Beissinger and Nur 1997, Cam et al. 2003, Peery et al. 2006, Beissinger and Peery 2007). Thus, there is a 45.2% chance that a fledgling will survive to reach reproductive maturity. This provided the number of fledglings that would ultimately join the breeding population 3 years after hatching.

2.1.1.5 Cumulative addition of breeding adults

Calculations were reiterated annually in the model through each of the 30 years in order to calculate the cumulative benefits over the life of the Project and identify the point in time that the replacement of breeding adults approximated the 30-year take (estimated by the upper bound of uncertainty in the probablistic collision risk model of 7.77 adult murrelets after accounting for interannual variability). For the first three years following the implementation of mitigation actions, the number of nests used in the calculation of annual production matched the initial condition since it was assumed that any additional murrelets produced before that point would not be able to breed. Alcids are known to exhibit philopatry (see Pyle 2001, Whitworth et al. 2013) and, as such, additional fledglings produced within VDRC will likely return to VDRC to nest; after the first three years; calculations assumed that surviving fledglings would add to the number of nesting birds using the stand (0.5 nest for each breeding adult produced). Over time, the number of active nests in VDRC would increase until the stand was determined to be fully saturated at the lowest nest density observed elsewhere; given the assumption of 1 nest per 8.23 acres assumed for purposes of calculating replacement, VDRC which is approximately 225 acres would become saturated at 27 nests. Once VDCP reached capacity, new birds were assumed to nest elsewhere and their reproductive contributions were not calculated.

2.2 Sensitivity analysis

Since deterministic models can only produce single estimates of an outcome, rather than a probability distribution, a sensitivity analysis was used to assess how variation in input parameters affected the estimate of replacement given various stand-use scenarios. Each parameter in the model was perturbed by 10% and the overall change in replacement estimates was quantified. Parameters included acreage, minimum potential nest density, current occupancy of potential nests, reductions in predator abundance, nest survivorship, and the probability of a murrelet surviving from fledging to adulthood.

Section 3.0 Results

There is a range of scenarios for which replacement has been estimated based on differing assumptions. Each scenario used the lowest potential nest density (1 nest per 8.23 acres), which conservatively sets the upper limit of additional murrelets that could be produced as a result of the proposed mitigation strategy, but deviated in their assumptions regarding the proportion of potential nests that are currently used by murrelets nesting within VCDP and Cheatham Grove.

Corvid reductions on the order of 50% are considered most likely based on what was achieved following implementation of corvid management over a 3-year period in central California parks (54%; Suddjian 2009). In this most likely evidence-based predator reduction scenario, the goal of replacing 7.77 murrelets was estimated to occur between years 5 and 10 post-implementation depending on the initial stand-use scenario. Over a 30-year period, mitigation efforts at the level of 50% reduction were calculated to add between 47.6 and 96.8 breeding adults added to the regional population. This exceeds take by 6 to 12 times based on two stand-use scenarios considered to represent the current situation: one where nests available in VDCP and Cheatham Grove are either 0% and 33% of minimum nest density, respectively ("Scenario 1") and another where nests available in VDCP and Cheatham Grove both start at 33% of minimum nest density ("Scenario 2"; Figure 3). A third potential stand-use scenario represents the minimum potential production of adult murrelets over 30 year if nests available in VDCP and Cheatham Grove were both presently used at 100% (i.e., equal to the minimum potential nest density, "Scenario 3"; Figure 3).

Although evidence suggests that a 50% reduction in corvid abundance will be the most likely outcome achieved by the proposed mitigation, the minimum (32% reduction) and maximum (80% reduction) evidence-based outcomes were also estimated (Table 2). In all cases the goal of fully replacing 7.77 adult murrelets could be met between years 4 and 15 post-implementation of actions that reduce corvid abundance. Thus, take will be fully mitigated early in the 30-year duration of the Project. Cumulative production of new adults was estimated to exceed take by 2.8 to 21.7 times the take value (Table 2).

In the sensitivity analysis, results were most sensitive to changes in the estimated survival of nests, the extent of predator reduction, and the probability of surviving from fledging to adulthood (Table 3). This model was least sensitive to perturbations in habitat size, nest density, and the percent of nest sites currently occupied (Table 3).

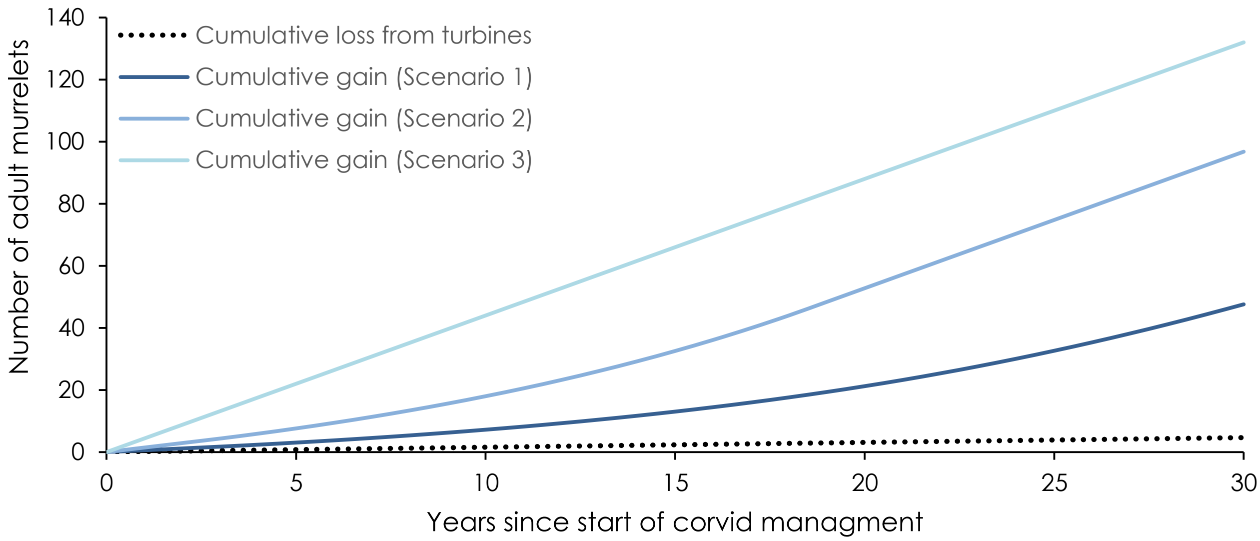

Figure 3. Three scenarios of cumulative gain of adult murrelets estimated to result following a 50% reduction in murrelet nest predators throughout Van Duzen County Park (VDCP) over 30 years plotted in relation to the cumulative loss of adult marbled murrelets estimated to result from turbine operation by the Humboldt Wind Project over 30 years. These projections are based on three stand occupancy scenarios where nests available in VDCP and Cheatham Grove are either (1) 0% and 33% occupied, respectively ("Scenario 1"), (2) both 33% occupied ("Scenario 2"), or (3) both 100% occupied ("Scenario 3"). The number of murrelet nests available to be occupied were based on the lowest density of nests reported in the literature (1 nest per 8.23 acres).

Table 2. Cumulative gain of adult murrelets estimated to result for different scenarios of initial stand-use by murrelets (0 or 33% of minimum nest density) and anticipated corvid reduction (32 to 80%). Resulting replacement ratios were calculated by comparing the count of new breeding adults to the loss of 7.77 adult murrelets over 30 years as estimated by the collision risk assessment.

Stand use							
VDCP	**Cheatham**	**Predator scenario**	**Corvid reduction**	**Nest survivorship**	**Gain in breeding adults**	**Replacement ratio**	**Reference for corvid reduction**
Low stand use at the initiation of corvid management							
0%	33%	Minimum evidence-based target	32%	51.5%	21.6	2.8:1	1
0%	33%	Performance-based outcome	40%	57.2%	31.9	4.1:1	2
0%	**33%**	**Likely evidence-based outcome**	**50%**	**64.3%**	**47.6**	**6.1:1**	**1**
0%	33%	Maximum evidence-based outcome	80%	85.7%	117.0	15:1	3,4
Modest stand use at the initiation of corvid management							
33%	33%	Minimum evidence-based target	32%	51.5%	53.2	6.8:1	1
33%	33%	Performance-based outcome	40%	57.2%	72.5	9.3:1	2
33%	**33%**	**Likely evidence-based outcome**	**50%**	**64.3%**	**96.8**	**12.4:1**	**1**
33%	33%	Maximum evidence-based outcome	80%	85.7%	168.9	21.7:1	3,4

1 Suddjian 2009

2 Peery and Henry 2010

3 Benson 2008

4 NPS 2010

Table 3. Sensitivity of the replacement calculator to variation in key parameters following hypothetical variation of 10% of the value used in modeling.

Stand use			Unmodified	Input change		Output change	
VDCP	Cheatham	Parameter	parameter	%	Absolute	%	Absolute
Low stand use by murrelets at the initiation of corvid management							
0%	33%		91	10	9.1	10	4.8
0%	33%		0.30	10	0.030	10	4.8
0%	33%		33.3	10	3.33	9	4.1
0%	33%		50.0	10	5.00	20	9.7
0%	33%		64.3	10	6.43	37	17.4
0%	33%		45.2	10	4.52	17	8.1
Modest stand use by murrelets at the initiation of corvid management							
33%	33%	Habitat size (ha)	91	10	9.1	10	9.7
33%	33%	Minimum nest density (#/ha)	0.30	10	0.030	10	4.4
33%	33%	Nest occupancy (%)	33.3	10	3.33	5	9.3
33%	33%	Predator reduction (%)	50.0	10	5.00	13	12.2
33%	33%	Nest survival (%)	64.3	10	6.43	23	22.0
33%	33%	Survival to adulthood (%)	45.2	10	4.52	13	12.2

Section 4.0 Discussion

When the recovery plan for marbled murrelets was written by the U.S. Fish & Wildlife Service (1997) two decades ago this synergism between corvid predation of murrelet nests was identified as a major issue to be addressed; "increased human activities in forests, such as picnic grounds, can attract corvids and thus increase the chances of predation (Singer et al. 1991, Marzluff and Balda 1992)" which has since been corroborated in the scientific literature (see Appendix B and Appendix C). Comprehensive corvid control throughout all parks containing murrelet nesting habitat has been identified as necessary to improve the chance of recovery for marbled murrelets (Peery and Henry 2010). This need is addressed by the mitigation strategy proposed to mitigate the loss of an estimated 4.65 adult murrelets resulting from turbines proposed for installation by the Humboldt Wind Project

The compensatory mitigation is projected to fully replace the 4.65 murrelets estimated to collide with turbines over 30 years as well as provide a net benefit to murrelets by exceeding take estimates by between 10 and 21 times based on the most likely evidence-based corvid reduction target of 50%. Thus, the rate of replacement substantially exceeds the rate of loss. In absolute numbers, corvid management actions proposed in VDRC would add 89 new reproductively capable individuals in excess of take to the population over 30 years. Even in a worst-case scenario under the assumption that murrelets are currently extirpated in VDCP, reducing corvid predation at murrelet nests remaining within the adjacent Cheatham Grove by eliminating anthropogenic food subsidies in VDCP will still provide full compensatory mitigation and add 40 adults to the population in excess of take.

The magnitude of mitigation benefit calculated here is conservative for several reasons: (1) nesting capacity of VDRC was estimated using the lowest density of active nest sites measured; (2) only a fraction (0-33%) of the minimum density of potential nests present in VDRC were assumed to currently be used by nesting murrelets; (3) it is possible that murrelets begin breeding at an age younger than what was assumed to calculate replacement and, if even a small proportion murrelets breed earlier than assumed here, the rate of replacement would be faster; (4) there is potential for additional birds to be produced in Keller Flats, which is located immediately across the river from VDCP, if this stand supports nesting by murrelets; (5) replacement calculations do not consider the reproductive contribution murrelets produced in excess of the nesting capacity set for VDRC although the estimate of nest capacity is likely underestimated (see point 1) and, if all available nest-sites in VDRC were to become occupied, prospecting murrelets may emigrate into the broader landscape and provide additional unquantified benefits. Had the contributions of these individuals also been considered, the rate of production would continue to compound in the latter years of the Project. One additional positive, but unquantified, outcome of implementing a corvid management strategy with a visitor education component on the broader landscape is that VDCP visitors will learn about the need to keep parks in old-growth forests "crumb clean" and will hopefully continue to apply this lesson as they recreate within other parks that could support nesting murrelets.

Both the collision risk model (H.T. Harvey & Associated 2019) and this replacement model rely on a set of conservative assumptions based on studies and values already published in the scientific literature. If for some unanticipated reason either model differed from the expected scenarios, the large margin between the measure of take and the calculated replacement benefit should absorb those differences without compromising the ability of the corvid management action proposed herein to fully mitigate take of murrelets by the Project.

Murrelet population viability models created by Peery and Henry (2010) suggest that a reduction of corvid predation by at least 40% could substantially reduce the risk of extinction for murrelets and may result in population growth over the long-term. After multiple years of successful corvid reductions at VDRC, the number of murrelets nesting in VDRC should increase until the habitat becomes saturated with nesting murrelets. It is possible that murrelets will be able to nest at much greater density than what was assumed for the replacement calculations, as nests have been found denser than one per 8.23 acres (Nelson and Wilson 2002, Plissner et al. 2015). Once capacity is reached within VDRC, newly produced additional breeders could spread into nearby habitats for nesting.

Other mitigation strategies often involve habitat creation, acquisition and protection, especially in situations where habitat will be directly removed or degraded because of a project. The Humboldt Wind Project will not remove habitat or degrade murrelet nesting habitat. Thus, the goal of the mitigation strategy proposed herein is to replace adult murrelets estimated to be impacted by Project operation. In oil spills, settlement monies have been used to compensate for losses by either acquisition of lands (e.g., Gazos Creek) or habitat enhancement through activities similar to proposed here (e.g., Humboldt Redwoods State Park, Big Basin Redwoods State Park). In fact, the retrofitting of infrastructure for corvid control in parks and preserves has been a major priority of natural resource trustee agencies including U.S. Fish and Wildlife Service, California Department of Fish and Wildlife, National Park Service, and California State Parks to enhance habitat for murrelets. Substantial sums of money have been spent to accomplish this task.

4.1 Effectiveness monitoring

Murrelet nests are infrequently found due to the difficulty of accessing the canopy of old-growth forests and the cryptic behaviors exhibited by murrelets in and around their nests (Nelson and Hamer 1995, Golightly and Schneider 2009). Monitoring of the effectiveness of mitigation or replacement efforts for murrelets is difficult regardless of actions taken (e.g., habitat creation, protection, or enhancement) and calculations of benefit are often more difficult than those presented here because of a lack of data to inform the modeling (e.g., colonization rates in newly created habitat). Murrelet nests are hard to find and, if found, are difficult to monitor by non-invasive means and with adequate sample sizes (see Evans Mack et al. 2003, Ripple et al. 2003, Peery et al. 2004b, Hébert and Golightly 2006).

There are few techniques to assess marbled murrelet productivity directly. The only way to measure the number of new adults added would be to detect changes in the ratios of young to adults in the at sea surveys conducted by the U.S. Fish & Wildlife Service. Populations of marbled murrelets offshore of the project area are currently monitored at sea as part of the Northwest Forest Plan effectiveness monitoring (McIver 2019). However, the expected changes from the proposed mitigation (9.4 birds in 6 years) would be impossible to detect in the at-sea numbers in a population of 8574 birds (in 2017) in the zone offshore of the proposed mitigation (Zone 4). Both the time frame (adding a bird or two a year) and the large variance in the at sea estimates (6358-11255 birds; 95% CI) precludes using existing monitoring at-sea to accomplish such an assessment of effectiveness for this project at this scale. Even if mitigation actions associated with this Project produced substantially more birds than needed for replacement, the juvenile to adult ratios derived from at-sea surveys would still lack power and it would be difficult to detect this improved production using traditional statistics over 30 years. Currently, at-sea monitoring only occurs once every other year (McIver et al. 2019) which exacerbates the inability to quantitatively detect and measure changes in juvenile to adult ratios that result from the implementation of mitigation actions. Alternatively, audio visual survey techniques (Evans Mack et al. 2003) have been used to measure presence or absence of nesting in a survey area as inferred by "occupied" behaviors, but these surveys are unable to measure murrelet abundance, nesting density, or population size at the local stand scale. Audio/visual surveys measure presence or absence and do not measure abundance.

Conversely, surveys for corvids should be responsive in time and at the local scale to represent changes in corvid abundance from the proposed mitigation; because corvid predation has such a profound impact on murrelet nesting it is reasonable to measure reductions in corvids to assess potential benefit to murrelets. It is important to note that the inability to directly quantify improvements in murrelet productivity would be an issue for almost all types of mitigation actions (such as habitat acquisition or conservation easement to mitigate losses of murrelets or other rare species). Failure to utilize mitigations such as habitat replacement or enhancement where the additions are known to provide substantial reproductive improvement to the population (e.g., restoration of habitat degraded by corvids but otherwise good habitat) foregoes opportunities to contribute to population recovery immediately.

Because it is not possible to directly measure changes in nest success of murrelets at the scale of VDRC or the number of nests in the park, determinations of effectiveness must rely on an indirect assessments of the benefit to murrelets achieved via corvid management in terms of reductions in the abundance of nest predators and the concomitant reduction in predation risk for murrelets nesting in VDRC. It is well established that corvids are major predators of murrelet eggs and chicks (Nelson and Hamer 1995, Hébert and Golightly 2007, Malt and Lank 2009, Golightly and Schneider 2009, 2011). It is also known that the major ongoing risk to murrelets in California is nest predation (RIT 2012, Golightly and Gabriel 2009, Peery and Henry 2010). At Redwood National and State Parks, nest failure due to corvid predation was 71.4% (Golightly and Schneider 2011) and an analysis of all studies reporting corvid-specific nest failure rates suggests that nest loss due to corvids could be as high as 90.9%, with Steller's jays accounting for 69.7% of all losses (Singer et al. 1991, Luginbuhl et al. 2001, Marzluff and Neatherlin 2006, Hébert and Golightly 2007, Malt and Lank 2009, Golightly and Schneider 2011).

Consequently, the effectiveness of the proposed mitigation will be ascertained by monitoring the expected decrease in corvid abundance and activity at VDRC and nearby old-growth groves. Given the relative importance of Steller's jay as a predator of murrelet nests and the marked increases in their abundance within high-use areas of California's parks (Wallen et al. 1999, West and Peery 2017, Halbert and Singer 2017), they will be the focus of effectiveness assessments. Point count surveys of corvids are the traditional method used to detect changes in the relative abundance of corvids as a means of assessing the effectiveness of corvid management actions (Luginbuhl et al. 2001, Benson 2008, George 2009, Suddjian 2009, West and Peery 2017, Halbert and Singer 2017). Thus, the project will conduct point-count surveys beginning prior to installation of infrastructure, signage, and outreach activity at VDRC.. At 2, 4, 6, 8, and 10 years after initiation of corvid management, the surveys will be repeated. A minimum expectation for effectiveness will be approximately a 32% minimum decrease in corvid activity between the present condition and year 6 after initiation of corvid management (see Appendix C).

It is important to recognize that other mitigation efforts for murrelets have also used reductions in corvid abundance as a proxy for monitoring effectiveness (e.g., CDFW 2019a, 2019b, 2019c, 2019d, 2019e). It is also notable that the problems for monitoring effectiveness of the proposed murrelet mitigation strategy are also associated with land acquisition, conservation easements, and other techniques at this scale. For other species where there has been uncertainty in effectiveness or the inability to measure that effectiveness, the U.S. Fish and Wildlife Service has commonly used increased ratios of mitigation (e.g., 3 acres of habitat added or every acre that was lost) to ensure that adequate compensation did occur. This has been done despite not having direct measures of replacement due to difficulty measuring because of time scale to effect. Here too the proposed mitigation in VDRC substantially overcompensates (by 6 to 12 times) to ensure that replacement occurs.

If for unanticipated reasons the minimum target of 32% reduction in corvids is not reached by year 6 after installation of infrastructure and initiation of outreach, an additional technique that has been used in other parks will be applied to VDCP. Aversive conditioning will be used consistent with the procedures described in Gabriel and Golightly (2014) and Gabriel et al. (2014, 2015, 2016) to train jays and other corvids to avoid murrelet eggs. Effects of this technique are very quick and evidence suggests that the avoidance of murrelet eggs by corvids likely persists for years after application (Gabriel et al. 2015). This technique is meant to be used in circumstances where anthropogenic foods have been curtailed.

4.2 Project benefits to murrelets not quantified in the proposed mitigation

The installation of wind turbines in Humboldt County will have additional unquantified positive benefits for marbled murrelets despite the potential impacts resulting from collision with turbines. This Project will directly offset the need to generate electricity using carbon-based fuels, which will help mitigate the progression of climate change; climate change threatens the quality of murrelet nesting and foraging habitats and is therefore a major threat to the continued persistence of murrelets. Further, the added diversification of electrical power production in Humboldt County will lessen the transportation of petroleum on marine waters; over the last 25 years, oil spills have been the primary source of direct anthropogenically caused mortality for individual murrelets in California including Humboldt Bay. It is difficult to quantitatively evaluate the exact benefits to murrelets that would be derived from slowing the progression of climate change and the reduction of oil transport at sea; however, qualitatively both will reduce risks to murrelets and their habitats and ultimately be reflected in their population.

4.2.1 Climate change and risk to murrelets

The potential for climate change to result from the use of carbon-based fuels to produce electricity is well documented (Burroughs 2001, IPCC 2014). Changes in climate predicted for the 21st century are expected to threaten biodiversity and ecosystem integrity globally (IPCC 2014), and latitudinal shifts in various species (including both trees and vertebrate species) have already been documented (Chen et al. 2011). Wind turbines use wind, not carbon-based fuel, to generate electricity. As such, they off-set the need for carbon-based electricity generation and the installation of turbines represents a step in minimizing the current progression of climate change. Minimization of climate change is essential to effectively conserve murrelets as continued climate change will impact this species by altering the composition and quality of both their inland nesting habitats and their at-sea foraging habitats.

Murrelets nest in coastal temperate rain forests of the Pacific Northwest. Climate change effects have already been documented for this region including increased temperatures (Karl et al. 2009), shifts in species distributions (Wang et al. 2012), and reduced fog levels (Johnstone and Dawson 2010). Old-growth coastal redwoods, used by murrelets for nesting in California (Baker et al. 2006, Golightly et al. 2009), have a southern extent at 37^{o}N, and the forests in southern Humboldt County are only 3^{o} north of this southern extent (DellaSalla et al. 2015). Changes in moisture and temperature regimes will likely affect the distribution and health of coastal redwoods in a way that is detrimental to murrelets that nest in the protected remnants of old-growth redwood forest in Humboldt County (see DellaSalla et al. 2015 for projected vegetation changes and DellaSalla 2017 for describing the impacts to marbled murrelet nesting habitat). Thus, murrelet nesting habitats in California and elsewhere will be degraded by climate change by altering the distribution, quantity, and quality of nesting habitat. Further, the same issues of moisture and temperature may also make the coastal forests at greater risk of fire. Fire risk was specifically identified in the Recovery Plan for marbled murrelets (USFWS 1997). Thus, to the extent that this Project contributes to the lessening of threats posed by climate change to coastal old-growth forests suitable for murrelet nesting, it will benefit murrelet populations.

To date, the measurable impacts of climate change resulting from the release of carbon dioxide (and other greenhouse gasses) into the atmosphere have impacted marine systems much more than terrestrial systems; the majority (>90%) of the energy accumulation in the Earth's climate system since 1971 has been stored in the oceans (IPCC 2014). As a result, the upper ocean (0-700 m) in the Pacific Northwest and around the Earth, has warmed (IPCC 2014; see Figure 1.10). Similar to other seabirds, the warming of the upper ocean impacts the ability of murrelets to survive and reproduce by altering the distribution and abundance of zooplankton and small fish; murrelets rely on zooplankton and small fish as food (Burkett 1995). Prey conditions have consequence for many seabirds, including murrelets, as they influence the reproductive decisions and success; when prey conditions are poor, there is evidence that many species of alcids including murrelets forgo breeding altogether (Abraham and Sydeman 2004, Peery et al. 2004a, Hébert and Golightly 2006). If climate change detrimentally affects the prey that murrelets rely on, murrelet survival and reproduction will likely suffer.

4.2.2 Minimization of Murrelet mortality resulting from oil spills near Humboldt Bay

The diversification of electrical power generation in Humboldt County (adding wind generation) could be beneficial for both murrelets and people. Transporting petroleum products, including fuels used for electricity generation such as diesel, inherently has a risk of an oil spill. Oil spills damage the environment and fatally impact organisms. Previous oil spills in the marine system have killed many seabirds, including marbled murrelets. Murrelets are particularly vulnerable because of their near-shore presence (Hébert and Golightly 2008). Because murrelets do not do well in captivity, individuals entering an oil spill recovery facility for rehabilitation generally do not survive.

Habitat loss was the historical cause of population decline for murrelets (USFWS 1997) and the remaining habitat suitable for nesting in California is now protected in preserves and parks (Golightly and Gabriel 2009). Current threats to individuals include mortality from oil spills at sea and nest failure caused by predation. In the last 25 years, California oil spills have killed more than 325 murrelets in five separate spill events (Kure-Humboldt Bay, Stuyvesant-Humboldt Coast, Command, Luckenbach, and Cosco Busan Oil Spills). Two of these events were associated with Humboldt Bay and were responsible for 82% of oil-spill-caused murrelet mortalities in California over this period, thus directly impacting the local population including murrelets that potentially use the Humboldt Wind Project area.

Furthermore, in the event of a natural disaster such as an earthquake, the risk posed by oil spills to murrelets would likely be increased in Humboldt County. Electricity in Humboldt County is provided by a limited number of connections to the electrical grid outside the county. Further, the fuel for some electrical generation is supported by a single natural gas pipeline. These limited number of connections makes the county vulnerable and may be disrupted or be completely cut-off in a natural disaster, causing the county to be dependent on within-county sources of energy production. Currently, the major source of power available to meet the county's needs in a natural disaster is the 165 MW electric generating facility at King Salmon (described by the California Energy Commission 2019). The facility is primarily powered by natural gas, but in the event of a natural gas interruption, this facility switches to diesel fuel to generate electricity. A limited supply of diesel is maintained on site in storage tanks and it is likely that the stand-by diesel would quickly need replenishment if natural gas is disrupted, especially in a natural disaster. This would necessitate that additional diesel be brought into the county by barge through Humboldt Bay. The entrance to Humboldt Bay has a bar that frequently creates dangerous conditions for marine vessels entering and exiting; in fact, one of the two spills referenced above occurred at the entrance of Humboldt Bay. Increased transport of oil through Humboldt Bay represents an additional threat to marbled murrelets. The augmentation of energy from the Humboldt Wind Project will allow the county to be more self-sufficient in the event of a natural disaster. As such, diesel at the King Salmon plant would need to be replenished less frequently and there would be more flexibility to transport diesel into the county at times when marine conditions were suitable for the safe passage of barges into Humboldt Bay. It is notable that the two spills that damaged so many murrelets were relatively small (2000 and 4500 gallons) compared to the amount of petroleum that is contained in a typical barge that would deliver fuel to Humboldt County. Ultimately, diversifying the sources of electricity generation in Humboldt County would benefit people, by increasing the energy security of Humboldt County, as well as murrelets, by reducing their risk of encountering oil at sea.

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Appendix A. Outreach to Riverside Park Community to aid in corvid management efforts

Riverside Park Community is an unincorporated rural area of private homes located at least 1050 feet (320 m) to the west of VDCP's Pamplin Grove (the western-most grove). The community consists of approximately 53 parcels that have dwellings and other out-buildings. Although trash pick-up service is provided to the community by Recology Inc, there is potential for Steller's jays and ravens to access supplemental food at these residences, either via the trash or improperly stored food items. Thus, it is possible individuals in the Riverside Park Community also contribute to the corvid abundance in nearby VDCP.

Many of the central California parks where corvid management has been implemented are also surrounded by private property that have a similar potential to provide food supplements to corvids. However, the number of homes and business activities near Big Basin Redwoods State Park are many times the number and extent associated with the Riverside Park Community. At Big Basin Redwoods State Park there are multiple rural roads with houses and small ranches along the periphery of the park. In addition to single home residences surrounding Big Basin, nearby properties also include private camps, a golf course and club, and the community of Boulder Creek and several other smaller communities. Still, the corvid management within Big Basin and other central California parks were able to reduce corvid abundance by 54% (Suddjian 2009).

Mitigation for the Humboldt Wind Project will include outreach to the community of Riverside Park to promote proper trash containment and other measures that reduce the accessibility of anthropogenic foods to all wildlife. This may include facilitation of proper trash storage and pick-up, reduction of human wildlife conflicts, advising residents (when receptive) of methods to reduce interactions with wildlife (e.g., bears and racoons that can open otherwise inaccessible trash and food sources and facilitate supplemental feeding of corvids). VDCP outreach staff will regularly visit the neighborhood to identify potential problems and sources of supplemental food and attempt to facilitate resolution of those problems and minimization of corvid access to human foods. Staff will also coordinate activities with the County of Humboldt, California State Parks, California Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service; this coordination will include reporting of conditions and other issues in brief annual reports.

Appendix B. Background on reducing anthropogenic foods available to murrelet nest predators

Actions comparable to what is proposed for VDRC have successfully reduced anthropogenic food availability at multiple parks containing murrelet nesting habitat in central and northern California (Bensen 2008, Suddjian 2009, Halbert and Singer 2017). Thus, hardware installation and visitor education are expected to minimize anthropogenic foods available to jays and other corvids at VDRC. Food-control hardware proposed for mitigation would directly reduce the availability of properly discarded food wastes within VDRC. However, corvid access to anthropogenic foods can continue regardless of hardware's ability to restrict access to foods because park visitors may directly provide human food in protected areas (Marion et al. 2008), including VDRC and neighboring park lands. To successfully minimize the availability of anthropogenic foods within VDRC, visitors must also be educated about the detriments of feeding wildlife. Visitors need to understand that feeding corvids, intentionally or inadvertently, increases the risk of nest predation and extinction for murrelets in California (Marion et al. 2008, NPS 2008, Golightly and Gabriel 2009, Peery and Henry 2010) so that they are motivated to properly handle and dispose of foods within VDRC.

Many park visitors intentionally feed wildlife because of a false perception that feeding wildlife is not harmful or is a desirable means of luring animals closer (Marion et al. 2008). Many visitors are eager to intentionally share their foods with Steller's jays as this species is perceived positively and, in contrast to ravens, are uninhibited about approaching park visitors. Additionally, because Steller's jays are frequent visitors at household feeders, it may be difficult for many visitors to differentiate between the consequences of providing food to jays at their home relative to marbled murrelet nesting habitat. Unless visitors perceive that feeding jays in murrelet habitat is detrimental, intentional feeding would likely continue at VDRC despite the presence of animal-resistant hardware. Visitor education would increase awareness that feeding jays has undesirable consequences, at least within protected areas, thereby reducing the frequency of purposeful jay provisioning at VDRC.

In addition to acquiring foods provided intentionally by visitors, jays and other corvids are resourceful and quick to eat foods left unintentionally by visitors or accessed by other wildlife. Visitors that do not fully comprehend the relationship between murrelet reproduction, corvid abundance, and human food will not be sufficiently motivated to ensure that they remove each crumb they create. Educational programs in central and northern California describe their outreach efforts as part of a "crumb-clean campaign" designed to convince visitors that even seemingly insignificant amounts of food attract corvids and enhance predation risk for murrelets (Halbert and Singer 2017, Society for Ecological Restoration 2019).

Active visitor education is key to enhancing visitor awareness of the marbled murrelet. This species is elusive, rare, and nest in the upper canopy outside of visitor view (McShane et al. 2004, Golightly and Schneider 2009, 2011), and most visitors to VDRC (and other parks) have never heard about this species, let alone observed one first-hand or witnessed the eggs and chicks being killed by corvids. As such, education is essential for visitors to have empathy for murrelets and understand that by choosing to feed corvids, whether purposefully or unintentionally, could lead to the extirpation of this species in California within the next 100 years (McShane et al. 2004, Peery and Henry 2010).

Although outside the scope of this mitigation, educating visitors at VDRC can have a longer-term positive benefit to the extent that these visitors apply what they've learned as they recreate in the various parks in Humboldt County, are motivated to remove anthropogenic foods from parks even if they were not the source, and are empowered to inform other visitors about the consequences of feeding corvids in the event that they observe other visitors doing so. This improved awareness of the consequences of feeding wildlife in parks may have positive consequences for other species not addressed by this document.

Appendix C. Linking reductions in corvid abundance to increased survival of marbled murrelet nests

Steller's jays are the primary predator of marbled murrelet nests, accounting for an average of 69.7% (range:60-82%) of losses due to corvids (Singer et al. 1991, Luginbuhl et al. 2001, Marzluff and Neatherlin 2006, Hébert and Golightly 2007, Malt and Lank 2009, Golightly and Schneider 2011). Other corvids also depredate murrelet nests, with an average of 98% (range: 96-100%) of all nest predation events being attributable to some corvid species (Singer et al. 1991, Luginbuhl et al. 2001, Marzluff and Neatherlin 2006, Hébert and Golightly 2007, Malt and Lank 2009, Golightly and Schneider 2011). Given the relative importance of Steller's jays as predators of murrelet nests and the greater power to detect change by monitoring jays relative to murrelets as well as other corvid species, they are the focus of this logic linking reductions in corvid abundance to increases in murrelet nest success.

D.1 Changes in Steller's jay abundance, activity, and productivity

Jay abundance in many areas of murrelet nesting habitat, including VDRC, has been elevated because of increased accessibility of anthropogenic food in these areas (NPS 2008, George 2009, Suddjian 2009, NPS 2010, Peery and Henry 2010). Increased accessibility of food in murrelet nesting habitat has caused jays and other corvids to reduce territory size and concentrate in these areas (Marzluff and Neatherlin 2006, Goldenberg and George 2012, Scarpignato and George 2013, Goldenberg et al. 2016, West and Peery 2017, Halbert and Singer 2017). In addition to increasing corvid abundance in specific areas, increased food availability can also improve corvid survival (Martin 1987, Reynolds et al. 2003, Robb et al. 2008, Marzluff and Neatherlin 2006) and reproductive success (Marzluff and Neatherlin 2006, West and Peery 2017). Therefore, it is expected that comprehensive reductions in food availability would cause corvid abundance to decrease throughout VDRC.

Evidence corroborating this assertion comes from four parks containing murrelet nesting habitat in central California (Big Basin Redwoods State Park, Portola Redwoods State Park, Butano State Park, and San Mateo County Memorial Park); in these parks jay abundance has been successfully reduced by minimizing food accessibility (USFWS et al. 2004, Suddjian 2009, Halbert and Singer 2017). In 2005, each park introduced visitor education and added animal-resistant garbage receptacles to prevent wildlife from feeding on trash. We expect that jay responses to food reductions should be consistent between central and northern California since the primary condition contributing to increased jay and corvid abundance throughout California has been increased availability of anthropogenic foods (Boarman and Heinrich 1999, Liebezeit and George 2002, George 2009).

The extent that jay abundance was reduced following installation of bear-resistant hardware and implementation of visitor education in central California's parks was assessed through annual monitoring of corvid abundance. Surveys occurred in 2003 and 2004, two years prior to implementing actions that minimized food availability within these parks, to establish a baseline abundance of jays. Then, following implementation of actions in 2005, jay abundance was monitored for 3 additional years (2006 to 2008) to determine the extent that jay abundance was reduced relative to the baseline. The raw data and results of these monitoring efforts were reported by Suddjian (2009). We used raw data from that report to quantify the percent by which jays had been reduced in the first year post-implementation by comparing the average jay abundance in each survey area in years prior to implementation to the average jay abundance in the same areas in the first year following implementation.

Although ongoing problems in some central Californian parks made trash control only partially successful, jay abundance still declined by 32% within high-use areas (i.e., campgrounds) of these parks within the first year post-implementation actions reducing the magnitude of anthropogenic foods accessible by jays (Wilcoxon signed rank test: $W=2$, $P<0.05$). At 3 years post-implementation of food reduction efforts, Suddjian (2009) reported a 54% decline in Steller's jay abundance for all campgrounds (all parks combined). Notably, this trend was accompanied by an additional 29% decrease in jay abundance in the park's backcountry areas. Because backcountry areas were unlikely to provide additional food resources to jays, this reduction of jays in these low-use areas presumably resulted from the reduction of jays in high-use areas and concomitant reductions in jay dispersal into backcountry areas. This presumption was later corroborated by West (2017), who reported that increased reproductive success of jays near campgrounds resulted in a spillover effect of young jays into surrounding forests. Thus, overabundance of foods in high-use areas of the park resulted in an elevation in jay abundance both in food-rich areas of these parks as well as within backcountry areas that neighbored high-use areas.

Food control efforts proposed for VDRC are expected to result in equal reductions in jay abundance relative to what occurred in the central Californian parks. The central Californian parks only achieved partial trash control, in part due to neighboring ownerships. To reduce corvid abundance to the maximum extent possible food control efforts must be comprehensive. The central Californian parks are in urban and suburban settings which make it virtually impossible for these parks to be isolated from external conditions promoting increased corvid abundance. At VDRC, there is a nearby community (Riverside Park Community; Appendix A) which will be included in the detailed planning as mitigation moves forward.

To determine the maximum likely reduction in jay abundance achievable within VDRC, it was assumed that jays could be reduced to "background" level, but no further. For this purpose, we defined background level as the population abundance of jays in the low human-use areas of central Californian parks since they provided the most accurate and defendable assessment of jay abundance within high and low human-use and undeveloped areas of California's old-growth habitats (Wallen et al. 1999, Liebezeit and George 2002, NPS 2008, George 2009, Suddjian 2009). Prior to reducing food availability in the central Californian parks, jays were 6.2 times more abundant in high human-use areas relative to the undeveloped areas (Suddjian 2009). The maximum achievable reduction of jay abundance within VDRC was estimated by calculating the percent decrease in the abundance of jays in backcountry areas relative to high-use areas documented in central Californian parks. Based on this calculation, we estimate that jay abundance within VDRC could be reduced by as much as 84%. We expect that this maximum reduction would be achieved during, or shortly following food control efforts. This reduced jay abundance would be maintained at this lower level for the 30-year life of the Project.

The maximum expected reduction in jay abundance estimated for high-use areas of VDRC using data from central California corresponds well with data on jay abundance in high- and low-use areas of Redwood National and State Park in northern California; in Redwood National and State Park jays were reported to be between 3 and 6 times more abundant in campgrounds relative to backcountry areas prior to implementing actions that minimized accessibility of anthropogenic foods to corvids within that park (Bensen 2008, NPS 2010). Based on the percent decrease in the abundance of jays in backcountry areas relative to high-use areas documented in Redwood National and State Park, the maximum achievable reduction in jay abundance within VDRC could vary from 67% and 83%, which is comparable to the expectations of an 84% reduction derived from corvid studies in central Californian parks and referenced above.

D.2 Expected increase in marbled murrelet nest success following reduction in nest predators throughout VDRC

Many studies suggest that increased abundance of predators in an area coincides with an increased risk of nest predation (Ratti and Reese 1988, DeSanto and Wilson 2001, Malt and Lank 2009, Smith et al. 2010). For example, fledging success of upland duck nests depended on the density of predator species, including American crows (*Corvus brachyrhynchos*; Johnson et al. 1989, Pieron and Rohwer 2010). Jay abundance around human activity centers has risen significantly in recent times, even in areas of protected old-growth forest (Liebezeit and George 2002, Bensen 2008, Suddjian 2009).

At artificial murrelet nests, the predation rate was positively correlated with Steller's jay abundance (Luginbuhl et al. 2001, Malt and Lank 2009). Thus, at actual murrelet nests it is likely that the rate of predation is similarly increased where jay abundance is elevated. A population viability analysis for murrelets in central California demonstrated that the most effective way to increase murrelet productivity and minimize the current risk of extinction is by reducing the predation of murrelet nests by Steller's jays and other corvid species (Peery and Henry 2010); because predation risk varies as a function of jay abundance, reductions in jay abundance in parks with murrelet nesting habitat is needed to reduce frequency of nests depredation by jays (and likely other corvids). Based on the murrelet population viability analysis and additional predator reduction studies, it is likely that by reducing the abundance of Steller's jays across a sufficiently large area of coastal old-growth habitat the survival of murrelet nests would increase markedly and even possibly facilitate localized population growth (Balser et al. 1968, Sovada et al. 1995, Frey et al. 2003, Peery and Henry 2010).

Steller's jays forage throughout the forest, including the canopy. Because jays do not use a specialized search strategy for nests, but instead find nests incidentally while searching for primary food such as berries or insect prey, Vigallon and Marzluff (2005) found that the likelihood of jays encountering nests was greatest in areas where their foraging efforts were concentrated (i.e., areas with a large supply of berries or insects) and risk of predation decreased proportionally with decreased jay activity. We followed Vigallon and Marzluff's (2005) recommendation to infer changes in nest predation risk by assuming a proportional relationship between predator abundance and nest predation rates. Further, we assumed that the rate of nest encounter by jays is equivalent to the rate of nest predation by jays (i.e., each nest encountered is predated); there has been only one reported observation of a jay encountering a murrelet nest with a chick present where the chick was not depredated prior to fledging (Hébert and Golightly 2007).

To determine the extent that nest success could increase following a reduction in the abundance of jays (and likely other corvids), we assumed that for every 5% decrease in the predator abundance would translate to some proportional decrease in the probability of murrelet nest depredation as well as the reciprocal increase in the probability of murrelet nest survival. To do this required specifying a nest predation rate for the baseline condition of 100% relative abundance (i.e., the predation rate prior to predator reductions); the predation rate in the absence of predator reductions was assumed to be 71.4%, which matched the rate of nest loss due to corvid predation measured in Redwood National Parks (Golightly and Schneider 2011) prior to and in the early stages of implementing comprehensive corvid management in this park (Benson 2008, NPS 2010).

Using this baseline condition of 71.4% nest failure due to corvid predation prior to reductions in corvid abundance (e.g., corvid abundance was 100% of baseline), the proportional relationship was established by quantifying the function of the line that would fit nest failure due to corvid predation between 0% and 71.4% (Figure C-1). The resulting relationship was then used to quantify the reciprocal increase in nest survival; for example, if corvid abundance was reduced by half to 50% of the baseline, the corresponding probability of nest predation would be 0.357 and the reciprocal probability of nest survival would be 0.643 (1.000-0.357).

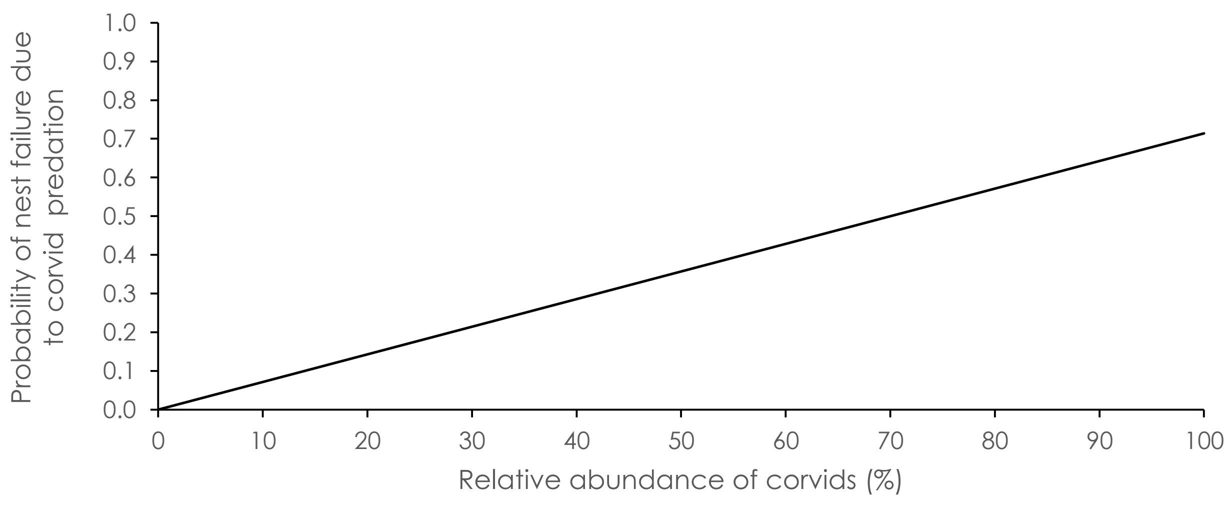

Figure C-1.Proportional relationship between reductions in corvid abundance from their current level (100%) and the corresponding probability of murrelet nest failure due to corvid predation. The probability of nest failure due to predation prior to reductions in predator abundance, 0.714, was derived from Redwood National and State Park in northern California.

To compare the proportional impact that reductions in jay abundance had on survival of murrelet nests was quantified using murrelet nest predation rates derived from northern California. We conducted a literature review of studies that measured the increase in avian nest success following a reduction in predator abundance. To be included in our assessment, studies had to indicate both predator abundance and prey nest survival. Two types of studies were used: studies that measured the reproductive success of prey following predator reduction efforts and studies that correlated prey reproductive success with predator abundance. For these predator reduction studies, we determined both the amount that predator abundance decreased and the extent that prey nest success increased following predator reduction efforts. For correlational studies, we determined the difference in predator abundance and prey reproductive success for areas with high predator abundance relative to areas with low predator abundance. Due to the specificity of data needed for this analysis, the number of studies that could be used were limited. Any potentially confounding influences of other non-predator variables measured by these studies (i.e., habitat characteristics) were disregarded.

From each study, the extent that prey nest success increased following a 5% reduction in predator abundance was calculated (Table C-1). On average, nest success of prey species increased 1.186 times (range: 1.125 to 1.267 times) following a 5% reduction in predator abundance. For comparative purposes, the proportional relationship between relative corvid abundance and the probability of murrelet nest failure due to corvid predation is equivalent to an increase in nest success by 1.125 times following a 5% reduction in predator abundance. Thus, the empirically derived relationship for murrelets matches the minimum response of what has been found by other studies and is lower than what was found at studies designed to simulate predation risk imposed by corvids on murrelet nests (Luginbuhl et al. 2002, Malt and Lank 2009). Thus, the proportional relationship derived as a means of linking reductions in the abundance of Steller's jays and other corvids is corroborated by other studies and represents the most conservative estimate.

Table C-1. Increase in prey nest success following a 5% decrease in predator abundance. The percent decrease in predator abundance was calculated using the average predator abundance determined by each of these studies. The extent that prey nest success increased for every 5% reduction in predator abundance was calculated using the average increase in the parameter that best indicated nest success reported by each of these studies. A linear relationship between predator abundance and prey reproductive success was assumed.

Predator species	Prey species	Increased nest success	Source
Steller's Jay	Artificial murrelet nest	1.145	1
Corvids	Artificial murrelet nest	1.208	2
Fox	Various ducks	1.125	3
Fox, corvids	Grey partridge	1.166	4
Fox, marten, stoat	Various grouse	1.205	5
Fox, carrion crow	Capercaillie	1.267	6
Average for all studies	**1.186**		
Average for artificial murrelet nests	**1.177**		
Value used for calculations in this report	**1.125**		

1 Malt and Lank 2009
2 Luginbuhl et al. 2001
3 White et al. 2014
4 Tapper et al. 1996
5 Kauhala et al. 2000
6 Baines et al. 2004