Marbled Murrelet (*Brachyramphus marmoratus*)

Climate Change Vulnerability Assessment for the Santa Cruz Mountains Climate Adaptation Project

*This document represents an initial evaluation of mid-century climate change vulnerability for **marbled murrelet** in the **Santa Cruz Mountains region** based on expert input during an October 2019 vulnerability assessment workshop as well as information in the scientific literature.*

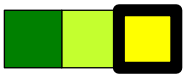
Species Description

The marbled murrelet (*Brachyramphus marmoratus*) is a small seabird in the Alcidae family[1], and populations are distributed from Santa Cruz, California north through the Aleutian Islands of Alaska[2,3]. In the Santa Cruz Mountains region, they occur across a 37-mile (60 km) range from the Pilarcitos Creek watershed in San Mateo County south to Henry Cowell State Park in Santa Cruz County[4].

Marbled murrelets forage on small schooling fish and krill within the nearshore marine environment[5,6]. They are unique among seabirds in that they travel inland to reproduce in mature and old-growth forests dominated by coast redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga heterophylla*)[2,7–9]. Nest site requirements include platforms of moss, ferns, or other epiphytes located on branches or broken treetops in large-diameter trees; adequate canopy cover over the nest; and proximity to the marine environment[4,7–10]. Nesting sites are frequently located on gentle, low-elevation slopes or alluvial flats near streams[8,9].

Vulnerability Ranking

High Vulnerability



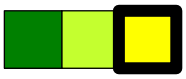
Mod Confidence

Marbled murrelets are sensitive to changes in climate stressors and disturbance regimes (e.g., warmer air temperatures, changes in precipitation patterns, altered wildfire regimes, more frequent/intense storms) that reduce the quality and/or availability of nesting habitat within old-growth forests, which is likely to impact reproductive success and species distribution. Because they are dependent on both forest and marine habitats, marbled murrelets are also vulnerable to changes that impact prey availability within ocean environments. Non-climate stressors such as the presence of corvids, timber harvest, fire exclusion/suppression, and commercial fisheries can exacerbate sensitivity to changes in climate factors and disturbance regimes by decreasing reproductive success, increasing habitat loss and fragmentation, and reducing prey availability.

The Santa Cruz Mountains region supports a very small population of marbled murrelets, representing the southern extent of the species' range. Nesting habitat has declined over the past century, and most remaining old-growth forests in the region are highly fragmented. Low reproductive rates and high site fidelity also increase vulnerability to population declines. Most management strategies for marbled murrelets focus on protecting and enhancing terrestrial nesting habitat, but actions focused on reducing nest predation by corvids could also increase population stability in this species.

Sensitivity and Exposure

High Impact



Mod Confidence

Sensitivity is a measure of whether and how a species is likely to be affected by a given change in climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors. **Exposure** is a measure of how much change in these factors a species is likely to experience.

Sensitivity and future exposure to climate and climate-driven factors

The marbled murrelet is sensitive to climate stressors that reduce the quality and/or availability of nesting habitat, potentially impacting reproductive success and distribution.

Climate Stressor	Trend Direction	Projected Future Changes
Air temperature	▲	• 1.5–3.1°C (2.7–5.6°F) increase in annual mean temperature[11,12]
Precipitation	▲▼	• Shorter winters and longer, drier summers likely, with higher interannual variability[13,14]

- **Increasing air temperatures** are likely to decrease nest platform availability by reducing epiphyte occurrence[15,16]. Studies suggest that warmer air temperatures could also impact redwood growth due to enhanced water stress[17,18]. The distribution of occupied marbled murrelet nesting sites is closely correlated with cooler maximum summer temperatures[8]. However, it is currently unknown whether marbled murrelets exhibit physiological sensitivity to temperature, or whether the association between temperature and occupied nesting sites is primarily due to indirect effects of cooler microclimates on nesting habitat quality[8].
- **Changes in patterns of precipitation** are likely to alter plant moisture stress in coastal forests[17,19,20], which are characterized by frequent fog that relieves summer drought stress and closed canopies that create cool, moist microclimates[19,21,22]. These conditions support the growth of epiphytes that provide nest platforms for marbled murrelets[23], but drier future conditions may reduce the suitability of nesting habitat by impacting plant growth and mortality[24,25]. For instance, many epiphytes within coastal redwood forests are sensitive to desiccation, and changes in microclimate conditions due to reduced precipitation and/or increased drought would likely limit epiphyte growth and distribution[15,23].

Sensitivity and future exposure to climate-driven changes in disturbance regimes

Marbled murrelets are sensitive to changes in disturbance regimes that directly impact survival as well as those that result in the loss of nesting habitat and increase habitat fragmentation.

Disturbance Regimes	Trend Direction	Projected Future Changes
Wildfire	▲	• Slight to moderate increase in wildfire risk, particularly in areas of higher rainfall[11,12]
Storms	▲	• Increased storm intensity and duration, resulting in more frequent extreme precipitation events and flooding[13,26,27]

- Although redwoods are adapted to survive fire[28], climate-driven changes in **wildfire regimes** may result in uncharacteristically severe fires that result in the loss of nesting habitat in coastal old-growth forests[4,24]. The risk of severe fires is greater where old-growth stands are surrounded by dense forest dominated by small-diameter conifers and broadleaf trees, which increases fuel availability and continuity[29].
- Climate-driven changes in the **intensity and/or frequency of storm events** may increase windthrow (i.e., uprooting or breaking of trees by the wind), particularly at the edge of clearcuts[30] and/or in waterlogged soils[21,28]. This could cause the loss of mature trees or limbs used for nesting[24,25,31].

Dependency on habitat and/or other species

Marbled murrelets are dependent on both marine foraging habitats and terrestrial nesting habitats, increasing their vulnerability to changes that affect habitat quality and/or availability in either environment[24,25]. They are considered habitat specialists due to their dependence on large-diameter trees with branches or broken tops that support nest platforms of moss, ferns, and other epiphytes[10]. Thus, marbled murrelets are very sensitive to the loss or fragmentation of their nesting habitat and changes in microclimate conditions that impact moss and epiphyte growth[24,25]. Because the development of a forest structure that includes the habitat elements required to support reproduction can take centuries, suitable habitat can be eliminated much faster than it is created[25,32].

The dependence of marbled murrelets on marine foraging habitats increases their vulnerability to changes in ocean conditions (e.g., sea surface temperature, acidification, currents) that impact prey availability[24,33]. Years with abundant prey are generally associated with cooler waters and strong upwelling[6,34], which likely increase murrelet survival and reproductive success[6,35]. During years with reduced prey availability, murrelets must spend more time foraging and travel farther to find sufficient food for themselves and their young[36,37].

Sensitivity and current exposure to non-climate stressors

Non-climate stressors can exacerbate habitat sensitivity to changes in climate factors and disturbance regimes by decreasing reproductive success, increasing habitat loss and fragmentation, and reducing prey availability.

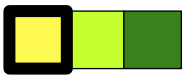
- Human activity and habitat fragmentation are associated with **changes in the distribution and abundance of corvids** (e.g., common ravens [*Corvus corax*], Steller's jays [*Cyanositta stelleri*]), which prey on murrelet eggs and chicks[4,38,39]. Although they are native species, increases in Santa Cruz corvid populations since the 1980s[39] have coincided with dramatic reductions in murrelet recruitment[4]. Corvid nest predators are attracted to supplemental food from recreational visitors around campgrounds and picnic areas[40], and roughly half of known murrelet nests in the Santa Cruz Mountains region occur within 1 km (0.6 ft) of state and

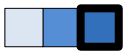
county park campgrounds[9]. Additionally, many remaining old-growth stands are small and surrounded by development and other anthropogenic land uses, which also increases the likelihood of high corvid populations within these areas[4].

- **Timber harvest** on private lands is a significant threat to marbled murrelets across their range due to the continued loss of old-growth coastal forests utilized as nesting habitat[2,4,24]. Their remaining breeding habitat is highly fragmented, increasing vulnerability to wildfire and exposing murrelets to higher rates of nest predation[41,42]. Increasing fragmentation as a result of timber harvest can also increase the rate of windthrow at stand edges[28] and creates overall drier forest conditions[43], potentially altering epiphyte growth and composition and enhancing fire risk[15,21].
- Reduced fire frequency as a result of **fire exclusion and suppression** contributes to shifts in fuel structure and increased fuel loading in coastal old-growth forests, increasing the risk of more intense fires[28] and associated losses in marbled murrelet nesting habitat in the future[4,24].
- The impacts of **commercial fisheries** have not been well-documented in marbled murrelets, but they could reduce prey by impacting food webs[4]. Murrelets could also be displaced from foraging sites that are heavily fished[4]. Finally, mortality due to bycatch in gill-net fisheries has been documented in Alaska and British Columbia, but those practices are banned in central California[44].

Adaptive Capacity

Low Adaptive Capacity





High Confidence

Adaptive capacity is the ability of a species to accommodate or cope with climate change impacts with minimal disruption.

Species extent, integrity, connectivity, and dispersal ability

The Santa Cruz Mountains support a very small population of murrelets (~650 individuals) representing the southern extent of the species' range, and nests have been documented within just seven coastal watersheds in San Mateo and Santa Cruz counties[4]. Over the past century, marbled murrelet nesting habitat in the region has declined due to the logging of mature and old-growth forests[4]. Only about 10,000 acres of old-growth habitat remains with the region, with almost half of that found within Big Basin Redwoods State Park and much of the remaining area fragmented in stands of less than 150 acres[4]. An additional ~5,000 acres of mature second-growth habitat has also been identified, occurring on both public and private lands[4]. Marbled murrelets do not typically disperse very far inland for nesting (17.7–35.4 km [11–22 miles]), so they are heavily dependent on coastal old-growth habitat[45].

Very low reproductive rates observed in the region suggest that recruitment is currently inadequate to support the population[46,47]. It is likely that marbled murrelets in the Santa Cruz Mountains region represent a sink population that would decline rapidly in the absence of immigration from northern populations[46]. Because the population is too small to be limited by nest site availability[39], it is likely that limited food availability in some years and high rates of nest predation are the most important factors limiting reproductive success in this region[41]. The small size of this population also increases

vulnerability to stochastic events (e.g., uncharacteristically severe fires), because even relatively low levels of adult mortality could cause significant population declines or extirpation[4,48].

Intraspecific/life history diversity

Marbled murrelets have adapted several characteristics that reduce the risk of detection by nest predators, including effective camouflage and secretive behavior[1]. For instance, murrelets are primarily active around their nests when the light is low at dawn and dusk[1]. While incubating, they switch off every 24 hours and they stay completely motionless for over 98% of the time while on their nest[1,49]. Marbled murrelets exhibit very strong site fidelity[24,49], increasing the potential for breeding disruption as a result of nesting habitat degradation or loss[1,24]. The loss of nesting habitat may also limit the ability of this species to respond to shifts in prey availability near their nesting site[24].

The Santa Cruz Mountains population of murrelets appears to be genetically distinct from the those to the north[50]. However, the very small size of this population increases the risk of inbreeding due to genetic bottlenecks[48].

Resistance and recovery

Marbled murrelets have low resistance to loss or fragmentation of nesting habitat, such as might occur following large, uncharacteristically severe fires[24,25]. However, old-growth forests are relatively resistant to wildfire due to their cool, moist microclimate[29], and the thick, fire-resistant bark of large redwoods reduces the risk of severe damage or mortality in nest trees[28].

Recovery from disturbance events or population declines is very slow due to low reproductive rates[1,32]. Marbled murrelet clutches are usually just a single egg[10]. Additionally, they do not breed every year, further reducing their reproductive rate and increasing vulnerability to population declines[1,32]. Within the small Santa Cruz Mountains population, nesting success rates since 1991 may be as low as 16%[4,7,9].

Management potential

Although they are not well-known by the general public, marbled murrelets are an enigmatic species with a loyal following among those who are aware of them. Birders and other conservation interest groups are generally strong supporters of protection for this species[48]. Marbled murrelets receive regulatory protection through the federal Endangered Species Act which lists them as a threatened species[45]; they are also state-listed as endangered in California[51]. Overall, there is strong public and societal support for old-growth forest protection, though continued outreach is needed to raise visibility of this unique species and their connection to old-growth redwood forests[48]. However, there is a relative lack of information on this species compared to many other old-growth specialists, largely because characteristics that make marbled murrelets difficult to detect by nest predators also make them difficult to study[4,48].

Because many stressors that affect marbled murrelets are difficult to control (e.g., prey availability within marine habitats), management of marbled murrelets focuses heavily on protecting nesting habitat within old-growth redwood forests[48]. It is also critical to protect older second-growth and regenerating stands that represent potential nesting habitat, including those on privately-owned land that are at risk of harvest or development[4,24,25]. In these areas, management strategies that accelerate the development of old-growth forest structure could benefit murrelet populations[31,52]. Reducing nest predation by corvids is also an important management focus; although it is not directly related to climate change, studies suggest that successful management of this factor could increase population

stability in the region[39]. Most corvid management strategies to date have focused on a combination of reducing the availability of anthropogenic food sources in recreational areas and public education efforts to increase awareness of the problem among recreational users[4]. Surrounding clusters of old-growth and/or mature second-growth stands with regenerating forest may also help reduce the predation risk associated with hard edges[42].

Recommended Citation

EcoAdapt. 2021. Marbled Murrelets (*Brachyramphus marmoratus*): Climate Change Vulnerability Assessment Summary for the Santa Cruz Mountains Climate Adaptation Project. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Further information on the Santa Cruz Mountains Climate Adaptation Project is available on the project page (http://ecoadapt.org/programs/awareness-to-action/santa-cruz-mountains).

Literature Cited

1. De Santo, T. L. & Nelson, S. K. Chapter 3: Comparative reproductive ecology of the auks (Family Alcidae) with emphasis on the Marbled Murrelet. in *Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152* (eds. Ralph, C. J., Hunt, G. L., Jr., Raphael, M. G. & Platt, J. F.) 33–48 (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1995).
2. Carter, H. R. & Erickson, R. A. Status and conservation of the Marbled Murrelet in California, 1892-1987. in *Status and conservation of the marbled murrelet in North America. Proceeding of the Western Foundation of Vertebrate Zoology, Camarillo, CA.* (eds. Carter, H. R. & Morrison, M. L.) 92–108 (1992).
3. Mendenhall, V. M. Distribution, breeding records, and conservation problems of the Marbled Murrelet in Alaska. in *Status and conservation of the marbled murrelet in North America. Proceeding of the Western Foundation of Vertebrate Zoology, Camarillo, CA.* (eds. Carter, H. R. & Morrison, M. L.) 5–16 (1992).
4. Halbert, P. & Singer, S. W. *Marbled Murrelet Landscape Management Plan for Zone 6*. (2017).
5. Burkett, E. E. Chapter 22: Marbled Murrelet food habits and prey ecology. in *Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152* (eds. Ralph, C. J., Hunt, G. L., Jr., Raphael, M. G. & Platt, J. F.) 223–246 (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1995).
6. Becker, B. H., Peery, M. Z. & Beissinger, S. R. Ocean climate and prey availability affect the trophic level and reproductive success of the marbled murrelet, an endangered seabird. *Marine Ecology Progress Series* **329**, 267–279 (2007).
7. Binford, L. C., Elliot, B. G. & Singer, S. W. Discovery of a nest and the downy young of the marbled murrelet. *The Wilson Bulletin* **87**, 303–319 (1975).
8. Meyer, C. B., Miller, S. L. & Ralph, C. J. Stand-scale habitat associations across a large geographic region of an old-growth specialist, the marbled murrelet. *The Wilson Bulletin* **116**, 197–210 (2004).
9. Baker, L. M. *et al.* Nesting habitat characteristics of the marbled murrelet in central California redwood forests. *The Journal of Wildlife Management* **70**, 939–946 (2006).
10. Hamer, T. E. & Nelson, S. K. Chapter 4: Nesting chronology of the Marbled Murrelet. in *Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152* (eds. Ralph, C. J., Hunt, G. L., Jr., Raphael, M. G. & Platt, J. F.) 49–56 (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1995).
11. Flint, L. E. & Flint, A. L. *California Basin Characterization Model: a dataset of historical and future hydrologic response to climate change (Ver. 1.1, May 2017)*. https://doi.org/10.5066/F76T0JPB (2014).
12. Flint, L. E., Flint, A. L., Thorne, J. H. & Boynton, R. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. *Ecological Processes* **2**, 25 (2013).
13. Pierce, D. W., Kalansky, J. F. & Cayan, D. R. *Climate, drought, and sea level rise scenarios for the Fourth California Climate Assessment*. (2018).

14. Swain, D. L., Langenbrunner, B., Neelin, J. D. & Hall, A. Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change* **8**, 427 (2018).
15. Glavich, D. A., Geiser, L. H. & Mikulin, A. G. Rare epiphytic coastal lichen habitats, modeling, and management in the Pacific Northwest. *bryo* **108**, 377–390 (2005).
16. Geiser, L. H. & Neitlich, P. N. Air pollution and climate gradients in western Oregon and Washington indicated by epiphytic macrolichens. *Environmental Pollution* **145**, 203–218 (2007).
17. Carroll, A. L., Sillett, S. C. & Kramer, R. D. Millennium-scale crossdating and inter-annual climate sensitivities of standing California redwoods. *PLOS ONE* **9**, e102545 (2014).
18. Carroll, A. L., Sillett, S. C., Palladini, M. & Campbell-Spickler, J. Dendrochronological analysis of *Sequoia sempervirens* in an interior old-growth forest. *Dendrochronologia* **52**, 29–39 (2018).
19. Johnstone, J. A. & Dawson, T. E. Climatic context and ecological implications of summer fog decline in the coast redwood region. *PNAS* **107**, 4533–4538 (2010).
20. Flint, L. E. & Flint, A. L. Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis. *Ecol Process* **1**, 2 (2012).
21. Olson, D. F., Jr., Roy, D. F. & Walters, G. A. *Sequoia sempervirens* (D. Don) Endl. - redwood. in *Silvics of North America: Volume 1: Conifers. Agriculture Handbook 654* (eds. Burns, R. M. & Honkala, B. H.) 541–551 (U.S. Department of Agriculture, Forest Service, 1990).
22. Mooney, H. & Dawson, T. E. Coastal redwood forests. in *Ecosystems of California* (eds. Mooney, H. & Zavaleta, E.) 535–552 (University of California Press, 2016).
23. Sillett, S. C. & Van Pelt, R. Trunk reiteration promotes epiphytes and water storage in an old-growth redwood forest canopy. *Ecological Monographs* **77**, 335–359 (2007).
24. USFWS. *Marbled murrelet (*Brachyramphus marmoratus*): 5-year review*. (2009).
25. Raphael, M. G., Falxa, G. A. & Burger, A. E. Chapter 5: Marbled murrelet. in *Synthesis of science to inform land management within the Northwest Forest Plan area. Gen. Tech. Rep. PNW-GTR-966* (eds. Spies, T. A., Stine, P. A., Gravenmier, R., Long, J. W. & Reilly, M. J.) 301–370 (U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2018).
26. Dettinger, M. Climate change, atmospheric rivers, and floods in California – a multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association* **47**, 514–523 (2011).
27. Shields, C. A. & Kiehl, J. T. Simulating the Pineapple Express in the half degree Community Climate System Model, CCSM4. *Geophysical Research Letters* **43**, 7767–7773 (2016).
28. Lorimer, C. G. *et al.* Presettlement and modern disturbance regimes in coast redwood forests: implications for the conservation of old-growth stands. *Forest Ecology and Management* **258**, 1038–1054 (2009).
29. Stuart, J. D. & Stephens, S. L. North Coast bioregion. in *Fire in California's ecosystems* (eds. Sugihara, N. G., van Wagtendonk, J. W., Fites-Kaufmann, J., Shaffer, K. E. & Thode, A. E.) 147–169 (University of California Press, 2006).
30. Sinton, D. S., Jones, J. A., Ohmann, J. L. & Swanson, F. J. Windthrow disturbance, forest composition, and structure in the Bull Run Basin, Oregon. *Ecology* **81**, 2539–2556 (2000).
31. DellaSala, D. A. *et al.* Climate change may trigger broad shifts in North America's Pacific coastal rainforests. in *Encyclopedia of the Anthropocene. Volume 2: Climate Change. Reference Module in Earth Systems and Environmental Sciences* (eds. Dellasala, D. A. & Goldstein, M. I.) 233–244 (Elsevier, 2018). doi:10.1016/B978-0-12-809665-9.09367-8.
32. USFWS. *Recovery plan for the threatened marbled murrelet (*Brachyramphus marmoratus*) in Washington, Oregon, and California*. (1997).
33. Lorenz, T. J., Raphael, M. G. & Bloxton, T. D., Jr. Marine habitat selection by marbled murrelets (*Brachyramphus marmoratus*) during the breeding season. *PLOS ONE* **11**, e0162670 (2016).
34. Ainley, D. G., Sydeman, W. J., Parrish, R. H. & Lenarz, W. H. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California — a predator's perspective. *California Cooperative Oceanic Fisheries Investigations Reports* **34**, 133–139 (1993).
35. Vilchis, L. I. *et al.* Assessing ecological correlates of marine bird declines to inform marine conservation. *Conservation Biology* **29**, 154–163 (2015).
36. Lorenz, T. J., Raphael, M. G., Bloxton, T. D. & Cunningham, P. G. Low breeding propensity and wide-ranging movements by marbled murrelets in Washington. *Jour. Wild. Mgmt.* **81**, 306–321 (2017).
37. Schneider, S. R. & Golightly, R. T. *Seabirds as indicators: understanding variability in marine productivity and prey communities through long-term studies of reproduction, foraging effort, and diet*. (2018).

38. Raphael, M. G., Mack, D. E., Marzluff, J. M. & Luginbuhl, J. M. Effects of forest fragmentation on populations of the Marbled Murrelet. *Studies in Avian Biology* **25**, 221–270 (2002).
39. Peery, M. Z. & Henry, R. W. Recovering marbled murrelets via corvid management: a population viability analysis approach. *Biological Conservation* **143**, 2414–2424 (2010).
40. Goldenberg, W. P., George, T. L. & Black, J. M. Steller's Jay (*Cyanocitta stelleri*) space use and behavior in campground and non-campground sites in coastal redwood forests. *The Condor* **118**, 532–541 (2016).
41. Peery, M. Z., Beissinger, S. R., Newman, S. H., Burkett, E. B. & Williams, T. D. Applying the declining population paradigm: diagnosing causes of poor reproduction in the marbled murrelet. *Conservation Biology* **18**, 1088–1098 (2004).
42. Malt, J. & Lank, D. Temporal dynamics of edge effects on nest predation risk for the marbled murrelet. *Biological Conservation* **140**, 160–173 (2007).
43. Dawson, T. E. Fog in the California redwood forest: ecosystem inputs and use by plants. *Oecologia* **117**, 476–485 (1998).
44. Carter, H. R., McAllister, M. L. C. & Isleib, M. E. P. Chapter 27: Mortality of marbled murrelets in gill nets in North America. in *Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152* (eds. Ralph, C. J., Hunt, G. L., Jr., Raphael, M. G. & Platt, J. F.) 271–284 (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1995).
45. USFWS. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for the Washington, Oregon, and California Population of the Marbled Murrelet. *Federal Register* **57 (191)**, 45328–45337 (1992).
46. Peery, M. Z., Becker, B. H. & Beissinger, S. R. Combining demographic and count-based approaches to identify source–sink dynamics of a threatened seabird. *Ecological Applications* **16**, 1516–1528 (2006).
47. Beissinger, S. R. & Peery, M. Z. Reconstructing the historic demography of an endangered seabird. *Ecology* **88**, 296–305 (2007).
48. Vuln. Assessment Workshop. Personal communication. (2019).
49. Golightly, R. T. & Schneider, S. R. *Observations of incubation in year 8 of a long-term monitoring effort at a Marbled Murrelet nest in northern California*. http://hdl.handle.net/2148/824 (2009).
50. Friesen, V. L. *et al.* Population genetic structure and conservation of marbled murrelets (Brachyramphus marmoratus). *Conserv Genet* **6**, 607–614 (2005).
51. California Fish and Game Commission. *Animals of California declared to be endangered or threatened*. *Government Code Section 11346.2 (d), Regulation 92:1-8* (1992).
52. Sillett, S. C. *et al.* Manipulating tree crown structure to promote old-growth characteristics in second-growth redwood forest canopies. *Forest Ecology and Management* **417**, 77–89 (2018).