Marbled Murrelet
(Brachyramphus marmoratus)

5-Year Status Review

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U.S. Fish and Wildlife Service
Washington Fish and Wildlife Office
Lacey, Washington

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5-YEAR STATUS REVIEW

Species reviewed: Marbled murrelet (*Brachyramphus marmoratus*)

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1.0 GENERAL INFORMATION

1.1 Reviewers

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1.2 Methodology used to complete the review:

This 5-year status review was conducted internally within the U.S. Fish and Wildlife Service (Service) through a multi-office team effort. Team members included Field and Regional Office biologists; no part of this review was contracted. We relied heavily on previous 2004 and 2009 5-year status reviews and McShane *et al*. (2004) for our baseline information and only provided updated information where it was available. Nearly all the information cited in this review has been peer reviewed separately through various publications.

1.3 Background:

1.3.1 FR Notice citation announcing initiation of this review: U.S. Fish and Wildlife Service. 2017. Endangered and threatened wildlife and plants; initiation of 5-year status reviews for 138 species in Hawaii, Oregon, Washington, and California. 82 FR 18665. April 20, 2017.

1.3.2 Listing history

Original Listing
FR notice: 57 FR 45328
Date listed: October 1, 1992
Entity listed: Washington, Oregon, and California Distinct Population Segment
Classification: Threatened

1.3.3 Associated Rulemakings: U.S. Fish and Wildlife Service. 1996. Endangered and threatened wildlife and plants; final designation of critical habitat for the marbled murrelet. 61 FR 26256. May 24, 1996.

We originally designated critical habitat for the marbled murrelet (murrelet) in Washington, Oregon, and California on May 24, 1996 (61 FR 26256). At that time, we designated 3,887,800 acres (ac) (1,573,340 hectares [ha]) of Federal and non-federal lands, consisting of 78 percent Federal land; 21 percent city, county, or State land; and 1 percent private land. Primary constituent elements (PCEs) were described as: (1) trees with potential nesting platforms, and (2) forested areas within 0.5 mile (mi) (0.8 kilometer [km]) of potential nest trees with a canopy height of at least one-half of the site potential tree height. In the 1996 murrelet critical habitat designation, critical habitat on Federal lands, including Forest Service lands, is only within Northwest Forest Plan (NWFP) Late Successional Reserves. The 1996 critical habitat rule did not designate critical habitat in NWFP matrix lands. In 2011, approximately 189,671 ac (76,757 ha) were removed from critical habitat in northern California and southern Oregon, resulting in a final revised designation of approximately 3,698,100 ac (1,497,000 ha) of critical habitat in Washington, Oregon, and California (76 FR 61599). In 2016, the Service affirmed that the 1996 designation, as revised in 2011, meets the statutory definition of critical habitat (81 FR 51348).

1.3.4 Review History:

In September 1, 2004, a 5-year status review was completed with no recommended change in status. Under the distinct population segment (DPS) analysis portion, a determination was made that the population did not satisfy the criteria for designation as a DPS under the Service's 1996 DPS Policy. However, the Service determined that the DPS analysis from 2004 was flawed. A 5-year status review was completed on June 12, 2009, with a revised DPS analysis and no recommended change in status.

1.3.5 Species' Recovery Priority Number at start of this 5-year review: 2 (full species, high degree of threat, high recovery potential)

1.3.6 Current Recovery Plan or Outline

Name of plan or outline: Recovery plan for the threatened marbled murrelet (*Brachyramphus marmoratus*) in Washington, Oregon and California.

Date issued: September 24, 1997

Dates of previous revisions, if applicable: N/A

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1 Is the species under review a vertebrate? Yes.

2.1.2 Is the species under review listed as a DPS? Yes.

2.1.3 Was the DPS listed prior to 1996? Yes. It was listed in 1992.

2.1.3.1 Prior to this 5-year review, was the DPS classification reviewed to ensure it meets the 1996 policy standards?

a) Our September 2004 5-year status review concluded that the population of murrelets in Washington, Oregon, and California should remain listed, but that the population did not qualify as a DPS under the DPS policy because the tri-state population was not discrete. However, the Service subsequently determined that the 2004 discreteness analysis was fundamentally flawed because it compared management and regulatory differences between the U.S. and Canada at the current levels of legal protection in the two countries rather than comparing the management/regulatory levels that would exist if the species were not listed in the U.S.

b) The latest 5-year status review was completed in June 2009, and found that the current DPS is indeed consistent with the 1996 policy standards.

c) A February 27, 2015, decision by the U.S. Court of Appeals for the District of Columbia affirmed the Service's finding that this listed taxon is a valid DPS.

2.1.3.2 Does the DPS listing meet the discreteness and significance elements of the 1996 DPS policy?

Yes (see discussion below). As discussed in our 2009 5-year status review, the discreteness analysis compares management/regulatory levels in the U.S. and Canada that would exist if the species were not listed in the U.S., because this is the approach used in an initial listing determination and the Act does not indicate that different analysis criteria should be used in a 5-year status review.

2.1.4 Is there relevant new information for this species regarding the application of the DPS policy?

Yes. Our analysis incorporates the DPS analysis from our 2009 5-year status review and considers new information regarding conservation status and management of habitat in Washington, Oregon, California, and Canada since our 2009 5-year status review.

Given the updated information, is the listed entity consistent with the DPS policy with regards to the Discreteness and Significance elements?

Yes, the currently listed entity is consistent with the DPS policy.

A) Is the currently listed murrelet population discrete according to the 1996 DPS Policy?

Yes, the murrelet population is discrete according to the 1996 DPS Policy.

Discreteness: A population segment of a vertebrate species may be considered discrete if it satisfies either one of the following conditions:

- It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation. [see *Biological Issues* below]
- It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the Endangered Species Act of 1973 (Act; 50 CFR 1431 *et seq*.) . [see *International Border Issues* below]

(1) ***Biological Issues:*** We have no evidence of marked genetic or morphological discontinuity between populations at the U.S. - Canadian border.

(2) ***International Border Issues****:* If the species were not listed, there would be differences in management of habitat, conservation status, and regulatory mechanisms across the international border that are significant in light of section 4(a)(1)(D) of the Act.

(2)(a) Control of Exploitation. Both countries similarly prohibit direct exploitation of murrelets therefore there are not substantive differences in the control of exploitation across the international border.

(2)(b) *Management of Habitat*. The management of habitat is different across the U.S. - Canadian border (assuming removal of Act protections) because the two countries would rely on regulatory mechanisms that are not equally protective of the murrelet or its habitat (see *Regulatory Mechanisms* below).

(2)(c) *Conservation Status.* There is a difference in conservation status between the U.S. and Canada. If the murrelet were not listed under the Act, no Federal protections would be afforded it under the Act. In Canada, under the Species At Risk Act (SARA 2002), the species would remain classified as "threatened," that is, "a wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction." SARA's prohibition of harm to the species and its residence would mean the species would have significantly greater legal protection on the Canadian side of the border. The murrelet is listed as endangered in Washington and California, and threatened in Oregon under the individual State endangered species acts, but these statutes provide relatively little protection to the species. Hence, there would be a significant difference in conservation status from a legal standpoint.

Since our 2009 status review, there continues to be a significant difference in conservation status from a population standpoint. The contiguous U.S. has a substantially smaller population of murrelets

(approximately 23,260; Pearson *et al*. 2018, Henry and Tyler 2017), than does Canada (approximately 99,000; Environment Canada 2014). This is a larger difference than that reported in 2009. There is no new information to indicate that the productivity differences reviewed in 2009 have changed. Since our 2009 status review, there is moderate evidence for a negative overall trend of -1.6 percent/year (95 percent confidence level -3.2 to 0.01) of the murrelet population in British Columbia (Bertram *et al*. 2015, p. 9). As in the DPS (Falxa *et al*. 2016, Pearson *et al*. 2018), the rate of decline varies in British Columbia, with some regions exhibiting declines as great as 8.6 percent/year (East Vancouver Island) (Bertram *et al*. 2015, p. 9).

Estimates of loss of old-growth forests in the U.S. Pacific Northwest since pre-industrial times (National Research Council 2000), compared to the amount of forests within the range of the murrelet in British Columbia that have become unsuitable due to anthropogenic causes (*e.g.*, industrial logging and urbanization) (Demarchi and Button 2001a, b as adapted by Burger 2002), show a higher percentage of murrelet habitat has been lost historically in Washington, Oregon, and California than in Canada. In the more recent past, Long *et al*. (2011, pp. 54-56) estimated the loss of approximately 22 percent of the suitable nesting habitat in British Columbia from 1978 until 2008. With the implementation of the Northwest Forest Plan in the U.S. Pacific Northwest, Raphael *et al.* (2016a, pp. 72-75) estimated a decline of approximately 12.1 percent of higher suitability habitat between 1993 and 2012 across all land ownerships; however, losses on non-federal lands were greater, as much as 29.8 percent in Washington.

Finally, there are differences in the amount of nesting habitat remaining for marbled murrelets between the contiguous U.S. and Canada. There are approximately 3.2 to 9.9 million ac (1.3 to 4 million ha) of nesting habitat remaining in British Columbia (Long *et al*. 2011, p. 54), while there are only about 2.23 million ac (900,000 ha) of suitable nesting habitat remaining in the contiguous U.S. (Raphael *et al*. 2016a, p. 69).

In conclusion, the conservation status of the marbled murrelet is significantly different across the international border. Murrelet population numbers are lower in the U.S. (approximately one-quarter of the Canadian population), productivity is lower, the historical loss of old-growth forests has been more severe, and the amount of remaining habitat is lower. This difference in conservation status would likely be exacerbated absent the Act's protections in the U.S.

(2)(d) *Regulatory Mechanisms.* Compared with protection in Canada, there would be significantly less regulatory protection for the murrelet in Washington, Oregon, and California if the species were delisted.

<u>Regulatory Mechanisms in Canada</u>: Since our 2009 5-year status review, changes in Canadian regulatory methods include the completion of the Recovery Strategy for the Marbled Murrelet in Canada (Environment Canada 2014). Our 2009 5-year status review included the population objectives that were set by the British Columbia province under the Identified Wildlife Management Strategy. However, with the completion of the Federal Recovery Strategy, the population and distribution objectives identified in the Recovery Strategy supersede the provincial objectives. The Recovery Strategy identifies short and long-term population and distribution objectives to ensure a high probability of persistence across the species range after 2032. The short-term (next 10 to 20 years) objective is to slow to a halt any decline of the population and the area of its nesting habitat and

to stabilize the total population and nesting habitat area above 70 percent of 2002 levels (Environment Canada 2014, p. 13). The strategy is comprised of six primary conservation regions that each have recovery objectives. The long-term objective to stabilize the population within the accepted range of natural variation is to be achieved by maintaining or restoring sufficient nesting and marine habitat and reducing other identified threats within each conservation region (Environment Canada 2014, p. 14). In addition, the strategy identifies terrestrial critical habitat across six primary conservation regions. Marine critical habitat has not yet been identified, but was identified as a gap to be followed up on.

Regulatory Mechanisms in Washington, Oregon, and California Without the Protections of the Act: If the murrelet were not federally listed in Washington, Oregon, and California, prohibitions under section 9 of the Act would no longer apply. Thus, there would be no Federal prohibitions against take through habitat destruction, or harassment of the murrelet. In addition, absent protection of the Act, Federal agencies would have no obligation under section 7 of the Act to consult with the Service on the effects of their actions on the species, to avoid jeopardizing the species, or to avoid adversely modifying previously identified critical habitat.

As discussed in our 2009 5-year status review, the murrelet would continue to receive protection under the Migratory Bird Treaty Act (MBTA) (16 U.S.C. § 703), which makes it unlawful to take migratory birds, including the marbled murrelet. The MBTA's definition of ''take'' includes direct pursuit, killing, and capturing, but does not include harm through habitat destruction, nor harassment (16 U.S.C. 715n). The Ninth Circuit has held that the MBTA does not protect migratory birds from habitat destruction such as logging of old growth forest (*Seattle Audubon Society* v. *Evans,* 952 F.2d 297 [9th Cir. 1991]). Similarly, a Department of the Interior Solicitor Office formal legal opinion dated December 22, 2017, finds that the MBTA does not prohibit incidental take of migratory birds. SARA, by contrast, protects the murrelet from not only direct killing, but also harm, harassment, and destruction of the species' ''residence''. Moreover, the MBTA's sanctions for violations are significantly lighter than SARA's, imposing only misdemeanor penalties of 6 months imprisonment and $15,000 in fines (16 U.S.C. 707), compared with the felony-level sanctions under SARA. For these reasons, SARA affords more protection for murrelets than the MBTA.

The adoption of the NWFP by the Forest Service and the Bureau of Land Management (BLM) greatly reduced the annual rate of habitat loss on Federal land in the U.S. after 1994. Nonetheless, loss of nesting habitat continues to occur on Federal lands, both in reserved and non-reserved land use allocations (Raphael *et al*. 2016a, pp. 66-67). These losses are primarily attributed to wildfire (in particular the Biscuit fire in Oregon in 2002) and timber harvest (Raphael *et al*. 2016a, p. 80). As of August 5, 2016, BLM lands in Western Oregon are managed according to updated Resource Management Plans (RMPs, BLM 2016a and BLM 2016b). The changes to the management of these lands compared to previous management under the NWFP includes an additional 31,991 ac (12,946 ha) of suitable murrelet nesting habitat in Late Successional Reserves/Riparian Reserves, including an additional 18,034 ac (7,298 ha) of highly suitable habitat. For new marbled murrelet sites recognized under the revised RMPs, occupied stand protection and associated Late Successional Reserve mapping changed from only protecting contiguous habitat within 0.5 mi (0.8 km) to protecting all forest structure within 0.25 mi (0.4 km), with an additional 300-foot (0.09-km) buffer. The revised RMPs include protection from disruption in stands known to be occupied by murrelets, which the NWFP did not. BLM inland marbled murrelet zones are not consistent with the NWFP mapped inland zones, but are consistent with the inland zones as described in the NWFP text (USDA and USDI 1994, p. C-10)

and as described by the Forest Ecosystem Management Assessment Team (USDA *et al*. 1993, pp. IV-23, IV-24). The NWFP remapping, indicated as planned in the record of decision for the NWFP, has not yet occurred (USDA and USDI 1994, pp. A-6, A-7). Protection of murrelets was reduced in inland zone 2, where murrelets are occurring at low densities and are only known to be using suitable habitat in the Roseburg BLM District. In inland zone 2, stands known to be used by murrelets for nesting are not protected from activities in the harvest land base. Also, in inland zone 2 within the District designated reserves, murrelets receive protections from disruption but no protection from habitat modification associated with activities. All occupied habitat was placed in reserves and more habitat, including high quality habitat, is in Late Successional Reserves in both inland zones under the RMPs. Ingrowth in high quality habitat is projected to occur at a higher rate than under the NWFP. Overall, the revised BLM RMPs are an improvement for murrelet conservation compared to the NWFP.

The national forests in the Pacific Northwest are in the process of revising their individual forest management plans. Upon completion of a record of decision, each of the revised forest management plans will supersede the NWFP guidelines. However, until that time, these national forests continue to manage their lands according to the NWFP.

If the murrelet was delisted, the BLM's RMPs and the NWFP (or new plans) could be amended to reduce protection for the species. While the murrelet may still receive some incidental benefit from continued protection of the reserve systems that are designed for the northern spotted owl, the conservation benefits would not likely extend to all areas currently protected for the murrelet because the northern spotted owl does not entirely overlap the murrelet in areas occupied or habitat features.

In our 2009 5-year status review, we provided information that indicated there are differences in management of marine habitat between Canada and the U.S. There is no new information that changes that analysis.

Absent listing under the Act, State laws would not necessarily protect murrelets on Federal lands. Other Federal laws governing management of Federal lands could preempt State law to the extent there is an irreconcilable conflict (*National Audubon Society v. Davis*, 307 F.3d 835, 854 (9th Cir. 2002)).

The murrelet continues to receive some protection under State laws in Washington, Oregon, and California, but these laws are less protective than SARA. In 2016, the Washington Department of Fish and Wildlife (WDFW) recommended that the murrelet in Washington be reclassified to endangered, which was accepted by the Washington Wildlife Commission. The recent change in classification from threatened to endangered in Washington does not enact new or change laws or protections analyzed in our 2009 5-year status review. However, the change in classification results in harsher punishment (Revised Code of Washington (RCW) § 77.15.120; and Washington Administrative Code (WAC) § 220-610-110) if a person is found guilty of unlawful take. In Washington State, unlawful take continues to include only the purposeful take of a murrelet, nest, or egg; this regulation does not provide habitat protection. The change in classification by WDFW has triggered a review of the Forest Practices Rules, but at this time, the Rules have not been reviewed; thus there have been no changes since 2009. Washington State law continues to be less protective than SARA because, by limiting its reach to "malicious" conduct, it does not govern as broad a range of conduct as does

SARA's strict liability standard, and because the penalties it imposes are still substantially lighter than those imposed by SARA.

There have been no changes in the laws that pertain to murrelets in Oregon from those described in our 2009 5-year status review. In 2017, the Oregon Department of Fish and Wildlife (ODFW) initiated a status review due to a petition requesting the murrelet in Oregon be reclassified as endangered under the Oregon Endangered Species Act (ODFW 2018). In February 2018, the Oregon Fish and Wildlife Commission voted to reclassify the murrelet to endangered; however, this decision was reversed in June 2018, and the murrelet remains listed as threatened.

There have been no changes in the laws that pertain to murrelets in California from those described in our 2009 5-year status review. The Service does not have information regarding the number of timber harvest plans and nonindustrial timber management plans (and associated acreages) that have been reviewed for possible take of marbled murrelets since 2009. While it is possible that suitable marbled murrelet habitat and possibly even occupied nesting habitat may have been removed during timber harvest since 2009, nearly all old-growth (as of 1990) had been removed from private lands (Thomas *et al*. 1990, p. 7), and thus the Service considers the amount (in acreage) of suitable murrelet habitat removed from private lands in California since 2009 to likely be small. Thus, similar to our 2009 5-year status review, the practical application of the California Forest Practice Rules (CFPRs) are likely only partially effective at protecting suitable habitat pursuant to the Federal Endangered Species Act due to the lack of a detailed description of habitat suitability within the CFPRs and the lack of adequate resource agency staff to review timber harvest plans and nonindustrial timber management plans that may contain suitable marbled murrelet nesting habitat.

As described above, were the species not listed, the differences in regulatory mechanisms that would exist on each side of the international border would be significant and would result in differences in management of habitat. Since our 2009 5-year status review, the gap in protections have grown even more significant, particularly in light of the completion of Canada's Recovery Strategy. Without Federal protective measures afforded by the Act in place, the species would face a greater risk of extirpation in the coterminous U.S.

B) Is the currently listed murrelet population significant according to the 1996 DPS Policy?

Yes, the murrelet population continues to be significant according to the 1996 DPS Policy.

Significance: Under the DPS Policy, if a population segment is considered discrete, its significance can be assessed. The DPS Policy states that a species' population can be considered significant based on considerations that may include, but are not limited to:

- Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon;

- Evidence that loss of the discrete population segment would result in a significant gap in the range of a taxon;

- Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range; or

- Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

Loss of the DPS would result in a significant gap in the range of the murrelet. This gap is significant because the Washington, Oregon, and California area accounts for roughly 18 percent of the total coastal distribution of the species, encompassing 17 degrees of latitude. In addition, the Washington, Oregon, and California area is located at the southern-most extent of the range. This DPS contains an ecologically distinct forest system, the coast redwood (*Sequoia sempervirens*) zone. Citing Noss 1994, Fraser (1999, p. 50), declared that in order to maintain opportunities for speciation and future biodiversity, the conservation of peripheral and disjunct populations is critical. Recovery of species without the conservation of these peripheral populations may be impossible if these populations are eliminated or severely damaged (Fraser 1999, p. 50).

Although there is no genetic distinction at the border, researchers have found moderate genetic differentiation throughout the range of the species, as reported in our 2009 5-year status review. Since our analysis in 2009, genetic work by Peery *et al*. (2010, p. 701) indicates the moderate genetic differentiation of the central California population from the northern populations likely developed over the past century as a result of genetic drift and reduced gene flow. However, the population continues to receive migrants from the northern populations, with migration increasing by 1.4 percent per year from 1997 to 2003 (Peery *et al*. 2010, p. 702). Peery *et al*. (2010, p. 702) found that migrants may have contributed offspring to the central California population, although at a much lower proportion than residents. They did acknowledge, however, that with statistical error, it was possible that no migrant contributed to the population during their study (Peery *et al*. 2010, p. 702). However, they also pointed out that the levels of heterozygosity they observed provided little evidence that inbreeding occurred and the migrants were contributing to the breeding population.

In addition, since our 2009 5-year status review, another new analysis using non-neutral markers found lower allele and peptide richness at both the individual and population levels in murrelets sampled from Oregon compared to murrelets in the Aleutian Islands, southeast Alaska, and central California (Vasquez-Carrillo *et al*. 2013, p. 6). In addition, Vasquez-Carrillo *et al*. (2013, p. 6) found unique alleles and peptides in all four of the populations they sampled. Thus, similar to murrelets in central California, murrelets in Oregon likewise have unique genetic characteristics.

Although research indicates moderate genetic differentiation across the range of the murrelet (Aleutian Islands to central California), the level of differentiation varies depending upon the marker used (neutral versus non-neutral) and does not indicate genetic differences sufficient to preclude the ability of adult murrelets from one portion of the range to interbreed when mature with murrelets from another portion of the range.

Conclusion

We still consider the Washington, Oregon, and California population of murrelets to be a valid distinct population segment under the 1996 DPS Policy. This population of murrelets is discrete at the international border because: (1) the coterminous U.S. has a substantially smaller population of murrelets than does Canada; (2) breeding success of the murrelet in Washington, Oregon, and California is considerably lower than in British Columbia; and (3) there are differences in the amount of habitat, the rate of habitat loss, and regulatory mechanisms between the countries. The coterminous U.S. population of murrelets is also considered significant in accordance with the criteria of the DPS Policy, as the loss of this distinct population segment would result in a significant gap in the range of the taxon and the loss of unique genetic characteristics that are significant to the taxon.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan[1] containing objective, measurable criteria?

_X_ ***Yes****, continue to section 2.2.2.*

2.2.2 Adequacy of recovery criteria.

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat? *Yes*

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria? *No.*

2.2.3 Recovery Objectives and Delisting Criteria

The murrelet recovery plan was completed in 1997, and includes interim recovery objectives, recovery actions necessary to address the recovery objectives, and interim delisting criteria.

The interim objectives of this recovery plan are: (1) to stabilize and then increase population size, changing downward trend to an upward trend throughout the listed range; (2) to provide conditions in the future that allow for a reasonable likelihood of continued existence of viable populations; and (3) to gather the necessary information to develop specific delisting criteria.

The following actions were identified as necessary to address the recovery objectives. These actions include: (1) establishing six Marbled Murrelet Conservation Zones (Conservation Zone) and developing landscape-level management strategies for each Conservation Zone; (2) identifying and protecting habitat areas within each Conservation Zone, including the marine environment, through implementation of the NWFP, designation as critical habitat, better use of existing laws, or other methods (*e.g.*, habitat conservation plans), and developing management plans for these areas; (3)

[1] Although the guidance generally directs the reviewer to consider criteria from final approved recovery plans, criteria in published draft recovery plans may be considered at the reviewer's discretion.

monitoring populations and habitat, and surveying potential breeding habitat to identify potential nesting areas (*e.g.*, occupied sites); (4) implementing short-term actions to stabilize and increase the population that include maintaining potential suitable habitat in large contiguous blocks and buffer areas, maintaining habitat distribution and quality, decreasing risk of fire and windthrow, decreasing adult and juvenile mortality, reducing nest predation, increasing recruitment, and initiating research to determine impacts of disturbance in both marine and terrestrial environments; (5) implementing long-term actions to stop population decline and increase population growth by increasing the amount, quality and distribution of suitable nesting habitat, decreasing fragmentation, protecting "recruitment" habitat, providing replacement habitat through silvicultural techniques, and improving marine habitat quality; (6) initiating research to develop and refine survey and monitoring protocols, refine population estimates, examine limiting factors, evaluate disturbance effects, and obtain additional life history data; and (7) establishing a regional coordination body for the marbled murrelet research efforts, including data storage and retrieval in databases and archives. The recovery plan notes that recovery actions may be better defined in the future depending on results of additional research.

The interim delisting criteria included in the recovery plan are: (1) trends in estimated population size, densities and productivity have been stable or increasing in four of the six Conservation Zones over a 10-year period, which should encompass at least one to two El Niño events, and (2) management commitments, including protection and monitoring in marine and terrestrial habitats, have been implemented to provide adequate protection of marbled murrelets in the six Conservation Zones for at least the near future (50 years). The recovery plan indicates that additional research and monitoring may provide necessary information on murrelet populations, habitat, survivorship, and productivity so that revised recovery criteria can eventually be developed. These criteria should be reasonable, attainable, and adequate to maintain the species over the period of reduced habitat availability during the next 50 years and to insure viable populations over the long-term (greater than 200 years). Until revised criteria are developed, the criteria presented in the recovery plan remain in effect.

The recovery objectives and delisting criteria have not been met, although each of the recovery actions, with the exception of establishing a regional coordination body, have been implemented to varying degrees. Research and monitoring has continued to be implemented since the analyses for our 2004 and 2009 5-year status reviews.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history:

Since the analyses for our 2009 5-year status review, more information has become available regarding the biology, life history, and habitat use of the murrelet.

Marine Distribution and Movements. As was concluded in our 2009 5-year status review, there are differences in home range size and use across the species' range, which may be tied to habitat use and forage availability. One additional study adds to this conclusion. In Washington, murrelets captured on the outer coast had larger marine ranges than those in the Puget Sound/Straits of Juan de Fuca (Lorenz *et al*. 2017, p. 313). All of the murrelets that were captured on the outer coast were detected

in the Puget Sound, but only a few murrelets captured in the Straits of Juan de Fuca were detected foraging on the outer coast (Lorenz *et al*. 2017, p. 312). In addition, murrelets in Washington have relatively long commuting distances from the nest to foraging habitat (mean 32 mi (53.1 km), range 10.4 to 90.2 mi (16.8 to 145.3 km)); the longest commute was by a murrelet from the only nest found in the Washington Cascade range, which happened to be one of only four successful nests from the study (Lorenz *et al*. 2017, pp. 313-314).

Elevation. As has been previously reported, murrelet nests have been located at a variety of elevations. The highest known nest elevation for the listed range is in Washington at 4,198 feet (1,280 meters) (Wilk *et al*. 2016, p. 167). There has been no new information to suggest the existence of nesting at higher elevations than previously reported in Oregon or California.

Ground Nesting. The first observed ground nest within the listed range was found on the northern Olympic Peninsula in Washington. This nest was on a cliff and appeared to have similar characteristics as a traditional tree limb nest; however, in the year that it was found, it was not successful as the chick was found at the base of the cliff (Wilk *et al*. 2016, p. 167).

Nest Re-use. Burger *et al*. (2009, entire) found that murrelets in British Columbia re-used nesting structures; however, there were differences in the degree of re-use such that nest re-use was more frequent in regions with significant loss of nesting habitat due to harvest than in less disturbed areas. Nest re-use has also been documented in Washington (Bloxton and Raphael 2009, p. 11).

2.3.1.2 Abundance, population trends (*e.g.*, increasing, decreasing, stable), demographic features (*e.g.*, age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Population Size

Conservation Zones 1 through 5: The best available current data on murrelet population size and status for Conservation Zones 1 through 5 (Figure 1) are the results from the effectiveness monitoring program of the NWFP, which has conducted at-sea population surveys during the breeding season since 2000 using a standardized survey protocol (Huff 2006; Miller *et al*. 2006; Raphael *et al*. 2007). Our 2009 5-year status review included 2000 to 2008 results from that program, which concluded there was a significant decline; results are now available through 2017 (Table 1, Figure 2) (Pearson *et al*. 2018). Beginning in 2014, this program began a reduced sampling effort design, such that Conservation Zones 1 through 4 are sampled every other year and Conservation Zone 5 is sampled every fourth year when Conservation Zone 4 is sampled. Due to the reduced sampling effort, an estimate for these Conservation Zones can only be made after 2 years of sampling has been completed. For 2016, the estimated population of murrelets in the 5-Conservation Zone area was 22,600 (95 percent confidence interval of 18,200 to 27,100; Pearson *et al*. 2018).

At-sea densities followed the same general pattern as reported previously, with high densities in Oregon and northern California (Conservation Zones 3 and 4), and very low densities in Conservation Zone 5, except in 2017, when a significantly higher number of murrelets were observed in Conservation Zone 5 (Pearson *et al*. 2018, p. 3).

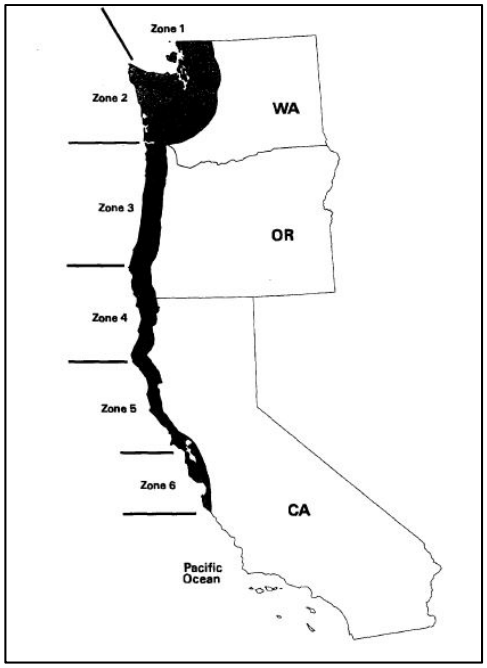

Figure 1. Marbled Murrelet Conservation Zones (USFWS 1997, Figure 8, p. 114).

Table 1. Summary of marbled murrelet density and population size estimates from 2001 through 2016 (rounded to nearest 100 birds) in Conservation Zones 1 through 5 in the area of the Northwest Forest Plan.

Year	Density (birds/km^2)	Bootstrap Standard Error (birds/km^2)	Coefficient of Variation of Density (%)	Number of Birds	Number of Birds Lower 95% confidence limit	Number of Birds Upper 95% confidence limit
2001	2.47	0.25	10.1%	21,800	17,500	26,100
2002	2.56	0.31	11.9%	22,500	17,300	27,800
2003	2.60	0.25	9.6%	22,800	18,500	27,100
2004	2.46	0.26	10.5%	21,600	17,100	26,000
2005	2.30	0.25	10.7%	20,200	16,000	24,400
2006	2.08	0.17	8.2%	18,300	15,300	21,200
2007	1.97	0.27	13.7%	17,300	12,700	22,000
2008	2.06	0.18	8.9%	18,100	15,000	21,300
2009	1.96	0.21	10.6%	17,300	13,700	20,900
2010	1.89	0.21	11.1%	16,600	13,000	20,300
2011	2.50	0.31	12.6%	22,000	16,600	27,400
2012	2.40	0.27	11.4%	21,100	16,400	25,700
2013	2.24	0.25	11.1%	19,700	15,400	23,900
2014	2.43	0.22	9.1%	21,300	17,492	25,118
2015	2.75	0.26	9.4%	24,100	19,700	28,600
2016	2.58	0.26	10.0%	22,600	18,200	27,100

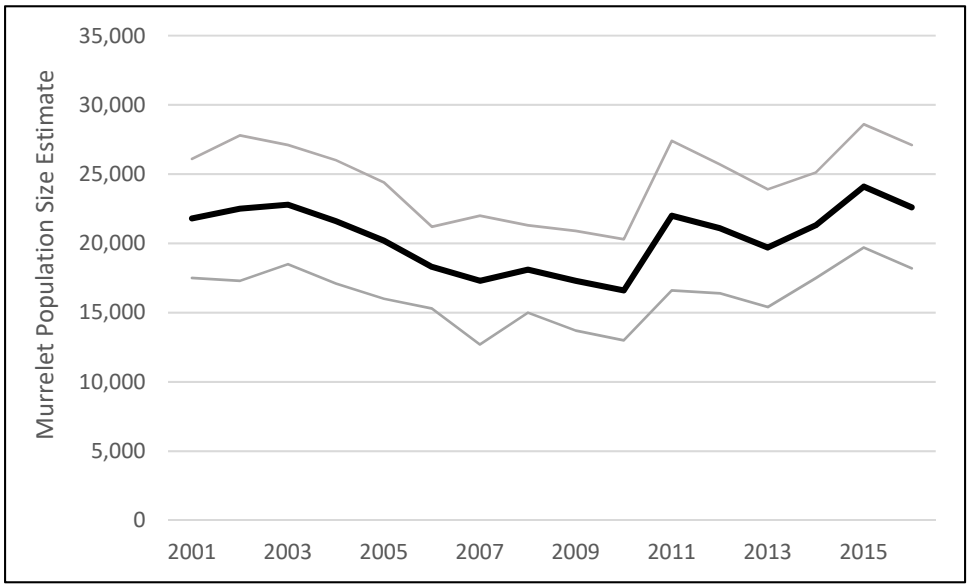

Figure 2. Marbled murrelet population size estimates from Table 1. Gray lines indicate upper and lower 95 percent confidence limits.

Conservation Zone 6: While the NWFP surveys did not include Conservation Zone 6, others have been conducting at-sea population surveys for murrelets in Conservation Zone 6 offshore of breeding habitat between Half Moon Bay and Santa Cruz, California (Henry and Tyler 2017; entire). Using distance sampling estimation techniques (same method as Conservation Zones 1 through 5), they estimated the 2016 Conservation Zone 6 population to be 657 birds (95 percent confidence interval: 406-1063) (Henry and Tyler 2017) (Table 2).

Table 2. Population estimates and 95 percent confidence limits for Conservation Zone 6. Source: Henry and Tyler (2017). No surveys were conducted from 2004 to 2006. The 1999 and 2000 surveys used slightly different routes from later years, and estimates from those 2 years should not be compared directly with data from 2001 through 2008.

Year	Number of Birds	Lower 95% Confidence Limit	Upper 95% Confidence Limit
1999	*N/A*		
2000	*N/A*		
2001	661	556	786
2002	683	561	832
2003	699	567	860
2004	*no surveys*		
2005	*no surveys*		
2006	*no surveys*		
2007	378	238	518
2008	174	91	256
2009	631	449	885
2010	446	340	585
2011	433	339	553
2012	487	403	588
2013	628	386	1022
2014	438	307	624
2015	243	152	386
2016	657	406	1063

Population Trends

Declining murrelet populations have been predicted by demographic models (USFWS 1997; McShane *et al*. 2004), which estimated losses of about 3 to 7 percent per year. New information, based on population estimates conducted by standardized protocols since 2000 provide direct data with which to evaluate population trends in the listed range. Since 2000, at-sea surveys provide population estimates for Conservation Zones 1 through 5 under the Effectiveness Monitoring Program of the NWFP (Miller *et al*. 2006; Falxa *et al*. 2016; Lynch *et al*. 2017; Pearson *et al*. 2018). The estimates of the average rate of change based on these surveys (Pearson *et al*. 2018) are summarized in Table 3.

Table 3. Estimates of average annual rate of change based on the at-sea population surveys. Confidence limits are for the estimates of percent annual change. The *P*-value is based on a 2-tailed test for whether the annual rate of change is less than zero. Adjusted R^2 indicates the strength of correlation; grayed *P*-values indicate the rate of change is considered statistically significant.

Conservation Zone or State	Period of Analysis	Annual Rate of Change (%)	95% Conf. Limits		Adjusted R^2	*P*-value
			Lower	Upper		
Zone 1	2001-2016	-4.9	-7.7	-2.1	0.454	0.003
Zone 2	2001-2017	-2.4	-6.6	1.9	0.030	0.246
Zone 3	2000-2016	1.1	-0.9	3.3	0.022	0.266
Zone 4	2000-2017	3.7	1.4	6.1	0.425	0.004
Zone 5	2000-2017	7.2	-4.4	20.3	0.080	0.204
Zones 1-5	2001-2016	0.15	-1.2	1.6	0.000	0.824
WA	2001-2016	-3.94	-6.1	-1.7	0.467	0.002
OR	2000-2016	1.8	0.1	3.6	0.198	0.042
CA	2000-2017	4.5	2.2	6.9	0.486	0.001

Due to the nature of sampling a highly mobile bird that is sparsely and patchily distributed and due to the level of survey effort, the population and trend estimates tend to have fairly wide confidence intervals. The Effectiveness Monitoring team provided details on how they evaluated the data for evidence of a trend (Falxa *et al*. 2016, p. 8):

> "For the purposes of evaluating the evidence for a linear trend, we considered: (1) the magnitude of the annual trend estimate, particularly in relation to zero, where zero represents a stable population, and (2) the width and location of the 95 percent confidence intervals surrounding that trend estimate, also in relation to zero. The evidence for a population trend, versus a stable population, is stronger when the trend estimate and its 95 percent confidence interval do not overlap zero, and when the trend estimate is farther from zero. When the confidence interval of a trend estimate is tight around zero, then we would conclude that there is no evidence of a trend. Finally, when the confidence interval of a trend estimate broadly overlaps zero and the trend estimate is not close to zero, this indicates evidence that is not conclusive for or against a non-zero trend. Confidence intervals that are mainly above or below zero, but slightly overlap zero, can provide some evidence of a trend. "

Based on this process of evaluation of trend and information in Table 3, there is no evidence of a trend for Conservation Zones 1 through 5 combined, as of 2016 (the most recent year available). At the scale of individual conservation zones, there is evidence for population declines in Conservation Zone 1. While the data indicate there may be a negative trend in Conservation Zone 2, the confidence interval overlaps zero; therefore, the trend for this Conservation Zone is uncertain. There is evidence of a positive trend in Conservation Zone 3 and 5; however, the confidence intervals overlap zero. Therefore, the trends for these Conservation Zones are also uncertain. In addition, in Conservation Zone 5, the confidence intervals are very wide, as few birds are generally detected in this zone. There is evidence of a positive trend in Conservation Zone 4. At the State scale, there is evidence for a

negative trend in Washington (comprised of Conservation Zones 1 and 2) and a positive trend in Oregon (comprised of Conservation Zone 3 and the northern portion of Conservation Zone 4) and California (comprised of the southern portion of Conservation Zone 4 and all of Conservation Zone 5).

In Conservation Zone 6, the murrelet population in the portions of the zone that are surveyed appear to have undergone a significant and rapid population decline sometime after 2003 continuing through 2008 and then rebounded back to similar population estimates by 2016 (Henry and Tyler 2017; Table 2). The researchers propose the rebound may be a result of corvid population/predation control measures implemented by the California Department of Parks and Recreation (Henry and Tyler 2017, p. 7). Another hypothesis is that the rebounding population estimates may be due to birds immigrating from northern populations; however, genetic data collection conducted pre- and post-decline does not support this hypothesis because most birds sampled had a high probability of belonging to the central California population (Vasquez-Carrillo *et al*. 2013b, p. 176). While the predation control measures may have played a role in the rebounding population estimate, the more likely hypothesis is that during the years of lower population estimates the birds were outside of the area surveyed (Vasquez-Carrillo *et al*. 2013b, p. 177).

Conclusions, Population Size and Trend: The murrelet population estimate for Conservation Zones 1 through 6 was estimated to be approximately 23,260 (rounded to nearest 100) birds in 2016. While there continue to be significant declines in the murrelet population in Washington State, there does not appear to be a trend (negative or positive) at the listed-range scale. This is a change from information reported in our 2009 5-year status review.

Reproduction. McShane *et al*. (2004, p. 3-2) considered murrelet breeding success to be a function of nest predation, timing, foraging conditions, prey availability, and adult survival during the breeding season. Impacts to breeding success from predation are discussed under Factor C: predation. We have no new information on adult survival.

Only one reproduction study has been completed since our 2009 5-year status review. In Washington, murrelets were radio-tagged and tracked to their nests. From this study, researchers have shown that the breeding propensity of the tagged birds was 13.1 to 20 percent over 5 years (2004 to 2008) (Lorenz *et al*. 2017, p. 313), the percentage that bred was highly variable from 20 percent in 2005 to 5 percent in 2006 (Lorenz *et al*. 2017, p. 312), and there was a high rate of nest failure with only 2 chicks fledging out of 40 nest initiations (Bloxton and Raphael 2008, pp. 7 and 10). A component that may have led to the poor breeding of birds from this study was their long commute between the nest and foraging with the furthest nest being 36 mi (58 km) from the coast (Wilk *et al*. 2016, p. 167). The mean commuting distance between nesting and foraging locations was 33 mi (53.5 km ± 28.4 km) and ranged from 10.4 to 90.2 mi (16.8 to 145.3 km) including one bird that nested on Vancouver Island commuting 85.8 mi (138.3 km) each way between nest and foraging (Lorenz *et al*. 2017, p. 314).

Since 2009, there is little or no additional data to suggest there has been an improvement in nesting success in Washington, Oregon, and California.

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (*e.g.*, loss of genetic variation, genetic drift, inbreeding, etc.):

New information since the analysis for our 2009 5-year status review more clearly defines population structure and genetic viability. A number of studies have examined the population structure of murrelets using genetic markers. These studies are relevant to the conservation status of the species because they can help identify populations that are demographically isolated or that contain unique genetic resources with adaptive advantages, which, if preserved, may help reduce extinction risk (reviewed by Friesen *et al*. 1996, p. 682). Below we review new studies that have investigated murrelet population structure and variation and any significant conclusions.

As discussed in our 2009 5-year status review, genetic studies have found evidence for a genetic cline (*i.e.*, gradual change in the genetic makeup of populations across the geographic distribution of the species), comprising three genetic units: (1) western and central Aleutian Islands; (2) eastern Aleutian Islands to northern California; and (3) central California (Congdon *et al*. 2000; Friesen *et al*. 2005; Friesen *et al*. 2007; Hall *et al*. 2009). This population structuring appears to have occurred over the last century as populations became increasingly isolated due to habitat fragmentation caused by extensive logging of old-growth habitat along the north coast of California (Peery *et al*. 2010, p. 703).

Peery *et al*. (2010) and Hall *et al*. (2009) found migrants from the north intermingled with the central California murrelets during winter and breeding seasons. However, migrants appeared to contribute only a few offspring to the population (Hall *et al*. 2009, p. 5,080; Peery *et al*. 2010, p. 702).

Since our 2009 5-year status review, a new analysis using non-neutral markers found unique alleles and peptides in all four areas (Aleutian Islands, southeast Alaska, Oregon, and central California) sampled (Vasquez-Carrillo *et al*. 2013a, p. 6). In addition, they found lower allele and peptide richness at both the individual and population level in murrelets sampled from Oregon (Vasquez-Carrillo *et al*. 2013a, p. 6).

The current information on murrelet genetics indicates that: (1) there is clinal genetic variation in the species from the Aleutian Islands to central California; (2) murrelets appear to comprise three genetic units, including the western and central Aleutian Islands, eastern Aleutian Islands to northern California, and central California, with moderate genetic differentiation; (3) the genetic discreteness of the central California population appears to be a relatively recent phenomenon tied to habitat fragmentation; (4) there are unique alleles and peptides in population segments sampled across the species range; and (5) there is lower allele and peptide richness at both the individual and population level in murrelets sampled from Oregon.

2.3.1.4 Taxonomic classification or changes in nomenclature:

Two subspecies of the marbled murrelet were previously recognized—the North American marbled murrelet (*Brachyramphus marmoratus marmoratus*) and the Asiatic, or long-billed, murrelet (*Brachyramphus marmoratus perdix*). Subsequent genetic analysis suggested that the Asiatic murrelet is a distinct species (Friesen *et al*. 1994, 1996). The American Ornithologists' Union, in its "Forty-first Supplement to the Checklist of North American Birds," officially recognized the long-billed murrelet (*Brachyramphus perdix*) and the marbled murrelet (*Brachyramphus marmoratus*) as distinct

species (American Ornithologists' Union 1997). The Service revised the scientific name of this listed DPS of marbled murrelet from *Brachyramphus marmoratus marmoratus* to *Brachyramphus marmoratu*s in 2011 (76 FR 61600).

2.3.1.5 Spatial distribution, trends in spatial distribution (*e.g.*, increasingly fragmented, increased numbers of corridors, etc.), or historical range (*e.g.*, corrections to the historical range, change in distribution of the species' within its historical range, etc.):

Since the analysis for our 2009 5-year status review, there is no new information regarding spatial distribution or changes in the historical range.

2.3.1.6 Habitat or ecosystem conditions (*e.g.*, amount, distribution, and suitability of the habitat or ecosystem):

Since the analysis for our 2009 5-year status review, new modeling by Raphael *et al*. (2016a) has produced estimates of baseline nesting habitat at the start of the NWFP and estimated changes in that habitat over time. The modeling predicted there were about 2.53 million ac (1.03 million ha) of potential nesting habitat within all lands in the murrelet's range in Washington, Oregon, and California in 1993, with approximately 59 percent occurring on Federal lands and 41 percent on non-federal (State and private) lands (Raphael *et al*. 2016a, pp. 65, 71). In 2012, models predicted there were about 2.23 million ac (Raphael *et al*. 2016a, p. 72). For further information, see section 2.3.2.1.

2.3.1.7 Other: None

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

In the following sections, we provide an analysis of the new information pertinent to the marbled murrelet's terrestrial and marine environments. Within each section we update the existing information and discuss existing and new threats. In each of the sections, we discuss the aspects of climate change that will most likely affect the terrestrial and marine habitats of the murrelet. We present information that indicates that climate change is occurring globally, and discuss literature related to climate change that has been published for the Pacific Northwest (PNW), in particular those that are specific to the habitat and locales used by murrelets. Finally, we provide a discussion of potential threats to the murrelets ability to persist as a result of the loss/lack of cohesiveness between their terrestrial and marine environments.

Terrestrial Environment

In this section we summarize new information regarding potential threats to the murrelet's terrestrial environment, specifically its terrestrial nesting habitat. New information includes information on the amount of potential nesting habitat, losses and gains in potential nesting habitat, losses authorized through section 7 consultations under the Act, and other threats to the terrestrial environment, notably those associated with climate change.

Amount of Potential Nesting Habitat

In our previous 5-year status reviews, we summarized efforts made to predict the amount of suitable nesting habitat in the tri-state area. These estimates were derived using a variety of methods and provided a fairly wide range in the estimates of the amount of suitable potential nesting habitat (USFWS 2009, p. 29). New information on the amount of potential murrelet nesting habitat, in 1993 and 2012, is available from an analysis covering both Federal and non-federal lands within the five Conservation Zones within the NWFP area (Raphael *et al*. 2016a). This modeling effort provides improved data from what was available for previous 5-year status reviews, especially for non-federal lands. Based on modeling efforts, Raphael *et al*. (2016a, pp. 65, 72) predicted there were about 2.53 million ac (1.03 million ha) and 2.23 million ac (0.9 million ha) of potential nesting habitat in 1993 and 2012, respectively. In 1993, approximately 59 percent of the potential nesting habitat occurred on Federal lands and 41 percent on non-federal (State and private) lands (Raphael *et al*. 2016a, pp. 65, 71). In 2012, however, 66 percent of the potential suitable habitat occurred on Federal lands, primarily in reserved land allocations, and 34 percent on non-federal lands (Raphael *et al*. 2016a, pp. 66-69).

In Conservation Zone 6, there are approximately 10,000 ac (4,047 ha) of old-growth nesting habitat; however, 77 percent is contained in five areas: Big Basin Redwoods State Park (4,400 ac [1,781 ha]), public utility lands in upper Pilarcitos Creek (1,135 ac [459 ha]), Portola State Park (974 ac [394 ha]), Butano State Park (622 ac [252 ha]), and Pescadero Creek County Park (531 ac [215 ha]). The remaining patches are scattered and mostly under 100 ac (40 ha] in size (Halpert and Singer 2017, pp. 58-62).

Habitat Changes

Habitat Loss: Extensive harvest of late-successional and old-growth forest was the primary reason for listing the murrelet as threatened. Due primarily to extensive timber cutting over the past 150 years, at least 82 percent of the old-growth forests existing in western Washington and Oregon prior to the 1840s has been harvested (Teensma *et al*. 1991; Booth 1991; Ripple 1994; Perry 1995; USFWS 1997, p. 4). About 10 percent of pre-settlement old-growth forests remains in western Washington (Norse 1990; Booth 1991). In California, old-growth coastal redwood forests had been reduced by 85 to 96 percent at the time of listing (USFWS 1997, p. 4).

Although the NWFP has reduced the rate of habitat loss due to timber harvest on Federal lands, the threat of continued loss and degradation of suitable nesting habitat remains on Federal and non-federal lands through timber harvest and natural events such as wildfire, insect outbreaks, and windthrow. In addition, insects and disease can kill complete stands of habitat and can contribute to forest fire conditions. As discussed below under climate change, global warming may increase the adverse effects of natural events on murrelets.

New information on habitat changes (losses and gains) for Federal and non-federal lands within the five Conservation Zones in the NWFP area is available from the analysis of Raphael *et al*. (2016a), which used habitat models to estimate changes in potential murrelet habitat for the period from 1993 to 2012. Between 1993 and 2012, there was a net loss of about 307,900 ac (124,600 ha) across all land ownerships, with declines in Washington (215,000 ac [87,000 ha]), Oregon (88,000 ac [35,600 ha]), and California (22,000 [8,900 ha]) (Raphael *et al*. 2016a, p. 72). Of the total net loss, approximately 293,000 ac (118,600 ha)were on non-federal lands, primarily due to timber harvest

(Raphael *et al*. 2016a, pp. 75, 81). Losses on Federal lands were primarily attributed to wildfire and some timber harvest (Raphael *et al*. 2016a, p. 80).

Raphael *et al*. (2016a, pp. 75, 80) also estimated the net change in potential murrelet habitat by Conservation Zone (Table 4). Conservation Zone 2 had the greatest overall net loss of habitat acreage, but Conservation Zone 4 lost the highest percentage of potential murrelet habitat.

Table 4. Net change in potential marbled murrelet habitat by conservation zone, 1993 to 2012 (reproduced from Raphael *et al*. 2016a, p. 80, Table 2-11).

Conservation Zone	Potential murrelet habitat change (acres)	Potential murrelet habitat change (percent of available)
Zone 1 (northern Washington)	-90,118	-10.9
Zone 2 (outer coast of Washington)	-115,638	-16.1
Zone 3 (northern and central Oregon)	-52,184	-7.9
Zone 4 (southern Oregon and northern California)	-52,436	-17.0
Zone 5 (north-central California)	+2,419	+17.2

Raphael *et al*. (2016a, pp. 82-85) acknowledged a number of sources of uncertainty that could result in false modeling results; however, they concluded that these sources of uncertainty should predispose the models to perform worse, but the metrics used to measure performance indicated that "good models were generated." While Raphael *et al*. (2016a, p. 86) acknowledged the uncertainties in the modeling, they believe "that a real loss in habitat has occurred from 1993 to 2012" and the rate of loss on non-federal lands has been 10 times greater than on Federal lands. If this rate of loss continues, Raphael *et al*. (2016a, p. 86) believe the conservation of the murrelet will not be possible because almost half of the higher-suitability nesting habitat is on non-federal lands. Therefore, to further recovery of the murrelet, the areas on non-federal lands that already have structural components need to be retained until the Federal lands can provide these habitat features.

Non-federal lands are managed for different purposes, but in general those managed for timber are managed on a much shorter rotation schedule than that needed to develop habitat suitable for nesting. A recent study conducted on Vancouver Island, British Columbia that measured ecological services recovery (natural regeneration) in timber harvested areas (clearcuts) found that at about 125 years, structural components, such as large branches needed for nests, begin to develop (Sutherland *et al*. 2016, p. 66), which is a much longer timeframe than most rotation schedules. Sutherland *et al*. (2016, p. 69) also considered viability of restoration and concluded that retaining (conserving) large areas of forests that already have the ecological services, such as structural components, is preferable to retention of patches within clearcuts or restoration of degraded forests.

In 2016, BLM in Oregon adopted new RMPs. BLM's 2016 RMPs now protect more marbled murrelet habitat. The changes from the NWFP include an additional 31,991 ac (12,946 ha) of habitat in Late Successional Reserves/Riparian Reserves, including an additional 18,034 ac (7,298 ha) of highly suitable habitat in Late Successional Reserves/Riparian Reserves. This change has reduced the potential for marbled murrelet habitat to be lost from timber sales. Additionally there are changes to

how habitat is managed relating to occupancy in inland Zones 1 and 2. For new marbled murrelet sites recognized under the revised RMPs, occupied stand protection associated with Late Successional Reserve mapping has changed from only protecting contiguous habitat within 0.5 mi (0.8 km) to protecting all forest structure within 0.25 mi (0.4 km) with an additional 300-foot (0.09-km) buffer. Protection of occupied or assumed occupied marbled murrelet habitat now includes protection from disruption. Protection of occupied or assumed occupied marbled murrelet habitat was reduced in Zone 2, where marbled murrelets are at low density and are currently using only an area in the Roseburg BLM District for breeding habitat. In Zone 2, there is no protection of occupied or assumed occupied marbled murrelet habitat from activities in the harvest land base; and in the District-designated reserves, there is still protection from disruption but no protection from habitat modification associated with activities. All known occupied stands were placed in reserves. Overall, this is an improvement for marbled murrelet habitat, as protected occupied habitat includes contiguous forest regardless of age of the stand, allowing ingrowth and a reduction of edge effects, and occupied or assumed occupied marbled murrelet habitat is now significantly protected from disturbance during the breeding season.

We have no new information regarding habitat changes in Conservation Zone 6.

Habitat Removal Authorized through Section 7 Consultation. Since the analysis for our 2009 5-year status review, the Service, in the tri-state area, has authorized incidental take associated with the removal of a total of 3,841 ac (1,554 ha) of potential or known nesting habitat, in addition to removal of 1,472 individual potential nest trees.

In Washington, since the last review the Service has authorized incidental take associated with the removal of 411 potential nest trees and 2,924 ac (1,183 ha) of potential/known nesting habitat. The Service has authorized incidental take associated with the removal of 230 individual trees and 123 ac (50 ha) of suitable nesting habitat in Conservation Zone 1, and removal of 181 individual trees and 2,801 ac (1,134 ha) of suitable nesting habitat in Conservation Zone 2.

In Oregon, the Service has authorized incidental take associated with the removal of 1,061 potential nest trees and 764 ac (309 ha) of potential/known nesting habitat. The Service has authorized incidental take associated with the removal of 1,056 individual trees and 458 ac (185 ha) of suitable nesting habitat in Conservation Zone 3, and removal of 5 individual trees and 306 ac (124 ha) of suitable nesting habitat in Conservation Zone 4.

In California, the Service has authorized incidental take associated with the removal of 153 ac (62 ha) of potential/known nesting habitat in Conservation Zone 4. No removal was authorized via incidental take in Conservation Zones 5 and 6.

Habitat Patterns: The factor that is most strongly correlated to the trend of the population is the amount and cohesion (large contiguous patches) of suitable nesting habitat (Raphael *et al*. 2016b, p. 101). In other words, the highest population estimates are in areas of the marine ecosystem with large, more contiguous patches of nesting habitat in the adjacent terrestrial areas. There is also a correlation between the population trends and the loss of suitable habitat. For example, Raphael *et al*. (2016b, p. 104) detected the strongest correlation for changes in murrelet abundance and amount of higher suitability nesting habitat in Conservation Zone 2, where there was the greatest rate of decline in murrelet abundance.

In addition to direct habitat removal, forest management practices can fragment murrelet habitat; this reduces the amount and heterogeneous (contiguousness) nature of the habitat, reduces the forest patch sizes, reduces the amount of interior or core habitat, increases the amount of forest edge, isolates remaining habitat patches, and creates "sink" habitats (McShane *et al*. 2004). The ecological consequences of these habitat changes to murrelets can include effects on population viability and size, local or regional extinctions, displacement, fewer nesting attempts, failure to breed, reduced fecundity, reduced nest abundance, lower nest success, increased predation and parasitism rates, crowding in remaining patches, and reductions in adult survival (Raphael *et al*. 2002). As noted in our previous 5-year status reviews, there continues to be no estimates available for the amount of suitable habitat that has been fragmented or degraded since 1992. However, Raphael *et al*. (2016a, p. 77) conducted an analysis of the amount of higher suitability habitat that occurs within 295 feet (90 meters) of an edge, finding that in all three States more than 50 percent of higher suitability habitat and as much as 80 to 90 percent of habitat on non-federal lands in Washington and Oregon is edge habitat. In all three states, the proportion of higher suitability habitat in edge increased between 1993 and 2012 (Raphael *et al*. 2016a, p. 77).

Forest edges, natural versus manmade, can have a significant effect on the forest's microclimate, in particular on temperature and epiphytes. Interior forests and edges that are "soft" have more epiphytes on branches used as murrelet nest sites than "hard" edges (Van Rooyen *et al*. 2011, pp. 555-556). Natural edges (rivers, etc.) have the highest epiphyte cover and both "hard" and "soft" edges created by timber harvest have less epiphyte cover than adjacent interiors (Van Rooyen *et al*. 2011, pp. 555-556). Therefore, it is reasonable to assume that epiphyte cover has decreased in all three states as edge has increased.

While the amount and cohesiveness of the suitable habitat is important, so is the amount of human disturbance that acts on the nesting habitat. Raphael *et al*. (2016a, p. 82) found that nesting habitat was strongly correlated with areas of low human disturbance. Within the higher suitability murrelet nesting habitat modeled by Raphael *et al*. (2016a), California has the highest mean rank for human disturbance and Washington has the lowest (Raphael *et al*. 2016a, p. 82). Between 1993 and 2012, the mean rank for human disturbance went up in both Oregon and California (Raphael *et al*. 2016a, p. 82).

<u>Climate Change</u>:
Although the marine environment is the murrelet's principal habitat, terrestrial habitat serves a vital function seasonally for nesting and reproduction. The following section describes the effects or potential effects of climate change on murrelet's terrestrial habitat. In general, and similar to conclusions in our 2009 review (USFWS 2009), where climate models are informative, their projections for the forested habitats that murrelets occupy are largely unfavorable. As habitat changes, murrelets may not be able to evolve at a fast enough rate, if climate projections are close to predicted levels (Quintero and Wilens 2013, entire).

In our 2009 5-year status review, we discussed temperature, rainfall, and snowpack projections specific to the PNW as defined by Mote *et al*. (2003, 2008) and similarly by Millar *et al*. (2006, p. 45) and Littell *et al*. (2009, p. 3); this included Washington, Oregon, Idaho, western Montana and small portions of adjacent States. In addition, we examined the factors of fire, disease, insects, tree mortality, and changes in vegetation as they related to climate change in the PNW (see Lenihan *et al*.

2008, p. 220; Millar *et al*. 2006, p. 45). Our 2009 review presented published results that PNW experienced a warming of 1.4° Fahrenheit (F) (0.8° Celsius [C]) during the 20th century (see Mote *et al*. 2008, p. 3). In addition, our 2009 review presented information showing that the PNW is projected to warm by as much as 7.2° F (2.9° C) by the 2040s (see Mote *et al*. 2008, pp. 5-6), and that a majority of models project wetter winters and drier summers (see Mote *et al*. 2008, p. 7), and a reduction in regional snowpack, which supplies water for ecosystems during dry summer months (see Mote *et al*. 2003).

As a consequence, our 2009 5-year status review concluded that climate change is likely to further exacerbate habitat loss from drought related fire, mortality, insects and disease and increases in extreme flooding, landslides and windthrow events in the short term (10 to 30 years). Subsequent to our 2009 5-year status review, additional regional models specific to the PNW have been completed and the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report was released. Our review of information published since 2009 corroborates conclusions presented in our 2009 review. Pertinent information from our review that may provide stronger, newer, or different evidence is provided below.

Precipitation: Future projections of precipitation in the parts of the PNW used by murrelets indicate the changes from current conditions may be less severe than other areas. However, the majority of models project decreased precipitation during the summer (may be as much as a 40 percent) by 2080 (Mote and Salathe 2010, pp. 42-44).

Regional models vary in projections of winter precipitation, with topography and marine influences playing large roles. For example, modeling results by Salathe *et al*. (2010, pp. 62-64) indicate both substantial increases or decreases in winter precipitation on windward (west-facing) slopes of the Olympics and Cascades, but across the region the vast majority of models project increased precipitation during the winter (may be as much as 42 percent) (Mote and Salathe 2010, pp. 42-44) with more intense daily precipitation events over the complex terrain found in western Washington (Salathe *et al*. 2010, pp. 61, 70-71). The amount of precipitation in winter appears to have increased between 1920 and 2012 (Abatzoglou *et al*. 2014, p. 2,132); however, there has been increased water deficit during the growing season (summer) (Abatzoglou *et al*. 2014, p. 2,134). Even though models predict increased precipitation in winter, substantial losses of snowpack are predicted in both the Olympic and Cascade Mountains because the amount of snowpack is counteracted by increases in winter temperature (Salathe *et al*. 2010, p. 16).

Temperature: The PNW experienced widespread seasonal warming trends between 1920 and 2012 (Abatzoglou *et al*. 2014, pp. 2,128-2,133). The maximum and minimum temperatures across all seasons increased, with winter (December to February) temperatures increasing the most and the coldest night each winter becoming warmer. In addition, during the period of 1930 to 2010, many measurement stations in the PNW experienced increasing trends in extreme heat events in June and July (Oswald and Rood 2014, pp. 572-575, 577).

Summer temperatures are projected to continue to increase throughout the 21st century (Mote and Salathe 2010, pp. 37-42) with increasing heat waves (3 or more days where daily heat index exceeds 89.6º Fahrenheit [F] (32º Celsius [C])) in the lowlands of western Washington despite the moderating effects of coastal influences (Salathe *et al*. 2010, pp. 66, 69). Throughout the areas where murrelets

nest, the temperatures are projected to increase, although at a slower rate than other areas of the PNW (such as east of the Cascade Range), due to influences from the Pacific Ocean (Brewer and Mass 2016a, p. 6,398). Summer temperatures and precipitation in the western U.S. are influenced by the variability of large-scale circulation patterns, specifically the trough that forms immediately offshore of western North America (Brewer *et al*. 2012, p. 3,820) and a ridge that forms just east of the crest of the Rocky Mountains (Brewer and Mass 2016b, p. 5,965). The position, amplitude, and modulation of the trough/ridge alters the onshore and offshore flows, impacting temperature and precipitation (Brewer and Mass 2016b, p. 5,965). When the trough/ridge combination results in strong offshore winds, extreme heat events occur in the marine-influenced areas along the west coast (Brewer and Mass 2016a, p. 6,386). The west coast–wide 2014/2015 drought discussed above resulted from the trough/ridge combination (Wise 2016, entire). While extreme heat events are projected to increase in frequency, duration, and intensity due to warming temperatures in most areas of the PNW (Brewer and Mass 2016a, entire), all future climate models indicate reductions in ridging over the eastern Pacific during the summer resulting in a weakening of the strong onshore and offshore flows (Brewer and Mass 2016b, p. 5,970). Weakening of the offshore flow events will result in fewer heat waves in the coastal areas of western Oregon and Washington by late century under the high emissions pathway (Brewer and Mass 2016a, pp. 6,397, 6,399). While the number of days of extreme warmer temperatures may not increase in the future, the temperatures on those days are predicted to be several degrees warmer (Brewer and Mass 2016, p. 6,398). In addition, the projected weakening of the onshore winds will reduce the marine influence over the coastal areas, which generally keeps the area cooler and wetter.

Drought (Water Deficiencies): During the worst drought ever recorded for Washington, Oregon, and California in 2014/2015, Oregon and Washington had nearly normal precipitation; however, the warmer winter temperatures prevented snow accumulation (Mote *et al*. 2016, pp. 10,982-10,983). While sea surface temperatures and anthropogenic greenhouse gases played a role in making 2014/2015 warmer, resulting in a snow drought, the impact varied between California, Oregon, and Washington, with anthropogenic greenhouse gases having a larger impact in Oregon and Washington (Mote *et al*. 2016, pp. 10,986-10,987). The magnitude of the snow drought in Oregon and Washington was exacerbated by "the Blob" warm sea surface temperatures (Mote *et al*. 2016, pp. 10,986-10,987) (see Marine section for information regarding "the Blob").

Chmura *et al*. (2011, p. 1,126) reported that increased concentrations of atmospheric carbon dioxide may have positive effects on growth and productivity of northwestern forests in the U.S. in the 21st century. However, Chmura *et al*. (2011, p. 1,123) also reported that the most significant challenge likely facing forests in the PNW is an increase in the frequency, duration and intensity of droughts due to warmer temperatures (as a result of increased concentrations of atmospheric carbon dioxide), and that forest responses to climate change will depend on local site conditions.

The marine climate associated with the forested areas of the PNW are generally considered to be less exposed to drought/dry conditions. However, changing climatic variables have already been impacting the forests in this area. The tree mortality rates in undisturbed old growth forests (over 200 years old) tripled between the early 1970s and 2000 and affected trees of all sizes (van Mantgem *et al*. 2009, pp. 522-523). Drought is projected to increase throughout most of the PNW, except for higher elevations on the Olympic Peninsula and Cascade Mountains (Littell *et al*. 2013, p. 112; Littell *et al*. 2016, p. 2359). Warmer spring/summer temperatures are projected, despite the moderating effects of

coastal influences (Salathe *et al*. 2010), resulting in hotter droughts when they occur. Greater tree mortality is likely to occur during hotter droughts (Allen *et al*. 2015, p. 22). In addition, low-elevation forests will experience more severe and/or longer duration water limitations resulting in decreased seedling regeneration and tree growth because the timing of the majority of precipitation is outside of the growing season (Littell *et al*. 2013, p. 112).

Wildfire: Between 1979 and 2015, anthropogenic climate change caused a significant increase in duration (additional days) of fire-weather season and more than doubled the size of area burned (Abatzoglou and Williams 2016, pp. 11,771-11,772). In the past several decades, the PNW has seen the greatest percent increase in the number of wildfires and extent of area burned over other areas of the western U.S. (Westerling 2016, p. 4; Davis *et al*. 2017, p. 176). There have been small but significant increases in annual fire extent (greater area burned) over time that is associated with drought conditions (Reilly *et al*. 2017, pp. 9-10).

The amount of area burned by fire is significantly related to climatic factors such as higher summer temperatures, lower summer precipitation, and water balance deficits (Littell and Gwozdz 2011, p. 131). On the western slopes of the Cascade Range, summer temperatures correlate to the amount of area burned, although this does not hold true throughout the forested areas within the range of the murrelet (Littell and Gwozdz 2011, p. 130). In the forested areas used by murrelets there does not appear to be a water balance deficit associated with either low or high fire years, possibly because these areas are more influenced by maritime weather conditions (Littell and Gwozdz 2011, p. 132). However, the best fit model for predicting the amount of area burned by fire is the water-balance deficit in October in the Oregon/Washington Coast Ranges and water-balance deficit in December plus the July/August maximum temperature in the western Cascades (Littell and Gwozdz 2011, p. 129).

Most forecasting of wildfire within the range of the murrelet is weak due to the low number of fires during the 20th century (Sheehan *et al*. 2015, p. 22). However, in the forested areas of the western Cascade Mountains in Washington, mean area burned is expected to increase by a factor of 3.8 compared to the period 1980 to 2006 (Littell *et al*. 2010, p. 142). Wildfires in western forests are projected to increase under all climate scenarios and as the fires become larger and more frequent, the burn severities steadily increase throughout the 21st century (Rogers *et al*. 2011, pp. 6, 9; Sheehan *et al*. 2015, p. 20). Predictions for the 21st century are that most of the area west of the Cascades range in Washington and Oregon will experience extensive wildfires and the percent area burned will approach 100 percent except along the Pacific coastline and high elevations (Sheehan *et al*. 2015, p. 22). Even forests at higher elevations and on steeper slopes are predicted to experience large wildfires (Davis *et al*. 2017, p. 177).

Parks *et al*. (2016, p. 6) modeled the coastal areas inhabited by murrelets as having a moderate to high fire severity during the period of 1984 to 2012. Forested areas along the coast may be the most vulnerable because they will not benefit from increased winter precipitation as they are already adapted to wet conditions, thus will suffer more intense summer droughts and the greatest relative increases in fires (Rogers *et al*. 2011, p. 6). Within the range of the murrelet on the southern Oregon coast, northeast corner of the Olympic Peninsula, and western Cascade Range, about 20 percent of the forest classified as low fire suitability is projected to transition to moderate suitability (Davis *et al*. 2017, p. 180). Along the Washington and Oregon coasts, forests classified as having a high suitability

for large wildfires will increase by approximately 1 to 2 percent by the end of the 21st century (Davis *et al*. 2017, p. 179).

In general, wildfire and drought are not considered to play a role in the temperate marine forests where murrelets nest. Even though there is low fire activity in the recent record in the Oregon Coast Range and Olympic Mountains, the consequences of rare events are extreme with millions of acres burned in single events (Littell *et al*. 2010, p. 142). Although it is uncertain to what degree climate change will influence high-intensity, stand replacing fires within the range of the murrelet, warmer and drier summers are likely to produce more frequent and extensive fires, thus reducing the extent and connectivity of late-seral/old growth forests potentially resulting in severe consequences for the murrelet (McKenzie *et al*. 2004, pp. 897-898; Littell *et al*. 2013, p. 132).

The marine-influenced coastal forests used by murrelets have long fire intervals, but when fires happen, they are severe. Many forest management schemes that are utilized in drier forests, such as surface and canopy thinning, can reduce the occurrence and effects of high-severity fires in those forest types; however, these activities may not be effective in coastal forests (Littell *et al*. 2013, pp. 134-135). Halofsky *et al*. (2018, entire) offer climate adaptation strategies to be considered for coastal forest management: (1) exclude wildfire where appropriate (such as in key habitats); (2) minimize stressors by diversifying homogenous second-growth forests, promoting species and structural diversity, and controlling non-native invasive species; and (3) develop and implement post-disturbance vegetation plans to promote climate-adapted landscapes that maintain genetic, species, and structural diversity.

Disease and Insect Outbreaks: Swiss needle cast (*Phaeocryptopus gaeumannii*) infects Douglas-fir (*Pseudotsuga menziesii*) resulting in loss of needles/foliage and significant reductions in tree growth (Hansen *et al*. 2000, p. 776; Maguire *et al*. 2002, pp. 90-92; Maguire *et al*. 2011, pp. 2,067-2,068; Lee *et al*. 2013, p. 682); however, it generally does not result in tree mortality (Maquire *et al*. 2011, pp. 2,069-2,070). Higher average temperatures, in particular warmer winters, and increased spring precipitation in the Oregon Coast Range have contributed to an increase in the severity and distribution of Swiss needle cast in Douglas-fir (Stone *et al*. 2008, pp. 171-174; Sturrock *et al*. 2011, p. 138; Zhao *et al*. 2011, p. 1,876; Lee *et al*. 2013, pp. 683-685; Ritóková *et al*. 2016, p. 2). The distribution of Swiss needle cast increased from about 131,087 ac (53,050 ha) in 1996 to about 589,840 ac (238,705 ha) of affected trees in 2015 within 31 mi (50 km) of the coast in the Oregon Coast Range (Hansen *et al*, 2000, p. 775; Ritóková *et al*. 2016, p. 5). The changing incidence of Swiss needle cast can affect mixed-species forest stands by allowing increased western hemlock (*Tsuga heterophylla*) growth in stands where severe Swiss needle cast affects Douglas-fir growth (Zhao *et al*. 2014, entire). If winter temperatures and spring/summer precipitation relationships hold, Swiss needle cast disease severity is expected to increase and spread inland and north with warmer winters at higher elevation coastal sites and at inland sites where fungal growth is currently limited by cold winter temperatures (Stone *et al*. 2008, p. 174; Zhao *et al*. 2011, p. 1,884; Lee *et al*. 2013, p. 688).

Native bark beetles have evolved with conifer forests of North America; however, when climatic conditions are conducive and an outbreak occurs, tree mortality rates rise and in some cases can result in tree and plant association replacements (Bentz *et al*. 2010, p. 602). Climatic variables within the range of the murrelet are currently suitable for outbreaks of bark beetles (Littell *et al*. 2010, p. 146) although few data are available on beetle outbreaks (Hicke *et al*. 2016, p. 150). Projected warmer

temperatures mean less winter beetle mortality and disruption of life cycle timing, such as faster development to adult stage (1 versus 2 years), higher adult longevity, and prolonged adult emergence and flight (Bentz *et al*. 2010, pp. 604-605). Higher temperatures as the 21st century progresses will increase the potential of spruce beetle (*Dendroctonus rufipennis*) outbreaks, which require mature spruce forests such as those found within the range of the murrelet (Bentz *et al*. 2010, p. 607). Warmer winters will increase the likelihood of mountain pine beetles (*Dendroctonus ponderosae*) surviving through the winter and facilitate movement into higher elevations (Bentz *et al*. 2010, p. 607; Littell *et al*. 2010, p. 146). Trees that are stressed, such as by drought, may enable a mass attack on a tree by fewer bark beetles than have been needed in the past (Bentz *et al*. 2010, p. 605; Halofsky *et al*. 2011, pp. 66-67).

Changes in Vegetation: While wildfire, drought, and insect outbreaks are the primary agents for shifts in forest vegetation, the future climate is projected to also become less favorable for current forest composition. Climate is projected to become unfavorable for Douglas-fir over 32 percent of its current range in Washington by the 2060s. Only about 13 percent of the current area would be climatically suitable for Douglas-fir; decline is projected to be most widespread at lower elevations, including areas within murrelet range, such as south Puget Sound and southern Olympic Mountains (Littell *et al*. 2010, p. 139). Under two of three future climate simulations evaluated by Rogers *et al*. (2011, fig. 5.3), most of the area within the range of the murrelet is currently categorized as maritime, but a nearly complete conversion of maritime conifer forests to temperate conifer forest (Rogers *et al*. (2011 figures. 5.4, 5.5) and subtropical mixed forest in western Oregon and Washington is projected under a warmer, drier climate (Rogers *et al*. 2011; fig. 5.3). Within the western Northwest subregion, vegetation is predicted to change from predominantly conifer to mixed forests during the 21st century (Halofsky *et al*. 2011, p. 73; Sheehan *et al* 2015, p. 22). The timing and extensiveness of the change differs depending upon the climate scenario used, but in any case the shift to mixed forest will begin in the south and expand northwards along the coast and upslope (Sheehan *et al* 2015, p. 22). Under the warmer scenario, by the late 21st century, remnant conifer forests may only occur in the northern Oregon coast range and the higher elevations of the Olympic Peninsula and Cascade Mountains (Sheehan *et al* 2015, p. 22). The next vegetation shift will be from cooler mixed forest to warm mixed forest, also beginning in the southern part of the range (Sheehan *et al* 2015, p. 22). Higher elevation species, such as mountain hemlock and firs, are likely to experience a much greater reduction in distribution than lower elevation species like Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), and western hemlock (Albright and Peterson 2013, p. 2,129; DellaSalla *et al*. 2015, pp. 5, 8) with significant losses of subalpine forests (Rogers *et al*. 2011, p. 6).

Similar to the PNW, the climate within central California has already experienced warming of approximately 1.8° F (1° C) during the 20th century (Flint and Flint 2012, p. 42) and regardless of model, shows a continued increase in all projections (Flint and Flint 2012, p. 12). Similar to the broader PNW region, the California redwood region may see a gain of 3 percent growth by 2050; however, this gain in growth is expected to be lost by 2080, when coast redwood is expected to experience reduction of nearly one-fourth of its modeled climate envelope (Della Sala *et al*. 2015, pp. 5-6). Flint and Flint (2012, p. 1) further refined the projections by downscaling to fine spatial scales for the Santa Cruz Mountains, at the southern range of coast redwoods. The results from the latter study indicate the redwoods in the Santa Cruz Mountains may persist only on north-and northeast-facing slopes, potentially leaving less than 10 percent of the redwoods within the middle 80 percent of the modeled suitable habitat (Flint and Flint 2012, pp. 37, 41-42).

Summary - Threats to Terrestrial Environment. In the analyses for our 2004 and 2009 5-year status reviews, habitat loss and fragmentation were expected to continue in the near future, but at an uncertain rate. Recent information indicates nesting habitat in Washington, Oregon, and California in Conservation Zones 1 through 5 continues to be lost to windthrow and fire on Federal lands and harvested on non-federal lands. Approximately 34 percent of the higher suitability nesting habitat within this area is on non-federal lands where the rate of loss has been 10 times greater than on Federal lands. Nesting habitat in Conservation Zone 6 is constrained to relatively small patches within State and County parks. In addition to the direct loss of habitat, the remaining suitable nesting habitat is fragmented and subject to human disturbance.

The climate in the coastal areas of the PNW where murrelets nest has been changing and is projected to continue to change through the 21st century. Climate change is predicted to alter the terrestrial environment within the range of the murrelet by changing precipitation (amount, type, and timing) and temperatures (timing and location). Anthropogenic climate change is likely to extend the fire season and increase fire severity, resulting in greater amount of area burned. There is likely to be an increased prevalence of disease and insect infestations/outbreaks that reduce tree vigor, or worse, increase tree mortality. Tree stress is likely to increase and existing tree species will shift upward in elevation to the extent possible, while forest types in the southern end of the range and in lower elevations will be lost and replaced with different forest types. Anthropogenic climate change has the potential to substantially affect the coast redwood forests of the PNW by the late 21st century, in which this forest type is projected to experience a reduction of nearly one-fourth of its range. Hotter droughts will exacerbate all of these impacts. Though considerable uncertainty exists with respect to any regional-scale impacts of climate change due to the differences in trajectories of climate change scenarios, modeling results underscore the potentially large impacts on the PNW and California ecosystems. Similar to our conclusions in our 2009 review, in this review we conclude that climate change is likely to continue to exacerbate the existing threat posed by continued nesting habitat loss. However, while it appears likely that the murrelet will be adversely affected, similar to our 2009 review, in this review we lack adequate information to quantify the magnitude of effects to the murrelet from the climate change projections described above.

Improved information indicates that a greater amount of nesting habitat occurs on non-federal lands than analyzed in previous 5-year status reviews and the habitat on those lands continues to be harvested, while remaining habitat within all land ownership is fragmented and subject to human disturbance. Climate change is likely to exacerbate the impacts of continued nesting habitat loss and fragmentation. Therefore, the available new information suggests the level of threat in the terrestrial environment may be greater than documented in previous reviews.

Marine Environment

In our 2009 5-year status review, the Service provided brief overviews and status of the marine environments used by the murrelet, including the California Current System (CCS), Straits of Juan de Fuca, and Puget Sound. In this section we summarize new information regarding potential threats to the murrelet's marine environment, including updates on toxins, hypoxic/anoxic events, prey availability and quality, and climate change.

Puget Sound

In our 2009 5-year status review, we noted that 52 non-native species had been documented in Puget Sound, which did not at that time include the European green crab. Since then, the European green crab has been found at a handful of locations throughout Puget Sound (Washington Sea Grant website, downloaded 9 January 2018). Should this invasive species become established in Puget Sound, the primary impact is likely to be to bivalve mollusks and small crustaceans, along with competition with the native Dungeness crab. Any impacts to murrelets would be indirect as a result of changes to the biological resources in Puget Sound.

Toxins

In our 2009 5-year status review, we provided findings regarding toxic contaminants found in Puget Sound. Further research has been conducted since that time and some of the findings are presented here. No specific studies were conducted on murrelets; however, several studies looked at contaminant levels in their prey, in particular Pacific herring (*Clupea pallasii*) and Pacific sand lance (*Ammodytes personatus*).

Pacific sand lance collected from nine locations throughout Puget Sound were sampled for toxic contaminants (such as polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ether (PBDE), and polychlorinated biphenyl (PCBs)). PCBs, PBDEs, PAHs, and some organochlorine pesticides were broadly detected, including banned chemicals such as PBDE flame retardants and DDT. Higher concentrations were found in fish collected from urbanized embayments; however, the widespread occurrence of toxic contaminants in Pacific sand lance tissues suggests persistent exposure (Puget Sound Ecosystem Monitoring Program [PSEMP] Toxics Work Group 2017, p. 16). Contaminant levels in Pacific herring in Puget Sound have been monitored since 1994. While PCBs have declined in areas with low development, they continue to be problematic in developed areas, such as south and central Puget Sound (PSEMP Toxics Work Group 2017, p. 29). PCBs appear to persist in the environment, despite prohibitions on production and use; however, PBDEs declined or remained static, suggesting that source controls and mitigation efforts have been somewhat successful (PSEMP Toxics Work Group 2017, p. 29).

Good *et al*. (2014, entire) measured contaminant levels in forage fish, comparing sites within Puget Sound to sites on the outer Washington coast. Good *et al*. (2014, pp. 5-7) found PCBs were higher (1.8 to 4.9 times) for Pacific sand lance, Pacific herring, surf smelt (*Hypomesus pretiosus*), and chinook salmon (*Oncorhynchus tshawytscha*) collected at Protection Island in Puget Sound than for fish collected at Tatoosh and Destruction Islands on the outer coast and PBDEs were higher (1.5 to 3.5 times) for Pacific sandlance, Pacific herring, surf smelt, and chinook salmon at Protection Island than at Tatoosh or Destruction Islands. Forage fish collected in Puget Sound were much more likely to be contaminated than those collected on the outer coast, which results in potentially higher contaminant burdens in the birds that are consuming these fish (Good *et al*. 2014, p. 8). Based on diet composition, Good *et al*. (2014, p. 10) estimated the dietary PCB exposure for rhinoceros auklet (*Cerorhinca monocerata*) chicks in Puget Sound to be 4.5 times greater than on the outer coast, and PBDE exposure to be 4.5 to 7.5 times greater than on the outer coast.

In addition to chemical toxicants, microplastics are being found in forage fish species. In a study in Haro Strait, British Columbia, 85 percent of Pacific sand lance collected contained colored plastic filaments (PSEMP Toxics Work Group 2017, p. 22). Due to the size of the microplastics, the authors

speculate that the sand lance mistake the microplastics for prey. The authors also speculate that there is a large potential for the transfer of microplastics into the upper trophic levels (such as to seabirds).

Harmful Algal Blooms and Biotoxins

In our 2009 5-year status review, we provided specific information about the various organisms that cause harmful algal blooms (HABs) within the CCS and Puget Sound. For further information, Lewitus *et al*. (2012 entire) provides a good review of the history, trends, causes, and impacts of HABs through 2010. The type of HABs described in our 2009 5-year status review continue to occur in Puget Sound and along the coasts of Washington, Oregon, and California. Here we present new HAB species and/or pertinent new information relating to information included in previous 5-year status reviews.

Two HAB events resulted in the stranding of live and dead seabirds in California (2007) and Washington/Oregon (2009) (Jessup *et al*. 2009, entire; Phillips *et al*. 2011, entire). Both events were caused by the dinoflagellate *Akashiwo sanguinea* which produces a proteinaceous foam that coated the feathers of the birds. This coating resulted in reduced waterproofing, ultimately resulting in hypothermia (Jessup *et al*. 2009, p. 2; Phillips *et al*. 2011, p. 120). Both of these events occurred during the winter months and, of the birds examined from the event in Washington/Oregon, 58 percent were undergoing molt of the primary feathers, making them more susceptible to plumage fouling (Phillips *et al*. 2011, pp. 123-124). While murrelets were not specifically identified in these events, other alcid species were affected. Both of these events occurred in areas where murrelets are known to occur and at a time of year when some murrelets may still be undergoing molt. Therefore, it is possible that murrelets were affected, but not found or recovered, and could be affected should similar future events occur.

In 2011 and 2012, paralytic shellfish poisoning (PSP) was identified as the cause of up to 21 percent of Kittlitz's murrelet (*Brachyramphus brevirostris*) (a very closely related species) nestling mortalities; likely resulting from being fed sand lance (*Ammodytes* species) infected with *Alexandrium* (Shearn-Bochsler *et al*. 2014, p. 935). Moore *et al*. (2015, entire) used a mechanistic approach to model the potential growth response (*i.e.*, proliferative phase) of *Alexandrium* species to climate-driven changes in Puget Sound. Moore *et al*. (2015, pp. 7-8) projected that future conditions in Puget Sound will result in higher growth rates and a longer bloom season as a result of increased sea surface temperatures. The largest increases (up to 30 more days) were projected to occur in the northern portions of Puget Sound and the eastern Strait of Juan de Fuca (Moore *et al*. 2015, p. 7). Because the areas where blooms are projected to be larger and longer overlap with the areas where the highest densities of murrelets in Puget Sound are observed during the breeding season (Falxa *et al*. 2016, p. 19), there may be an increasing risk of nestling mortality due to PSP.

An outbreak of *Pseudo-nitzschia* in the spring/summer of 2015 stretched from southern California to the Aleutian Islands (NOAA Climate 2015, p. 1) and rather than lasting a few weeks, as is typical, this event persisted from May to October (National Ocean Service 2016) and produced extremely high concentrations of domoic acid (NOAA Climate 2015, p. 2). This HAB was preceded by anomalous ocean conditions (lack of southwesterly storms and warm sea-surface temperatures) in January and February associated with "the Blob" (Du *et al*. 2016, pp. 4-7) (See *Climate Change* below). In Monterey Bay, California, this HAB produced the highest particulate concentrations of domoic acid ever recorded (Ryan *et al*. 2017, p. 5,575).

Dead Zones

In our 2009 5-year status review, we presented information regarding hypoxic/anoxic events (dead zones). Hypoxic events have continued to occur in Puget Sound and along the outer coasts of Washington and Oregon (PSEMP Marine Waters Workgroup 2017, p. 22; PSEMP Marine Waters Workgroup 2016, p. 15; Oregon State University 2017, entire). Hypoxic events along the coast have expanded upward into shallower water depths (Somero *et al*. 2016, p. 15). As discussed in our 2009 5-year status review, these events coincide with the murrelet breeding season and may be contributing to low food availability and low murrelet reproductive success. Impacts to water chemistry and marine life are expected to grow rapidly in intensity and extent in the CCS over the coming decades (Chan *et al*. 2016, p. 5). Therefore, it is reasonable to predict that the impacts to murrelets may also grow, resulting in lower prey availability and reproductive success.

Prey Availability

In our 2009 5-year status review, we presented information on the availability of the forage fish species known to be prey for murrelets. Here we provide updated information on these species, along with a brief discussion on the importance of having plentiful prey.

Due to the secretive nature of murrelets, there has been no direct research on the physiological consequences of a poor or inadequate diet on adults or chicks. However, research on other alcids with similar life histories indicates that poor or inadequate diets/low prey availability can result in poor body condition of adults by the end of the breeding season (Harding *et al*. 2011, pp. 54-55) because they try to compensate by bringing more fish (*i.e.*, make more provisioning trips) to feed chicks (Kadin *et al*. 2016, p. 174). In addition, in years when chicks are fed lower quality prey, there is decreased fledgling success (Kadin *et al*. 2012, pp. 243-244). In years of very weak marine primary production, tufted puffins (*Fratercula cirrhata*) experienced near total breeding failure (less than 10 percent successful), most rhinoceros auklets did not breed, and those that did experienced their worst breeding season in 20 years (Gaston *et al*. 2009, p. 271). Research on thick-billed murres (*Uria lomvia*) showed that each bird had an energy expenditure cap that did not vary across years, activity, age, sex, or environmental conditions , even though body mass and daily energy expenditure did vary (Elliott *et al*. 2014, pp. 140-141). In order to not exceed their energy expenditure cap, however, birds reduced their time spent flying, diving, and provisioning chicks, and increased time resting on the water (Elliott *et al*. 2014, pp. 140-141). In addition to the potential impacts on adults, restricted diets can result in lower body mass and slower skeletal growth in chicks (Lyons and Roby 2011, entire). However, in good marine condition years, these long-lived seabirds can bounce back, unless there are several years of poor marine conditions and declining prey populations.

From 2009 through 2017, a total of 14 dead marbled murrelets were incidentally found and collected in Washington (8), Oregon (2), and California (4). Necropsies performed by the National Wildlife Health Center attributed emaciation as the primary or secondary cause of death of 10 murrelets (Service files). The gross necropsy findings were consistent with starvation as a possible cause of the deaths. All of these murrelets were adults or recently fledged juveniles. While this is a limited sample, interestingly, six of these cases occurred in 2015 and 2016, coinciding with the "Blob" and the poor prey conditions.

Pacific herring. As of 2012, the aggregate of all herring stocks in Puget Sound, except for Cherry Point and Squaxin Pass stocks which are genetically different, was considered to be moderately healthy (Stick *et al*. 2014, p. 61). The Cherry Point stock showed no signs of recovery from a critically low level of abundance and the Strait of Juan de Fuca was at a critically low level of abundance, whereas Semiahmoo Bay and Portage/Samish Bay stocks showed increased abundance (Stick *et al*. 2014, p. 61). A recent synthesis of 40 years of trawling efforts in Puget Sound indicate significant Pacific herring declines in southern and central Puget Sound (Greene *et al* 2015, p. 162), while at the same time the proportion of jellyfish have increased from 27 to over 90 percent in south Puget Sound and from 10 to 92 percent in central Puget Sound (Greene *et al*. 2015, p. 163). There is currently only one commercial herring fishery that operates primarily in southern and central Puget Sound to provide bait for sport salmon and groundfish fisheries; this fishery targets juvenile herring (Stick *et al*. 2014, p. 67). Along the Washington outer coast, spawning populations of Pacific herring occur in embayments of Willapa Bay and Grays Harbor; however, little is known about these stocks due to limited sampling (Stick and Lindquist 2009, p. 71). There is a fishery in Grays Harbor that lands seven tons or less per year, no reported landings from Willapa Bay, and directed herring harvest is not allowed in coastal waters (Stick and Lindquist 2009, p. 71).

Pacific herring abundance and distribution information for Oregon is not readily available. Recreational fisheries are allowed, although rare in marine waters (ODFW 2016, p. 40). Until there is sufficient data available, Oregon is prohibiting development of new directed commercial harvest of forage fish, including Pacific herring (ODFW 2016, p. 41).

As of 2016, herring stocks in California continue to fluctuate above and below the historical (1979 to present) average biomass of 50,300 tons (CDFW 2016, pp. 2, 4). From 2009/2010 through 2015/2016, a low biomass estimate of 4,800 tons was recorded in 2009/2010 and a high biomass estimate of 79,500 tons was recorded in 2012/2013 (CDFW 2016, pp. 2, 4). The 2015/2016 season was the second year in a row with below average biomass of 14,898 tons (CDFW 2016, p. 2). The below average biomass reported over the last 2 years may be attributed to conditions not favorable to herring survival as a result of the recent poor oceanic and estuarine conditions (CDFW 2016, p. 2) associated with record high sea surface temperature anomalies and the development of a large El Niño (National Marine Fisheries Service (NMFS) 2016a, p. 1). In 2014/2015, this resulted in the California Current Ecosystem to have lower productivity at nearly every trophic level (NMFS 2016a, p. 1). In addition, the ongoing drought has resulted in atypical estuarine conditions with reduced freshwater influence into the San Francisco Estuary which may have negative impacts on both spawning herring and young herring in the estuary (CDFW 2016, p. 2).

During the 2015/2016 season, the predominant age classes were 3- and 4-year olds, with the larger 5- to 7-year-old fish increasing since the 2014/2015 season (CDFW 2016, p. 7). Age class 2 herring was the lowest since the early 1990's, negatively affecting recruitment into the system (CDFW 2016, p. 7). There is little to no information on where the herring are during the non-breeding season. Most herring spawning occurs in the San Francisco Bay, where most of the commercial herring fishing occurs in California. In 2016, the San Francisco Bay herring population was near the lowest abundance level observed since 1979 (CDFW 2016, p. 4). A minor amount of spawning and minimal fishing occurs in Tomales and Humboldt Bays, and occasional spawning and no fishing occurs in Crescent City harbor. Herring fishing in Monterey Bay occurs outside the breeding season, and is for bait and aquarium fish.

The CDFW in coordination with commercial fishery representatives and members of the conservation community formed the Pacific Herring Steering Committee to develop a Fishery Management Plan for the Pacific herring in California that will conform more to the requirements of the Marine Life Management Act (MLMA) (CDFW 2017, website).

Surf Smelt. As was the case for previous 5-year status reviews, there continues to be no rigorous assessments of Washington's surf smelt stocks. However, there continues to be commercial and recreational fisheries for surf smelt in Washington. Surveys in 2013 and 2014 identified 20 new smelt spawning areas along the outer Washington coast; however, the specific smelt species was not identified nor did the surveys produce an assessment of the stock(s) using these areas (Langness *et al*. 2015, p. 15). A recent synthesis of 40 years of trawling efforts in Puget Sound indicates significant surf smelt declines in south and central Puget Sound (Greene *et al* 2015, p. 162), while at the same time the proportion of jellyfish has increased from 27 to over 90 percent in south Puget Sound and from 10 to 92 percent in central Puget Sound (Greene *et al*. 2015, p. 163).

We have no information on the status of this species in Oregon. Recreational fisheries for surf smelt do occur in marine waters (ODFW 2016, p. 40). Between 1980 to 1989 and 1993 to 2002 surf smelt (2,202 total fish) were landed in Oregon (Marine Recreational Fishery Statistical Survey) (ODFW 2016, p. 40). Directed commercial fishing for osmerid smelt (including surf smelts) is prohibited and bycatch may not exceed 1 percent of the landing by weight (Oregon Administrative Rules 635-004-0545).

We have no information on the status of surf smelt in California.

In 2016, the NMFS published a final rule prohibiting directed commercial fisheries for "Shared EC Species" (a collective suite of ecosystem component species, primarily forage fish species) in Federal waters, which includes surf smelt; however, four coastal Tribes in Washington are excluded from the prohibition (NMFS 2016b). This final rule also prohibits, with limited exceptions, at-sea processing of Shared EC Species for all three west coast States (NMFS 2016b).

Pacific Sand Lance. We have no new information on the status of this species in Washington or California. In 2016, the NMFS published a final rule prohibiting directed commercial fisheries for Shared EC Species, including sand lance, in Federal waters; however, four coastal Tribes in Washington are excluded from the prohibition (NMFS 2016b). This final rule also prohibits, with limited exceptions, at-sea processing of Shared EC Species for all three west coast States (NMFS 2016b).

Pacific sand lance abundance and distribution information for Oregon is not readily available. Recreational fisheries are allowed and sand lance may be incidentally taken during herring fishing (ODFW 2016, p. 40). Until there is sufficient data available, Oregon has prohibited development of new directed commercial harvest of forage fish, including Pacific sand lance (ODFW 2016, p. 41).

Anchovy (*Engraulis mordax*). In Washington, there is no northern anchovy stock abundance information; however, there are commercial fisheries that provide live and packaged bait for recreational and commercial fisheries (Wargo and Hinton 2016, p. 14). These fisheries occur in State waters on the southern Washington coast, Grays Harbor, Willapa Bay, and lower Columbia River

(Wargo and Hinton 2016, p. 14). Since 2000, the highest reported landings were in 2009 with over 800 metric tons being harvested; however, since 2010 the harvest levels have been below 300 metric tons (Wargo and Hinton 2016, p. 15).

We have no information on the status of this species in Oregon.

California fisheries for anchovy have undergone a pattern of expansion and collapse in response to fishing pressure and changes in ocean climate. Anchovy populations grew throughout the 1970s but then declined in the 1980s as the area off southern and central California warmed. The abundance of adult-stage anchovy off central California has declined in recent years (Ralston *et al*. 2015, pp. 29–30) with a major decline seen between 2005/2006 and 2008/2009. This decline has continued since the last spike observed in 2005 when well over one million metric tons was reported (Thayer *et al*. 2017, pp. 1, 4) compared to the recent multi-year average of 20,000 to 25,000 metric tons (Thayer *et al*. 2017, pp. 4-5). Northern anchovy populations are monitored under the Coastal Pelagic Species Fishery Management Plan (Pacific Fishery Management Council (PFMC) 2011, entire). The PFMC could consider revising the Annual Catch Limit for northern anchovies to better allow anchovy populations to recover.

Pacific Sardine (*Sardinops sagax caerulea*). In 1999, the Coastal Pelagic Species Fishery Management Plan was implemented to manage Pacific sardines and other coastal pelagic species. Under the management plan, the Pacific sardine population is assessed annually to provide a scientific basis for annual harvest quota that is established by the PFMC for the U.S. fishery (NOAA 2009). The estimated high of 1 million metric tons of biomass recorded in 2006 compared to the estimated 97,000 metric tons recorded in 2015 (PFMC 2015), demonstrates a continued decline of sardine biomass. As a result, in 2015, the PFMC closed the 2015/2016 west coast sardine fishing season due to very low sardine numbers (PFMC 2015). In 2017, sardine biomass again declined to 86,586 metric tons and the PFMC announced the continued closure for the third straight year of the Pacific sardine directed fishery through June 30, 2018 (PFMC website 2017). While non-treaty fisheries are closed, a small harvest amount was allocated to the Quinault Indian Nation (PFMC website 2017) that has conducted a commercial purse seine fishery within their usual and accustomed fishing grounds directly off Westport/Grays Harbor, Washington since 2012 (Wargo and Hinton 2016, p. 5).

<u>Prey Quality, Trophic Level Changes, and Competition</u>

In 2009, we summarized information regarding prey quality and observed/presumed trophic level changes in murrelet diets. We concluded it was a reasonable assumption that murrelets in central California and Puget Sound were feeding on lower-trophic level food items, but could not make a similar conclusion regarding murrelets foraging in the CCS of Washington, Oregon, and northern-California. However, the observed declines in forage fish species within the CCS would indicate murrelets are feeding on lower trophic prey items. In preliminary results of a new diet identification method, Peery *et al*. (2016, entire) identified five fish species had been recently consumed by the three murrelets sampled. Northern anchovy and Pacific sand lance were consumed by all three murrelets, one murrelet additionally consumed red Irish lord (*Hemilepidotus hemilepidotus*) and rockfish species (*Sebastes* species), and one murrelet additionally consumed rock greenling (*Hexagrammos legocephalus*). This study is ongoing and will have diet samples from California, Oregon and Washington to further inform this topic.

In addition to feeding on lower trophic level prey, murrelets may be experiencing limitations in available foraging areas due to competition with other seabirds. In British Columbia, Ronconi and Burger (2011, p. 361) found murrelets avoided common murres (*Uria aalge*), a prey competitor, in particular as murres became more abundant.

In a closely related seabird, Cassin's auklets (*Ptychoramphus aleuticus*), Sorensen *et al*. (2009, entire) found that pre-breeding prey quality can have a significant effect on reproductive success because females that foraged on energetically superior prey bred earlier and laid larger eggs, which can translate into faster growth rates and higher survival for chicks. In addition, Sorensen's *et al*. (2009, entire) data indicate the female auklets may need to attain a threshold body condition before they initiate breeding.

Climate Change

Climate change was not identified as a threat in the 1992 rule that listed the marbled murrelet as threatened, nor in the analysis for our 2004 5-year status review (USFWS 2004). Our 2009 review discussed climate change and global warming, and their possible effects to the marine coastal environment, and concluded that climate change is likely to result in changes to the murrelet's marine environment. For this review, we did not find any research since our 2009 review that offered additional substantive relationships between climate change and variables such as quality of murrelet prey, harmful algal blooms, intensity of El Niño events, ocean acidification, sea level rise, or health risks. Research on these topics is ongoing, and while physical changes to the near-shore environment appear likely in the future, much remains to be learned about the magnitude, geographic extent, and temporal and spatial patterns of change and their effects on murrelets. In our 2009 5-year status review we noted the area of uncertainty was the potential impacts of climate change on murrelet prey resources. More information regarding this topic has become available and is presented below. Climate change is likely to reduce murrelet breeding success via changes in prey availability resulting from changes throughout the marine food web. In addition, climate change may expose murrelet adults and nestlings to health risks due to increased exposure to HABs and the toxins they produce.

Ocean Acidification. Since our 2009 5-year status review, more information has been published regarding ocean acidification. While the conclusions provided in our 2009 review remain the same, there is more information available to inform that conclusion. Acidification results when carbon dioxide in the air dissolves in surface water, and is the direct consequence of increasing carbon dioxide emissions (IPCC 2014, pp. 41, 49). Marine waters are projected to continue becoming more acidic, although if carbon emissions are stringently and immediately curtailed, this trend may reverse during the late 21st century (IPCC 2014, pp. 8-9, 49). Both the surface and upwelled waters of North Pacific Ocean have become more acidic due to carbon dioxide emissions (Feely *et al*. 2008, pp. 1,491-1,492; Murray *et al*. 2015, pp. 962-963), and this trend is expected to continue (Byrne *et al*. 2010, p. L02601; Feely *et al*. 2009, pp. 40-46). Linked to reductions in dissolved oxygen (Riche *et al*. 2014, p. 49), acidification has important biological consequences and also responds to biological activity. For example, local areas of eutrophication are likely to experience additional acidification beyond that caused directly or indirectly by carbon dioxide emissions (Newton *et al*. 2012, pp. 32-33). Changes in temperature, carbon dioxide, and nutrient levels are likely to affect primary productivity by phytoplankton, macroalgae, kelp, eelgrass, and other marine photosynthesizers (Mauger *et al*. 2015, p. 11-5). In general, warmer temperatures, higher carbon dioxide concentrations, and higher nutrient levels lead to greater productivity (Gao and Campbell 2014, pp. 451, 454; Newton and Van Voorhis

2002, p. 10; Roberts *et al*. 2014, pp. 11, 22, 108; Thom 1996, pp. 386-387), but these effects vary by species and other environmental conditions, such as sunlight levels or the ratios of different nutrients (Gao and Campbell 2014, pp. 451, 454; Krembs 2012, p. 109; Low-Decarie *et al*. 2011, p. 2,530).

A wide variety of marine species among all trophic levels are directly affected by ocean acidification. At the lower trophic level, phytoplankton species that form calcium carbonate shells, such as coccolithophores, show weaker shell formation and alter their physiology in response to acidification (Feely *et al*. 2004, pp. 365-366; Kendall 2015, pp. 26-46). Like their phytoplankton counterparts, foraminiferans and other planktonic consumers that form calcium carbonate shells are less able to form and maintain their shells in acidified waters (Feely *et al*. 2004, pp. 356-366). Similarly, chemical changes associated with acidification interfere with shell development or maintenance in pteropods (sea snails) and marine bivalves (Bednaršek *et al*. 2014, pp. 5-6; Bednaršek *et al*. 2016, p. 3; Busch *et al*. 2014, pp. 5, 8; Waldbusser *et al*. 2015, pp. 273-278). Acidification affects crustaceans, for example, slowing growth and development in Pacific krill (*Euphausia pacifica*) and Dungeness crabs (*Cancer magister*) (Cooper *et al*. 2016, p. 4; Miller *et al*. 2016, pp. 118-119). Bony fishes are also negatively affected by acidification, including increased respiration rates, behavioral changes, negative growth rates, and reduced metabolic rates (Ou *et al*. 2015, pp. 951, 954; Somero *et al*. 2016, pp. 20-21).

Ocean acidification has increased severe pteropod shell dissolution incidences along the West Coast compared with pre-industrial conditions (Bednaršek *et al*. 2014, p. 6). Such dissolution incidences are expected to triple by 2050 (Bednaršek *et al*. 2014, p. 6), which is likely to alter available food sources for higher-trophic level species, such as forage fish and seabirds (Somero *et al*. 2016, p. 23). These effects on bivalves can be exacerbated by hypoxic conditions (Gobler *et al*. 2014, p. 5), or ameliorated by very high or low temperatures (Kroeker *et al*. 2014, pp. 4-5), so it is not clear what the effect is likely to be in a future that includes acidification, hypoxia, and elevated temperatures.

A food web model of Puget Sound shows that moderate or strong acidification effects to calcifying species are expected to result in reductions in fisheries yield for several species, including salmon and Pacific herring, and increased yield for others (Busch *et al*. 2013, pp. 827-829). Additionally, the same model shows that these ocean acidification effects are expected to cause reductions in forage fish biomass, which are in turn expected to lead to reductions in diving bird biomass (Busch *et al*. 2013, p. 829). While Busch and coauthors (2013, p. 831) express confidence that this model is accurate in terms of the nature of ocean acidification effects to the Puget Sound food web of the future, they are careful to note that there is a great deal of uncertainty when it comes to the magnitude of the changes. The model also illustrates that some of the effects to the food web will dampen or make up for other effects to the food web, so that changes in abundance of a given prey species will not always correspond directly to changes in the abundance of their consumers (Busch *et al*. 2013, pp. 827, 830).

In addition to direct impacts of various trophic levels of the food web, ocean acidification may exacerbate HABs resulting from *Pseudo-nitzschia fraudulenta*. This species exhibits higher growth rates with higher carbon dioxide concentrations (Tatters *et al*. 2012, pp. 3-4). But, more importantly, increased acidification of the water increases the toxicity of the domoic acid produced by this species, especially in conditions in which silicic acid (used to construct the algal cell walls) is limiting (Tatters *et al*. 2012, pp. 2-3).

Puget Sound. In 2016, the Service conducted a literature review of potential climate change impacts for a long-term activity in Puget Sound (see Appendix A for the climate change excerpt from the Biological Opinion). In that Opinion, the Service concluded that climate change is likely to reduce marbled murrelet breeding success via changes in prey availability and may expose adult marbled murrelets to health risks, such as more frequent domoic acid poisoning. For this review, we did not find any more recent research that offered additional or substantively different conclusions.

California Current System (CCS). In our 2009 5-year status review, we noted that future marine environments under global warming, as predicted by models, involve complex and interacting atmospheric and oceanic circulation dynamics, and that different models produced different outcomes. Similarly, in review of several more recent publications, we come to a similar conclusion. For example, Rykaczewski *et al*. (2015, p. 6,426) examined outputs from atmospheric-ocean general circulation models, and found that 71 percent of models (n = 21) projected significant decreases in summertime upwelling-favorable winds in the CCS through to year 2100, and that only one model projected a significant increase in summertime upwelling-favorable winds. In contrast, in a meta-analysis of wind trend studies between 1990 and 2012, Sydeman *et al*. (2014, p. 79) supported the hypothesis proposed by Bakun *et al*. (1990), of an intensification of upwelling favorable winds in the CCS. Examining a 60-year dataset of wind data in the CCS, Bylhouwer *et al*. (2013, p. 2,569-2,578) reported variable onset of upwelling at all locations and strong interannual to interdecadal variability. Similar to Sydeman *et al*. (2014) in California, Foreman *et al*. (2011, p. 8) reported an intensification of upwelling favorable winds off British Columbia, but also statistically significant trends toward later spring transitions and shorter seasons at five of six buoys. Increased intensity of spring and summer upwelling could result in more frequent hypoxic events, increased ocean acidification, changes in prey composition towards more subtropical species, and disconnections (temporally and spatially) between seabirds and prey resources (Bakun *et al*. 2015, entire). Interestingly, although the airspace over the ocean experiences the least projected future warming, this area is projected to have the largest increase in number of extreme heat days (Brewer and Mass 2016a, p. 6,399), possibly contributing to changes in winds that drive the upwellings along the coast (Brewer *et al*. 2012, p. 3,821).

Delayed upwelling in 2005 led to reduced growth rates, increased mortality, and recruitment failure of juvenile northern anchovies (*Engraulis mordax*) off of the Oregon and Washington coasts (Takahashi *et al*. 2012, pp. 397-403). In the northeastern Pacific, Chavez and coauthors (2003, pp. 217-220) have described a shift between an "anchovy regime" during the cool negative phase of the Pacific Decadal Oscillation (PDO) and a "sardine regime" during the warm positive phase, where the two regimes are associated with contrasting physical and biological states. However, global warming may disrupt the ecological response to the naturally-occurring oscillation, or alter the pattern of the oscillation itself (Chavez *et al*. 2003, p. 221; Zhang and Delworth 2016, entire). This "regime shifting" due to climate changes is likely to reduce marbled murrelet breeding success via changes in prey availability. While this assertion is not specifically supported by direct research on murrelets, it is supported by several studies of other alcid species in British Columbia and California. Common murres, Cassin's auklets, rhinoceros auklets, and tufted puffins in British Columbia; pigeon guillemots (*Cepphus columba*), common murres, and Cassin's auklets in California; and even Cassin's auklets in Mexico all show altered reproductive rates, altered chick growth rates, or changes in the timing of the breeding season, depending on sea surface temperature or other climatic variables, prey abundance, prey type, or the timing of peaks in prey availability (Abraham and Sydeman 2004, pp. 239-243; Ainley *et al*. 1995, pp. 73-77; Albores-Barajas 2007, pp. 85-96; Bertram *et al*. 2001, pp. 292-301; Borstad *et al*. 2011, pp.

291-299; Gjerdrum *et al*. 2003, pp. 9,378-9,380; Hedd *et al*. 2006, pp. 266-275). The abundance of Cassin's auklets and rhinoceros auklets off southern California declined by 75 and 94 percent, respectively, over a period of ocean warming between 1987 and 1998 (Hyrenbach and Veit 2003, pp. 2546, 2551). Although the details of the relationships between climate variables, prey, and demography vary between bird species and locations, the consistent demonstration of such relationships indicates that alcids as a group are sensitive to climate-related changes in prey availability, prompting some researchers to consider them indicator species for climate change (Hedd *et al*. 2006, p. 275; Hyrenbach and Veit 2003, p. 2551).

Preceding the development of El Niño conditions in 2015, a rise in sea surface temperatures in the Gulf of Alaska occurred in late 2013, likely due to a shift in wind patterns, lack of winter storms, and an increase in sea-level pressure (Bond *et al*. 2015, p. 3,414; Leising *et al*. 2015, pp. 36, 38, 61). This warm water anomaly expanded southward in 2014, evolved into a strong PDO in 2015, and then merged with another anomaly that developed off Baja California, becoming the highest sea surface temperature anomaly observed since 1982 when measurements began (NMFS 2016a, p. 5). These anomalies became known as "the Blob" (Bond *et al*. 2015, pg. 3,414) and helped to compress the zone of cold upwelled waters to the nearshore, which also concentrated the forage species into these same nearshore areas (NMFS 2016a, p. 7). The Blob's offshore warm water brought warm-water offshore species never found before or found at much higher abundance than usual, along with other El Niño-related species into or within the proximity of the nearshore coastal regions (Leising *et al*. 2015, pp. 32, 67). However, unlike the lead-in to previous strong El Niños, effective upwelling in the central and northern regions occurred with upwelling-related species near the coast (such as rockfish juveniles) which were still found in relatively high abundances (Leising *et al*. 2015, p. 67). The result of this event was a system with overall moderate productivity (depending on location), extremely high species diversity, and overall changes in ecosystem structure (Leising *et al*. 2015, p. 67). It is unknown what effect the Blob had on murrelets due to the mixed responses of seabirds to this event (Leising *et al*. 2015, p. 66). For example, a mortality event in 2014/2015, involving Cassin's auklets that were emaciated, was attributed to the warm water anomaly (the Blob) due to a lack of food resources (NMFS 2015, p. 13; Jones *et al*. 2018, entire). In addition, a mortality event involving common murres occurred along the coasts of Washington, northern Oregon, and central California in 2015; while the timing of the event wasn't unusual, the number birds involved was 2-3 times (or more) higher than normal in Washington and northern Oregon and even higher in the greater Farallones and Monterey Bay (NMFS 2016a, p. 15).

In addition to changes in the marine food webs due to changes in upwelling, a model of multiple climate change effects (*e.g.*, acidification and deoxygenation) in the Northeast Pacific consistently projects future declines in small pelagic fish abundance (Ainsworth *et al*. 2011, pp. 1,219, 1,224).

Marine Reserves

There are 127 Marine Protected Areas (MPAs) in Washington, which are managed by 12 Federal, State, and local agencies with varying authorities and goals (Van Cleve *et al*. 2009, pp. 6, 11, Appendix 1). These MPAs include uplands/shorelines which are managed by agencies, such as Washington State Parks and Olympic National Park, that encourage public use of the shoreline; however, the authorities of the agencies managing the uplands/shorelines may or may not extend into the sub-tidal areas offshore (Van Cleve *et al*. 2009, Appendix 1). Almost all (97 percent) of the MPAs

restrict harvest (shellfish, fish) to some degree; however, only 16 percent completely restrict harvest (Van Cleve *et al*. 2009, p. 46).

In 2012, the State of Oregon completed designation of five marine reserve sites in State waters (ORS 196.540 to 196.555, Senate Bill 1510). Each site has a no-take reserve and most also have at least one less restrictive marine protected area. Marine reserves are closed to extractive activities and prohibit all take of fish, invertebrates, wildlife, seaweeds, and ocean development, except as necessary for research or monitoring. Marine protected areas have varying degrees of protection for take and ocean development.

In California, four MPAs, encompassing 12,145 square miles (31,455 square km), exist within the National Marine Sanctuary System, administered by the National Oceanic and Atmospheric Administration, as follows: Cordell Bank (1,286 sq. mi. [3,330 sq. km]; established 1989), Greater Farallones (3,295 sq. mi. [8,534 sq. km]; established 1981), Monterey Bay (6,094 sq. mi.[15,783 sq. km]; established 1992) and Channel Islands (1,470 sq. mi.[3,807 sq, km]; established 1980).

The Marine Life Protection Act was passed in 1999 by the California Legislature, directing the California Department of Fish and Wildlife to redesign California's existing system of MPAs to increase its effectiveness for protecting the State's marine life, habitats, and ecosystems, including marbled murrelets. To help achieve these goals, from 1999 to 2012, four MPA designations (reserves, conservation areas, recreational management areas, and special closures) were established within five "Study Regions." In general, permitted activities are as follows: (1) reserves – damage or take of all marine resources is prohibited; (2) conservation areas – some recreational and/or commercial take of marine resources may occur; (3) recreational management area – limited recreational and/or commercial take of marine resources while allowing for legal waterfowl hunting; and (4) closure – access prohibited or boating activities limited in waters adjacent to seabird rookeries or marine mammal haul-out sites. The Study Regions (and numbers of MPAs within each) are as follows: North Coast (20), North-central Coast (25), San Francisco Bay (8), Central Coast (29), and South Coast (50). Currently, California MPAs encompass approximately 16.0 percent of State waters, including 9.4 percent of State waters in no-take MPAs (Gleason *et al*. 2013).

<u>Summary - Threats to the Marine Environment</u>. In our 2004 5-year status review, threats in the marine environment were acknowledged, but not fully developed. A more developed analysis in 2009 indicated murrelets are at threat from changes in prey quality and quantity, HABs and their associated biotoxins, and climate change. New information indicates toxins, even some that have been prohibited for decades, continue to persist in Puget Sound and be detected in murrelet prey. In addition, microplastics are being found in forage fish species and may be transferred up the food chain to murrelets. HAB events continue to occur and impact seabirds and in some areas, such as the Puget Sound and eastern Strait of Juan de Fuca, these events are projected to become larger and longer, thus increasing the risk of chick mortality due to PSP. Hypoxic/anoxic events have continued to occur throughout the marine environments, moved into shallower water depths, and are expected to grow in intensity and extent resulting in reduced prey availability and reproductive success.

New information indicates the status of most forage fish species is unclear or continues to not be available. Due to this lack of information, as of 2016, directed commercial fisheries have been prohibited for many of these species. Reduced fishing pressure on forage fish may provide a benefit to

murrelets if these efforts enable those prey species to rebound. However, climate change is projected to result in changes throughout the marine food web, likely reducing prey quality and quantity. Reduced quality and quantity of prey can have physiological consequences to adults and/or chicks and result in reduced murrelet breeding success. As discussed in our 2009 5-year status review, murrelets may be constrained in their ability to respond to shifts in prey conditions, in particular during the breeding season, because of the reduced distribution of nesting habitat.

Therefore, new information indicates there continues to be threats to murrelets in the marine environment and the impacts are projected to become greater in the future.

Terrestrial and Marine Environments: Cost of the Commute.
The murrelet's terrestrial and marine environments are not used independently and both environments need to be healthy for the continued existence of this species. Murrelets use the marine environment year-round and commute to terrestrial habitat for nesting. Terrestrial habitat is also visited outside of the nesting season.

In general, murrelets are found in the marine areas adjacent to terrestrial areas with larger amounts of higher quality nesting habitat and less human development (Lorenz *et al*. 2016, p. 10). Generally, nearshore murrelet abundance is strongly correlated with the amount and cohesiveness (more contiguous, less fragmentation) of higher suitability nesting habitat in the adjacent terrestrial areas (Falxa *et al*. 2016, p. 101). Falxa *et al*. (2016, p. 104) found a positive correlation between the population trend (change in number of murrelets) and the change in amount of higher suitability nesting habitat; specifically, as the amount of available higher quality nesting habitat decreased the associated murrelet population decreased. In Conservation Zone 1 (Puget Sound), Falxa *et al*. (2016, p. 106) also found that murrelet abundance was lower when there was a higher level of human disturbance in the marine environment.

In Washington, a study found that murrelets are traveling a mean distance of 33.2 mi (53.5 ± 28.4 km) (range 10.4 to 90.2 mi (16.8 to 145.3 km)) between their nest and foraging areas (Lorenz *et al*. 2017, p. 314). The murrelets in this study did not forage in the marine waters closest to their nest, they commuted on average another 13.3 mi (21.4 km), with the longest one-way marine commute being 91 mi (133.1 km) by a murrelet nesting on Vancouver Island, Canada that foraged at times in the San Juan Islands, Washington (Lorenz *et al*. 2017, p. 314). In many cases, the nests associated with the murrelets making these long marine commutes failed (Lorenz *et al*. 2017, p. 314).

Representatives of three different guilds of seabirds, including a pursuit-diving pelagic bird like the murrelet, all exhibited higher energy expenditures during the breeding season (Markones *et al*. 2010, entire). However, across a wide variety of bird species, adult birds have an intrinsic energy ceiling and increasing their energy costs (such as having to fly farther between foraging and nesting habitat) leads to a decline in self-maintenance and/or offspring provisioning because the adults make behavioral adjustments, such as reduced time spent flying/diving, to compensate for the increased energy demands (Elliot *et al*. 2014, p. 141). In some areas of the murrelet's range, nesting habitat may be distant from and the best marine foraging areas, such that adult murrelets reach or exceed their intrinsic energy ceiling. As discussed in our 2009 5-year status review (p. 23), adult murrelets likely follow a "fixed" investment strategy, such that they compromise reproductive investment to ensure their own survival. Members of the Service's murrelet recovery implementation team, based on their

best professional judgement, determined the primary cause of population decline was sustained low recruitment (USFWS 2012, p. 10) and Gutowsky *et al*. (2009, entire) concluded that murrelets that breed in the Puget Sound/Salish Sea have experienced declining reproductive rates over the past 150 years. The likely causes of the sustained low recruitment vary across the range, but include impacts in both the marine and terrestrial environments and the disconnect (distance) of nesting habitat and foraging areas. In the terrestrial environment, nesting habitat continues to be lost and the remaining habitat is reduced in quality due to fragmentation and human disturbance. In the marine environment, the status of all prey species is unclear, but murrelets are foraging on lower quality prey items (USFWS 2009, pp. 4-142) and may not be able to respond to shifts in prey conditions, especially during the breeding season when they need to remain closer to nesting habitat. The inability to obtain prey can compromise reproduction because receiving high-quality prey is essential for murrelet chicks to meet their growth needs. When chicks are fed fewer or lower quality prey items, they shift resource allocation to high-priority body components, such as wings, which are essential to successful fledging (*i.e.*, the need to reach marine waters on their first flight), potentially compromising development of other body components (Janssen *et al*. 2011, entire). A nutritionally-challenged chick that successfully fledges may be able to compensate at sea by increased foraging; however, there may be future fitness costs, such as reduced life span and reproductive output (Janssen *et al*. 2011, p. 865).

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

Previous 5-year status reviews stated there was no evidence of overutilization of murrelets for commercial, recreational, or educational purposes. This statement remains accurate.

Since May 1, 2009, the Service has issued section 10(a)(1)(A) recovery permits to 12 individuals for scientific research on murrelets in Washington, Oregon, and California. Through 2017, these permits authorized the harassment of a minimum of 645 murrelets, all murrelets associated with a minimum of 109 nest trees, and unintentional harm or harassment of 5 murrelets. Take of murrelet chick and eggs was also authorized but not quantified.

Recovery permits for future years (through 2022) have been issued to six individuals. These permits authorize the harassment of up to 900 murrelets and unintentional injury of up to 7 murrelets in Oregon from captures at sea, application of radio-tags, and monitoring of any nests located as a result of the study. In addition, future permits authorized the unintentional harm or harassment of up to 10 murrelets in Washington associated with recovery of grounded murrelets that would otherwise perish.

No take of murrelets have been reported for funded or non-funded activities under the Endangered Species Act section 6 cooperative agreements with the States of Washington, Oregon, and California.

The conclusions drawn in our previous 5-year status reviews regarding scientific research was that while individual murrelets are affected by telemetry and tree-climbing projects, these disturbances are relatively small scale, occur infrequently, and are unlikely to affect murrelet populations. The greatest impact to murrelet populations is removing adults, which may result when research includes attaching transmitters to adult birds. The recovery permits issued between May 1, 2009 and July 30, 2017, authorized the unintentional injury of up to three murrelets associated with telemetry projects in Oregon. Fifteen murrelets associated with these projects have died. Based on the confirmed removal

of adults from the murrelet population, it appears that overutilization due to research on murrelets may have occurred in Oregon since our previous 5-year status review.

Overutilization may occur if the targeted population is small, such as the Conservation Zone 6 population in California. Since 2009, 1 recovery permit was issued that authorized take (capture and banding) of up to 25 adult murrelets each year for 5 years, for a total of up to 125 murrelets. This represents a significant portion of the Conservation Zone 6 population, so it is possible that overutilization due to research on murrelets may have occurred in this Zone since our previous 5-year status review; however, no incidental injury or death of captured murrelets has been documented in permit reporting (Markegard 2019, *in litt*.).

Based on our review, overutilization for commercial, recreational, or educational purposes does not pose a threat to murrelets. However, overutilization due to research may have occurred since the analysis for our 2009 5-year status review.

2.3.2.3 Disease or Predation:

Disease

In the analysis for our 2004 and 2009 5-year status reviews, we did not identify disease as a threat to the murrelet. While diseases (bacterial, fungal, parasitic, and viral) and biotoxins were acknowledged to affect numerous populations of seabirds, no new information has identified any that affect alcids, nor in particular, murrelets (however, see HABs section above regarding Kittlitz's murrelet nestling mortality from PSP). Since our 2009 review, highly pathogenic avian influenza (HPAI) has been detected in North America. The first detection occurred in 2014, causing lethal infections in wild raptors and large-scale outbreaks in domestic poultry (NWHC 2016). Between 2014 and June 2017, HPAI has been detected in wild ducks, raptors, and geese in Washington, Oregon, and California (USGS *et al*. 2015, 2016, 2017). HPAI has not been identified in alcids. Therefore, disease is not considered to pose a current threat to the murrelet.

Predation

The analyses for our 2004 and 2009 5-year status reviews identified predation as being a significant threat to long term demography. Predation continues to have two primary components; losses of adults or fledged juveniles and nest predation (eggs or chicks). In 2009, we presented information regarding the rates of predation, presence of humans and possible disturbance to nesting murrelets, increased presence of predators and humans near murrelet nesting locations, forest fragmentation and edge effects on potential predation, and nest failure rates due to predation. There is no significant new information concerning these topics.

Known and suspected avian predators were identified in the previous reviews. Subsequently, Golightly and Schneider (2011, pp. 3-6) presented the first published documentation of gray jays (*Perisoreus canadensis*) predating a murrelet nest and ability of gray jays to carry off a recently hatched murrelet chick, demonstrating an ability to fly with loads of as much as 64 percent of their own body weight. Golightly and Schneider (2009, p. 5) observed disturbance to an adult nesting murrelet (*i.e.*, murrelet "flushed" from nest) and subsequent predation of an egg at a late stage of incubation (*i.e.*, feathered unhatched chick was inside egg). In addition, Golightly and Schneider (2009, p. 5) observed a common raven scavenging the egg contents approximately 2 hours after the

predation event. At a campground in Prairie Creek Redwoods State Park, Humboldt County, California, biologists documented, with the use of a video camera at a nest tree, disturbance to an adult murrelet and subsequent predation of a murrelet egg at the nest by two Steller's jays (*Cyanocitta stellerii*) (Redwood National and State Parks [RNSP] 2017, p. 11). This predation event occurred on 15 May 2016, and murrelets did not attempt to re-nest at this nest in 2016 (RNSP 2017, p. 11).

In RNSP, Scarpignato and George (2013, entire) reported on increased likelihood of common ravens (*Corvus corax*) locating and predating murrelet nests due to their frequent use of roads and old-growth edges and their overlap in use of the highest parts of the tree canopy. Also in RNSP, Goldenberg *et al*. (2016, p. 536) reported extensive home-range overlap among campground jays, possibly contributing to the high density of Steller's jays previously observed at these sites. In addition, Goldenberg *et al*. (2016, p. 536) reported that Steller's jays associated with campgrounds were more frequently observed greater than 3 feet (1 meter) from the ground, in comparison to non-campground jays. Goldenberg *et al*. (2016, p. 538) suggested that murrelets nesting within campgrounds may be more vulnerable to nest predation by Steller's jays and that this effect may persist up to 0.6 mi (1 km) from campgrounds. However, West *et al*. (2016, p. 11) found the "spillover effect" of campgrounds in State parks in California extended 1.24 mi (2km), such that the quality (low predation) of murrelet nesting habitat may be reduced due to the Steller's jays subsidizing their diet on human foods found in the campgrounds. In addition, jays utilizing campgrounds for food were in better body condition, had more young, and had smaller home ranges, which resulted in higher jay densities (West and Peery 2017, pp. 791-793).

Since our 2009 5-year status review, California State Parks have implemented a variety of measures aimed at controlling corvids, with the anticipation of reducing predation on murrelets. From 2015 to 2017, staff at California State Parks implemented infrastructure improvements at several State parks in Humboldt County, California, to reduce anthropogenic food sources for Steller's jays (California State Parks 2017). Infrastructure improvements included installation of wildlife-proof food lockers, trash/recycling bins, wildlife-proof grated water drains and dumpsters at Grizzly Creek Redwoods State Park and Humboldt Redwoods State Park (HRSP) (California State Parks 2017, p. 2-3). Population surveys of Steller's jays were conducted at HRSP in 2013, and future surveys are planned to potentially gauge the effectiveness of the infrastructure improvements (California State Parks 2017, p. 3).

RNSP implemented a Corvid Management Strategy in 2008 (RNSP 2008) and RNSP staff have focused upon implementation of corvid management actions at campgrounds annually since 2010 (RNSP 2016, p. 11). Corvid management actions at RNSP have included a visitor education program called "Keep It Crumb Clean," to reduce anthropogenic food sources at campgrounds, and concentrating interpretive and docent outreach at campgrounds during evenings when campers are present, to educate visitors on managing food at campsites (RNSP 2016, p. 14). From 2012 through 2016, mean numbers of Steller's jays detected within 164 feet (50 meters) of campgrounds at RNSP has apparently decreased by at least 50 percent, compared to the 2007 to 2011 time period, although it is likely too early to be able to attribute this decrease directly to corvid management strategies implemented at RNSP (Strong 2013, p. 13; RNSP 2016, pp. 7, 12). Similar to RNSP, California State Parks within Santa Cruz Mountains implemented similar management practices (Halpert 2017, pp. 140-143).

In addition, Gabriel and Golightly (2014, pp. 895-899) conducted field trials on murrelet-mimic eggs that contained a vomit-inducing compound (*i.e.*, carbachol), and reported a 37 percent reduction in attack of murrelet-mimic eggs, after aversive treatment, compared to control eggs. The extent of the efficacy of this method of deterring corvid predation on eggs is unclear due to the logistics of deploying the aversive treatment across a wide-enough landscape.

In 2017, the U.S. Forest Service in partnership with the Audubon Society of Portland, Cape Perpetua Foundation and Oregon Parks and Recreation Department initiated a Coastal Bird Stewardship Outreach Project in the vicinity of Oregon State Parks and the Siuslaw National Forest. Interpretation and new signage is being used to bring awareness of artificial food sources created by humans increasing corvid populations and how this negatively affects bird species of conservation concern including the murrelet.

In our 2004 and 2009 5-year status reviews, we found murrelets to be highly vulnerable to nest predation. While some efforts have been undertaken to reduce the risk of predation by corvids in California and Oregon, new information continues to confirm the importance of nest predation in limiting murrelet nest success.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

Information is provided below to update the analysis since our 2009 5-year status review. This includes information on the revisions of plans and regulations within the range of the murrelet that address increased or decreased regulatory protection with respect to murrelets. In addition, properties that are now managed for conservation benefits for the murrelet as a result of purchase, conservation easements or changes to land allocations are listed below. While these additions do not add to the amount of murrelet habitat, they now have adequate or additional regulatory mechanisms to protect them for murrelet conservation. Other than the revisions below, we know of no new additional regulations that have been implemented to address the threats to the murrelet. Therefore, we continue to assume that the threat posed by the inadequacy of existing mechanisms has been reduced since listing.

BLM Western Oregon Plan Revisions: See section 2.1.3.1 for description of revisions and relevance to murrelets.

National Forest Management Act: We are unaware of any substantive changes to the NFMA that might affect conservation of the murrelet.

Habitat Conservation Plans and Safe Harbor Agreements. Habitat conservation plans (HCPs) and safe harbor agreements (SHAs) in murrelet habitat are developed to provide long term certainty for both murrelet conservation and landowners. HCPs provide a framework for people to complete projects while conserving at-risk species of plants and animals. A SHA is a voluntary agreement involving private or other non-federal property owners whose actions contribute to the recovery of species listed as threatened or endangered under the Act. In exchange for actions that contribute to the recovery of listed species on non-federal lands, participating property owners receive formal assurances from the Service that if they fulfill the conditions of the SHA, the Service will not require any additional or different management activities by the participants without their consent. Central to

this approach is that the actions taken under the SHA will provide a net conservation benefit that contributes to the recovery of the covered species.

Since the analysis for our 2009 5-year status review, there have been no HCPs completed, nor have there been any SHAs completed in Oregon or California. One SHA has been completed in Washington.

City of Everett Lake Chaplain Tract: The Service issued an Enhancement of Survival Permit to the City of Everett, Snohomish County, Washington in July 2015, in accordance with their authority and responsibility under section 10(a)(1)(A) of the Act. This type of permit is commonly known as a SHA. This SHA encompasses 3,279 ac (1,325 ha) of land surrounding, or in close proximity to, Lake Chaplain owned and managed by the City of Everett. The conservation benefit provided by the SHA is the deferral of harvest of 1,066 ac (431 ha), which will be able to mature to 90 to 214 years of age. The permit covers forest management activities for a 50-year duration. Landowners participating in SHAs have the right to terminate their voluntary agreements prior to the expiration date.

Protected Murrelet Habitat: Habitat protected under Natural Resource Damage Assessment (NRDA) funds, Conservation Agreements, Cooperative Endangered Species Conservation Funds (CESCF) and National Coastal Wetlands Conservation Grants (NCWCG) through conservation easements or purchases provides protection of known occupied murrelet nesting and/or foraging habitat, nesting buffers, and the creation of additional murrelet habitat over time. For specific information on these areas please see Appendix B: Factor D.

Natural Resource Damage Assessment (NRDA) funds: Since our 2009 5-year status review, there has been no additional acreage conserved for murrelets with NRDA funds in Washington, Oregon, or California.

Cooperative Endangered Species Conservation Funds (CESCF; Non-traditional Section 6). Since our 2009 5-year status review, approximately 1,718 ac (694 ha) have been permanently conserved under the CESCF that have or will have habitat that could benefit murrelets. All properties are intended to be managed for the long-term conservation benefit of murrelets. Management of these lands may not impede the conservation benefit of murrelets and the Service has approval over management plans for these properties. See Table 5 for total acreages.

Table 5. Acreage conserved under CESCF for murrelets in the Pacific Northwest

Area	Total area	Area of terrestrial murrelet habitat
Mount Si, WA	381 ac [154 ha]	381 ac [154 ha]
I90, WA	666 ac [270 ha]	666 ac [270 ha]
Beaver Creek, OR	671 ac [272 ha]	671 ac [272 ha]
TOTAL	1,718 ac [695 ha]	1,718 ac [695 ha]

National Coastal Wetlands Conservation Grants. The NCWCG program was established by the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) of 1990. Under the NCWCG , the Service provides matching grants to States for acquisition, restoration, management or enhancement of coastal wetlands. The CWPPRA also establishes a role for the Service in interagency

wetlands restoration and conservation planning. In Washington State, approximately 1,776 ac (178 ha) were protected and restored during 2009 to 2017 and provide protection of marine forage species for the murrelet. In Oregon, 244 ac (99 ha) of marine shoreline were protected. We are unaware of any acreage identified under the NCWCG in California during this time period that provides conservation benefits to the murrelet.

New National Monuments. Since the analysis for our 2009 5-year status review, one national monument has been established within the range of the murrelet. In Washington, the San Juan Islands National Monument was established in 2013 which covers approximately 1,000 ac (407 ha) of land managed by BLM in the San Juan Islands. The lands included are rocky islands and do not provide nesting habitat. A resource management plan has not yet been completed.

New Wilderness Areas**.** Since the analysis for our 2009 5-year status review, no new wilderness areas have been designated.

State Forest Plans

There are no new or revised State forest plans since the analysis for our 2009 5-year status review was completed.

Ocean Regulations

The Outer Continental Shelf Lands Act of 1953 (OCSLA) (43 U.S.C. 1331 et. seq.) provides the Secretary of the Interior, on behalf of the Federal government, with authority to manage the mineral resources, including oil and gas, on the outer continental shelf (OCS) and defines the OCS as all submerged lands lying seaward of the State/Federal boundary. The Federal Oil and Gas Royalty Management Act of 1982 (30 U.S.C. 1701) mandates protection of the environment and conservation of Federal lands in the course of building oil and gas facilities. Presidential Executive Order 13795, signed on April 28, 2017, removed moratoriums on coastal areas, including National Marine Sanctuaries, for oil and gas leasing within the range of the listed murrelet population. Consequently, it is foreseeable that new offshore oil and gas platform development may occur off the coasts of Washington, Oregon, and California in habitat used by murrelets. Oil development as it relates to oil spills (see Factor E), may have detrimental effects on murrelets.

The Oil Pollution Act (OPA) of 1990 (33 U.S.C. 2701-2761) amended the Clean Water Act and addressed the wide range of problems associated with preventing, responding to, and paying for oil pollution incidents in navigable waters of the U.S. It created a comprehensive prevention, response, liability, and compensation regime to deal with vessel- and facility-caused oil pollution to U.S. navigable waters. The OPA required a phase-out of single-hull tankers from U.S. waters by 2015. All oil tankers arriving in Washington are double-hulled and in Puget Sound are accompanied by a tug escort (Etkin *et al*. 2015, pp. 272, 302).

Summary. Based on the information provided above we continue to assume that the threat posed by the inadequacy of existing mechanisms has been reduced since listing.

2.3.2.5 Other natural or manmade factors affecting its continued existence:

Oil Spills

Our 2004 and 2009 5-year status reviews identified the oil spills known to have mortalities of murrelets and the possible chronic sources of oil. Since our 2009 5-year status review, there have been no reported oil spills with documented murrelet injuries or mortalities. However, spills of various sizes of oil-based and chemical products have been reported in all three States in areas where murrelets occur. In Washington, the WDFW Oil Spill Team received 985 notifications of oil/chemical spills, a few of these had observable impacts on birds (primarily waterfowl), and only one for which there was a significant concern for impacts to murrelets although no injuries or mortalities were documented (pers. comm. D. Noviello, WDFW, Aug 2017). In Oregon, 64 spills were reported in the Pacific Ocean (not including bays or the Columbia River Estuary). In California, 3,532 oil/chemical spills were reported within the range of the murrelet. Murrelets are a small seabird and, as noted in previous reviews, are very difficult to detect during major oiling events. It is even more difficult to detect possible mortalities/injuries of murrelets from smaller to medium-sized events, even when other seabirds are impacted. Even though there have been no spill-related mortalities/injuries of murrelets reported since our 2009 5-year status review, there continue to be spills in the marine areas where murrelets could be exposed; therefore, to err on the side of caution, we presume that some murrelets in Washington, Oregon, and California have been impacted, but we are not able to produce a reliable estimate of the extent of that impact.

While the capacity of oil refineries in Washington remained steady at about 8.5 billion gallons/year, the transportation of crude oil (Bakken oil and diluted bitumen) to and from ports on the Columbia River, Grays Harbor, and Puget Sound has been shifting from ships (91 percent in 2003 down to 67 percent in 2013) to pipeline (24 percent) and rail (8 percent, up from 0 percent in 2003 to 2011) (Etkin *et al*. 2015, p. 30). As a result of the increasing movement of crude oil by means other than ships, the State of Washington enacted the Oil Transportation Safety Act (OTSA) (ESHB 1449) in April 2015. The OTSA requires advance notice of oil movement, railroad contingency planning, geographic response plans, updated vessel traffic safety evaluations and assessment, and equipment caches. The Washington Department of Ecology is in the process of implementing the requirements of the OTSA.

Even though there has been a shift to transport of oil via railroad, the majority of transportation is still via ships. The Strait of Juan de Fuca was transited annually by approximately 8,300 deep draft vessels (*e.g.*, container ships, tankers, oil barges) heading to ports in Washington and British Columbia, with approximately 3,700 of these going to ports in Washington (Van Dorp and Merrick 2017, p. 4). In addition, other deep draft vessels such as tugs, ferries, and fishing and recreational vessels move around Puget Sound resulting in approximately 230,000 transits annually (Van Dorp and Merrick 2017, p. 4).

In addition to, or possibly because of, the increased movement of oil by railroad, there are multiple proposed/finalized facility expansions and new pipelines that will result in increased vessel traffic through the Straits of Juan de Fuca to ports in Washington and British Columbia. Should all of the proposed new facilities and expansions in Washington and British Columbia come to fruition, the probability of at least one accident involving 2,500 cubic meters of oil or more occurring over a 10-year period increases by a factor of 2.7 above the current baseline; however the risk is much higher for some areas, such as the Haro Strait in British Columbia (factor of 11), the eastern portion of the Strait

of Juan De Fuca (factor of 5), and the western portion of the Strait Juan de Fuca (factor of 3) (Van Dorp and Merrick 2017, p. 18). Similarly, in this scenario the risk of one or more accidents over a 10-year period involving 1,000 to 2,500 cubic meters increases by a factor of 1.56 above the current baseline (Van Dorp and Merrick 2017, p. 20).

Based on the new information available, we have determined that impacts from oil spills do not appear to have increased from our analysis for our 2009 5-year status review. However, the risk of a catastrophic oil spill impacting murrelets remains throughout the range and may be increasing as a result of new and expanded facilities, in particular in Washington and British Columbia. Impacts result from direct mortality through oiling and reduction of reproductive success through changes in prey base, marine habitat, and disturbance. There have been no additional regulations or changes to regulations to address this threat, nor have recovery actions reduced it. Its magnitude appears to be unchanged at this time across the range, but likely increased in Washington.

Fisheries Bycatch

Gill Nets

Murrelet mortality associated with gill nets remains zero in California and Oregon, as discussed in McShane *et al*. (2004). McShane *et al* (2004) documented murrelet mortality in Washington and the following review updates or provides new information not considered in McShane *et al*. (2004) or our 2009 5-year status review.

Measures taken to reduce gill-net related mortalities in Washington have remained the same since the last analyses (*i.e.*, area closures, time-of-day restrictions, etc.). However, both treaty and non-treaty gill-net fishing continue to occur in the Straits of Juan de Fuca and Puget Sound.

In 2001, the Service issued a Biological Opinion to NOAA for the non-treaty fisheries. This Biological Opinion allowed for a maximum removal of up to six murrelets per year over 10 years. While this level of removal was considered in the analysis provided in McShane *et al*. (2004), the removal was anticipated to continue through 2011 and is therefore also pertinent to this review. In 2004, the Service exempted the removal of up to 9.6 adults and 1 chick per year over 10 years in a Biological Opinion to the Bureau of Indian Affairs (BIA) for Tribal treaty fisheries. In 2016, the Service issued a Biological Opinion to NOAA and the BIA for both non-treaty and Tribal treaty fisheries for the 2016/2017 season, exempting the take of approximately two murrelets in non-treaty gill-net fisheries and seven murrelets in treaty gill-net fisheries. In 2017, the Service issued a second Biological Opinion to NOAA and the BIA, this time covering non-treaty and Tribal treaty fisheries for the period from 2017 to 2037. This opinion exempted the take of 39 murrelets in non-treaty gill-net fisheries and 72 murrelets in treaty gill-net fisheries over the 20-year period. These 111 captures of murrelets in gill nets were anticipated to result in the death of 106 adult murrelets and subsequent loss of 4 eggs or nestlings over the 20 years.

As reviewed by McShane *et al*. (2004, pp. 5-25, 5-26), several studies have documented murrelets becoming entangled in gill nets in Washington. Since that review, seven murrelet carcasses recovered from observer programs in Washington gill-net fisheries in 1993 have been necropsied and injuries were consistent with death by drowning (Grettenberger *et al*. 2005, pp. 3, 5). Murrelet mortality has

not been documented recently in Washington gill-net fisheries, but this may be due to a lack of seabird observer coverage, rather than a lower-than-expected number of mortalities.

As summarized in McShane *et al*. (2004, pp. 5-30) gill-net fishing effort up through 2003 had declined below pre-1990s effort levels. Although still remaining well below the pre-1990s fishing effort, since 2000, gill-net fishing effort has fluctuated. Non-treaty fisheries reported relatively high numbers of landings for 2000, 2006, 2008, and 2011, and relatively low numbers of landings for 2002, 2003, 2006, and 2015 through 2017. Treaty fisheries data are available for 2004 through 2014, and show that effort generally increased, with some fluctuations, between 2004 and 2011, followed by a decline. In 2017, fisheries co-managers anticipated that gill-net fishing effort from 2017 through 2037 would be generally similar to the 2008 through 2014 effort for treaty fisheries and 2000 through 2015 effort for non-treaty fisheries. Small increases in effort were anticipated for a few fisheries, including in areas around Whidbey Island and Hood Canal. However, if declining salmon stocks lead to emergency fisheries closures, as occurred in 2016, overall future fishing effort is more likely to be lower than the co-managers anticipated.

Gill-net fishing in Canadian waters may also affect murrelet populations in Washington, since murrelets radio-tagged in Washington have been observed spending time in Canadian waters (Lorenz *et al*. 2016, p. 3). Smith and Morgan (2005, pp. i, 19-25) reviewed information on seabird entanglement in British Columbia net fisheries between 1995 and 2002, and estimated that hundreds of murrelet entanglements occurred each year across all British Columbia gill-net fisheries. Only fisheries operating in southwestern British Columbia would be expected to entangle murrelets breeding in Washington.

Based on the new information available, we have determined that gill nets may be responsible for direct mortality of murrelets, but the impacts continue to be localized to the Puget Sound area and northern Washington coast. There have been no additional regulations or changes to regulations to address this threat, nor have recovery actions reduced it. Fishing effort has fluctuated since our 2009 5-year status review, but there is no indication of an overall increasing trend in this threat.

<u>Purse Seines</u>

As mentioned by McShane *et al*. (2004, p. 5-30), murrelets have been observed to be entrapped by purse-seine nets in Conservation Zone 1. Murrelet mortalities have not been observed in purse seines, but purse-seine entanglement sometimes kills other birds (particularly the rhinoceros auklet, another alcid species). In three observer studies involving salmon purse seines in Conservation Zone 1, 5 percent of the entangled seabirds died, and the remaining 95 percent were released alive (Beattie and Lutz 1994, p. 13; NRC 1993, p. 13; NRC 1995, p. 17). We assume that the immediate mortality rate of murrelets caught in purse seines is similar. These studies did not report whether or not the surviving birds sustained injuries. Murrelets caught in purse seines could become injured through human handling as they are released, come in contact with the net, or come in contact with fish oil while they are in the net. Fish oil alters the microstructure of feathers, leading to a loss or reduction in waterproofing, thermoregulatory properties, swimming ability, and flight ability, often followed by death (UC Davis Wildlife Health Center 2017; Velarde *et al*. 2017, p. 77). Therefore, some murrelets released alive from purse-seine nets could suffer delayed mortality.

In Conservation Zone 1, purse seines are used in non-treaty and Tribal treaty salmon fisheries. Purse seines are also used for research off the coasts of Oregon and Washington. In 2016, the Service issued a Biological Opinion to NOAA and the BIA for both non-treaty and Tribal treaty fisheries for the 2016/2017 season, exempting the capture of approximately 10 murrelets in non-treaty purse-seine fisheries and 9 murrelets in treaty purse-seine fisheries, with approximately 3 of these captures resulting in injury or mortality. In 2017, the Service issued a second Biological Opinion to NOAA and the BIA, this time covering non-treaty and Tribal treaty fisheries for the period from 2017 to 2037. This opinion exempted the capture of 66 murrelets in non-treaty purse-seine fisheries and 71 murrelets in treaty purse-seine fisheries over the 20-year period. These 137 captures of murrelets in purse seines were anticipated to result in the death of 7 adult murrelets and subsequent loss of 1 egg or nestling over the 20 years. Also in 2017, the Service issued a Biological Opinion to NOAA covering fisheries and ecosystem research conducted between 2017 and 2027 by their Southwest and Northwest Fisheries Science Centers (SWFSC and NWFSC). This opinion exempted the capture of two murrelets in purse seines in Oregon or Washington.

Information is not available or has not been analyzed regarding murrelet encounters with other purse-seine fisheries.

Recreational Fishing

As mentioned by McShane *et al*. (2004, pp. 5-23), murrelets are sometimes caught and killed in hook-and-line fisheries, such as those commonly used by recreational fishers. The WDFW conducts dockside surveys of a sample of recreational fishers, asking about encounters with seabirds. These questionnaires have resulted in three records in which fishers reported contact with murrelets while fishing, as well as many reports of unidentified seabirds (V. Tribble 2017, *in litt*.). Many fishers also reported whether the bird had died or swallowed the hook, whether they had removed the hook from the bird, and sometimes described the body part that was hooked. Based on this information set, we assume that approximately 25 percent of murrelets hooked by recreational fishers are killed immediately or injured severely enough that delayed mortality is likely.

In 2016, the Service issued a Biological Opinion to NOAA and the BIA for both non-treaty and Tribal treaty fisheries for the 2016/2017 season, exempting the capture of one murrelet in non-treaty recreational fisheries, resulting in injury or mortality. In 2017, the Service issued a second Biological Opinion to NOAA and the BIA, this time covering non-treaty and Tribal treaty fisheries for the period from 2017 to 2037. This opinion exempted the capture of nine murrelets in non-treaty recreational fisheries, resulting in the death of two adult murrelets over the 20 years. In 2017, the Service issued a Biological Opinion to NOAA covering fisheries and ecosystem research conducted between 2017 and 2027 by the SWFSC and NWFSC, which included hook-and-line fishing. This opinion concluded that the probability of hooking a murrelet was too high to be called extremely unlikely, but not high enough to be reasonably certain.

Information is not available or has not been analyzed regarding murrelet encounters with other recreational fisheries, although these fisheries occur throughout the murrelet's listed range.

Trawl Fishing

Murrelet capture or mortality in trawl nets has not been reported, but new information indicates that murrelets may be at risk of mortality in some trawl gear. Most published research regarding the

effects of trawling on seabirds focuses on larger, surface-feeding birds such as albatross and gulls, though a few publications have reported trawling bycatch of alcids (Otsuki 2013, pp. 62, 64; Tasker *et al*. 2000, p. 534), as well as other pursuit-diving seabirds such as cormorants and penguins (González-Zevallos and Yorio 2006, p. 179; González-Zevallos *et al*. 2007, p. 112). Newly available information indicates that between 2002 and 2014, juvenile salmon surveys conducted off the coast of Washington by the NWFSC have caught and killed alcids (Catelani, *in litt*. 2017b). Out of 23 birds captured in these trawl surveys, 22 were alcids, including 16 common murres, 3 rhinoceros auklets, 2 tufted puffins, and a Cassin's auklet (Catelani 2017, *in litt*.; Drake, *in litt*. 2017; NMFS 2016c, p. 16). Fourteen of these died (Catelani, *in litt*. 2017b; Drake, *in litt*. 2017b). The NWFSC and SWFSC conduct a number of other trawl surveys, but did not maintain records of seabird encounters for these surveys prior to 2015.

In 2017, the Service issued a Biological Opinion to NOAA covering fisheries and ecosystem research conducted between 2017 and 2027 by the NWFSC and SWFSC, which included these same juvenile salmon surveys and other trawl surveys. The opinion concluded that murrelet capture in trawl gear was not reasonably certain, but the available information also did not support a conclusion that it was extremely unlikely to occur.

Information is not available or has not been analyzed regarding murrelet encounters with other trawl fisheries.

Derelict Fishing Gear

Our 2009 5-year status review discussed the prevalence of derelict fishing gear in Puget Sound and the Straits of Juan de Fuca, the likelihood that marbled murrelet deaths were being caused by derelict fishing gear, and efforts to remove derelict fishing gear from Puget Sound and the Straits of Juan de Fuca.

Since 2009, a partnership between WDFW and the Northwest Straits Foundation (NWSF) focused on removing legacy derelict nets from all high priority areas in Puget Sound to a depth of 105 feet (32 meters). Between November 2013 and June 2015, NWSF removed over 1,000 nets and nearly 150 crab and shrimp pots from Puget Sound (see Figure 3).

The NWSF observed 131,138 animals entangled in the 1,007 nets they removed, which included individuals from 11 different species of birds (NWSF 2015, p. 4). Based on analysis by researchers at the University of California, Davis (see Gilardi *et al*. 2010), the NWSF estimated that, if left in the water, the 1,007 removed derelict nets would have caused a total of 4,052 seabird mortalities annually (NWSF 2015, p. 4).

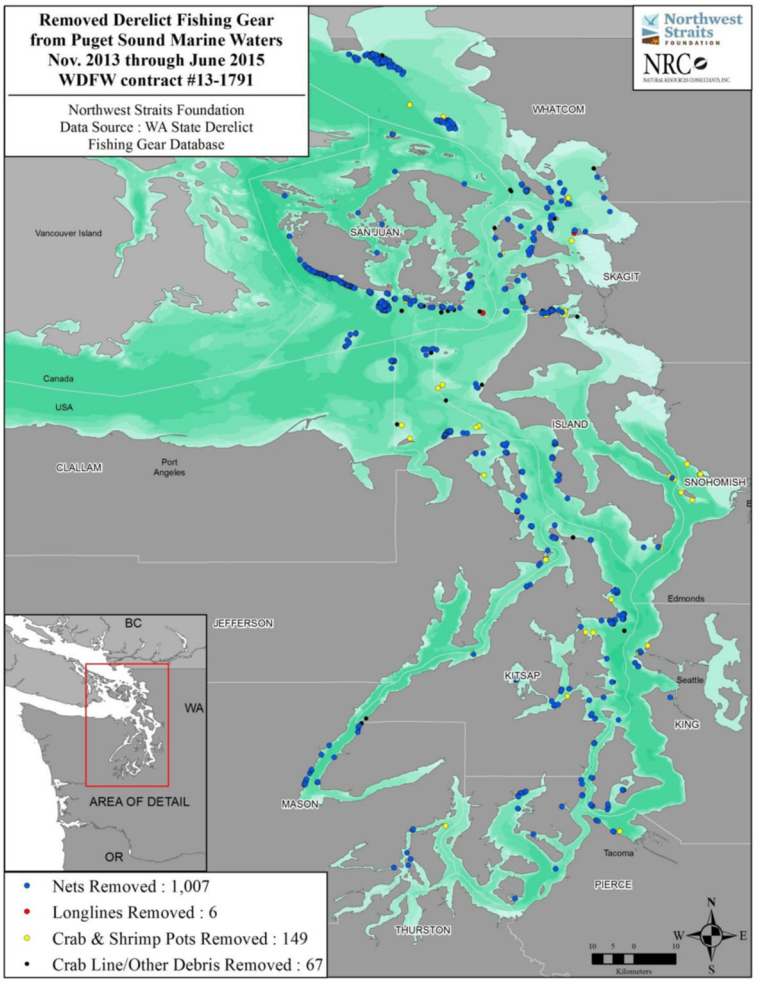

Figure 3. Derelict fishing gear removed from 2013 through 2015 (NWSF 2015, p. 3).

During the program to remove legacy derelict fishing gear, the NWSF also began a program to prevent further accumulation of derelict fishing gear in Puget Sound. The Reporting, Response, and Retrieval Program (RRR Program) relies on reports of newly lost fishing gear to locate and remove derelict fishing gear. As of February 2016, the NWSF received reports of derelict fishing gear largely from private citizens, although reports also came from fishers and staff from Federal, State, and Tribal agencies (Wilson, A., *in litt*. 2016, p. 5). From those reports, the NWSF was able to remove 37 newly lost fishing nets from Puget Sound waters between June 1, 2012 and February 29, 2016 (Wilson, A., *in litt*. 2016, p. 4). To aid in recovery of newly lost nets, and as a condition of the Service's Biological Opinion on 2017 to 2036 Puget Sound Treaty and Non-Treaty (All-Citizen) Salmon Fisheries (USFWS 2017, entire), all salmon fishers are required to report derelict salmon fishing gear to authorities within 24 hours of its loss (USFWS 2017, p. 130). Furthermore, the 2017 Salmon Fisheries Biological Opinion directed NOAA Fisheries and the BIA to ensure that Puget Sound salmon fisheries will add no more than five unrecovered derelict fishing nets to the marine environment annually (USFWS 2017, p. 131).

Analysis for the 2017 Salmon Fisheries Biological Opinion estimated the rate at which seabirds become entangled in derelict nets. The analysis relied on data from 5,785 derelict nets removed from

Puget Sound and estimated that each piece of derelict fishing gear that has been in the water less than 3 years will entangle 0.055 seabirds each day (older derelict net pieces have a lower entanglement rate of 0.008 seabirds per day, USFWS 2017, p. 103). Applying the proportion of seabirds that we expect to be marbled murrelets (Hamel *et al*. 2009, p. 51) yielded a murrelet entanglement rate of 0.0004 birds per day for recently lost net pieces. That estimate may be an underestimate for several reasons. Firstly, pursuit-diving seabirds (like murrelets) were disproportionately found entangled in derelict net pieces (Antonelis, K. *in litt*. 2016) compared to the proportion of all seabirds that are pursuit divers (Hamel *et al*. 2009, p. 51). Secondly, smaller birds (like murrelets) are more likely to fall out of nets during retrieval before they can be observed (USFWS 2017, p. 104). Finally, piles of bones observed beneath (but not entangled in) derelict net pieces suggests that observations from net retrieval may underestimate bird entanglement (Good *et al*. 2010, p. 46). Murrelets have still not been observed entangled in derelict fishing nets during net retrieval, but the factors discussed above that are likely to make our entanglement rate an underestimate continue to convince the Service on the veracity of this threat to murrelets.

Since 2009 efforts to remove derelict fishing gear from Puget Sound have decreased the number of derelict fishing net pieces in high-priority, shallow (less than 105 feet [32 meters]) habitats and reduced the accumulation of derelict fishing gear by retrieving newly lost net pieces. The effort to reduce the accumulation of derelict fishing gear from salmon fisheries in Puget Sound is expected to continue through 2036. However, even though efforts have reduced the severity of the threat, derelict fishing gear will continue to accumulate in Puget Sound and entanglement in that gear remains a threat to marbled murrelets.

Energy Development, Production, and Associated Infrastructure

Wave and Tidal Energy Projects**.** Section 23(b)(1) of the Federal Power Act of 1920 grants jurisdiction to the Federal Energy Regulatory Commission (FERC) for the licensing of hydropower development (for example, wave energy projects) in offshore waters of the U.S. FERC licensing procedures include analyzing potential project effects on natural resources including, but not limited to, water quality, water use, marine mammals, fish, birds, geology, land use, ocean use, navigation, recreation, aesthetics, and cultural resources.

The threat(s) these projects may pose to murrelets varies greatly, depending upon the proposed location and type of equipment. In some cases, such as tidal energy projects that will use underwater turbines, the threat may be mortality. In other cases, the projects may degrade marine habitat through shading, collision/entanglement obstacles, night-lighting, changes in prey abundance, and/or increased human presence. In some cases, the project may have little or no impact to murrelets. The following summarizes those wave and tidal projects that we are currently aware have been proposed and are moving forward through the permitting and testing phases or already occur within murrelet habitat.

In Washington, there have been several projects proposed, but we know of no actively operating or proposed projects (Washington Department of Ecology *et al*. 2017, pp. 2-171, 2-198).

In Oregon, since our 2009 5-year status review, anchors for one buoy were installed for the proposed Reedsport Ocean Power Technology (OPT) Wave Park in Douglas County, but the buoy was never installed, and in 2014 the anchors were removed and the project was abandoned. The Pacific Marine

Energy Center (PMEC) is moving forward with two wave energy projects. PMEC North Energy Test Site is near Newport, Oregon and serves as PMEC's non-grid-connected test facility for individual wave energy converters (WECs) and arrays. PMEC South Energy Test Site is near Waldport, Lincoln County, Oregon and will serve as PMEC's grid-connected test facility for individual WECs and arrays. At this time, no structures are in the ocean.

We identified in our 2009 5-year status review at least five proposed wave energy projects that may occur within the range of the murrelet in California. However, since 2009, no wave energy projects have been permitted by FERC nor do we know of any projects currently proposed (FERC 2017, website). The future of any wave energy project is unclear at this time; however, on October 7, 2015, Governor Edmund G. Brown, Jr. signed legislation to require 50 percent of the state's electricity to come from renewable energy by December 31, 2030 (California Energy Commission 2017) leaving the future for offshore wave energy uncertain.

Offshore Wind Projects**.** At this time we are unaware of any offshore wind energy projects proposed along the coasts of Washington, Oregon, or California. A report generated by Adams *et al*. (2016, entire), using a comprehensive database to quantify marine bird vulnerability to potential offshore wind energy infrastructure covers 81 regularly occurring seabirds to the CCS, including the murrelet. Three vulnerability indices were created: Population Vulnerability, Collision Vulnerability, and Displacement Vulnerability. Population Vulnerability was used as a scaling factor to generate two comprehensive indices: Population Collision Vulnerability (PCV) and Population Displacement Vulnerability (PDV). The murrelet had a PCV best estimate score of 73, ranking it "medium" among the suite of species, and a PDV best estimate score of 160, ranking it "high" among the suite of species and one of the greatest PDV scores (Adams *et al*. 2016, pp. 1, 58). More detailed information is available in Adams *et al*. (2016, entire).

California: In January 2016, the Bureau of Ocean Energy Management (BOEM) received an unsolicited request for a commercial lease from Trident Winds LLC. (Trident Winds). To determine competitive interest, BOEM published a notice in the Federal Register, "Potential Commercial Lease for Wind Power on the Outer Continental Shelf (OCS) Offshore California - Request for Interest (RFI) in Docket No. BOEM-2016-0051 on August 18, 2016. BOEM received one expression of interest from Statoil Wind US, LLC. The responses to the RFI indicated competitive interest in offshore California and therefore, BOEM and the State of California initiated the competitive planning and leasing process for possible future leasing for offshore wind development off California. Additionally, BOEM is working with the State of California on planning for potential leasing for offshore wind in Federal waters off California (BOEM 2017, website). The future of any offshore wind project is unclear at this time; however, on October 7, 2015, Governor Edmund G. Brown, Jr. signed legislation to require 50 percent of the state's electricity to come from renewable energy by December 31, 2030 (California Energy Commission 2017).

On-Shore Wind Projects**.** The threat(s) on-shore wind energy projects pose to murrelets may include direct mortality and habitat removal. Numerous radar studies have been conducted within the range of the murrelet that have concluded there is a risk of collision with wind turbines because some proportion of murrelets fly at or below the typical height of the structures and transmission lines (Beauchesne and Hemmera 2016, Sanzenbacher *et al*. 2015, Sanzenbacher *et al*. 2014, Stumpf *et al*. 2011, Lewis County Community Development Department 2010). However, not all sites are

equivalent, presenting varying levels of risk of collision. Collision should be considered as year-round risk because murrelets have been documented transiting between marine and terrestrial habitat at all times of the year, although the peak is during the breeding season (Sanzenbacher *et al*. 2014, entire). The following are those projects that we are currently aware have been proposed and are moving forward through the permitting and testing phases.

In Washington**,** one project has been constructed, one has been approved but not constructed, and one new one is being planned. The Grayland project discussed in our 2009 5-year status review has been constructed and is currently operational. There has been no mortality monitoring associated with this project. The Radar Ridge project was not permitted by the Washington Department of Natural Resources. The final environmental impact statement was completed for the Coyote Crest project which proposed to install 50 wind turbines (Lewis County Community Development Department 2010, entire); however, no construction has begun. The Skookumchuck Wind Energy Project, LLC, has proposed to install 38 wind turbines and associated infrastructure in Lewis and Thurston Counties, commencing operations in 2019 (83 FR 19569). The turbines are proposed to be constructed on a prominent ridgeline in the Weyerhaeuser Vail Tree Farm. This project poses a risk of collision to murrelets which have been documented in nearby suitable nesting habitat and transiting to and from marine foraging areas through the path of this project (Sanzenbacher *et al* 2015, entire).

In Oregon, we are unaware of any on-shore wind energy projects proposed along the coast.

In California, since our last review in 2009, Shell WindEnergy Incorporated announced in July 2012, that they were withdrawing from the Bear River project due to unfavorable market conditions and issues pertaining to the transportation logistics (Hansen and Grant Scott-Goforth/The Times-Standard 2012, website). Terra-Gen Development Company, LLC (Terra-Gen; San Diego, California), is planning development of the Humboldt Wind Energy Project (project) in western Humboldt County, California. The project would consist of as many as 60 wind turbines and associated facilities including meteorological (met) towers, electrical collection system, access roads, construction staging areas, operations and maintenance facility, and an approximately 25-mi (40-km) transmission interconnection line and associated point of interconnection. The proposed locations for the wind turbines include at least three coastal mountain ridges, ranging approximately 1 mile (1.6 km) north to 5 miles (8 km) northwest of Humboldt Redwoods State Park, a known nesting location for marbled murrelets. Stantec Consulting Services Inc. (Stantec; San Francisco, California) has prepared a biological resources work plan detailing biological resource surveys (including radar surveys for murrelets) to be conducted supporting the project, and is coordinating with regulatory agencies, including the Service and CDFW. Terra-Gen is anticipating construction of the wind turbines and associated roads and infrastructure as early as 2020.

<u>Liquefied Natural Gas Terminals and Pipelines</u>**.** Three liquefied natural gas (LNG) terminals were being proposed in Oregon, each with associated pipelines through the inland range of the murrelet, during our last 5-year status review. Currently only one LNG project is still being proposed in Oregon, the other projects have been withdrawn, and no new LNG projects have been proposed. No such installations are currently proposed in California or Washington.

A new iteration of the Jordan Cove Energy Project in Coos Bay, Oregon, was initiated on September 21, 2017, after previously being denied by FERC. The project involves the construction of the

approximately 235 mi (378 km) Pacific Connector Gas Pipeline from Coos Bay to Malin in the Klamath Basin. The pipeline, if approved, will traverse the murrelet inland range, potentially resulting in the loss or fragmentation of some current and future murrelet nesting habitat. The pipeline route is not final yet, so exact amounts of habitat affected are not available.

Powerlines. In 2014 and 2015, a total of three marbled murrelet adults were incidentally found and collected in Humboldt County, California, with injuries consistent with collisions with overhead powerlines, as follows. In July 2014, a live adult murrelet (sex unknown) was found near the town of Orick, adjacent to Redwood Creek and an overhead powerline. The bird was euthanized the following day at a wildlife care facility, and necropsy results noted slight bruising on the neck and lacerations on one wing (Service files). In spring 2015, two dead marbled murrelets were found and collected at the southern end of Elk Prairie, Prairie Creek Redwoods State Park. The carcasses were found 3 weeks apart (a male on April 24 and a female on May 12) with similar injuries; each bird missing a right wing, which appeared to have been sheared off. Both carcasses were found very near a power utility line at the edge of nesting habitat (old-growth redwood forest), which suggests these may have been nesting birds that collided with a power line wire while flying to or from a nest. To our knowledge, power line collision has not been previously documented as a threat or cause of mortality for marbled murrelets. The Service sent both of these specimens to the USGS's National Wildlife Health Center (NWHC, Madison, Wisconsin) to evaluate whether other factors may have contributed to the deaths of these birds. The NWHC confirmed that collision with the power line was the most likely explanation as the cause of death for each bird, and that no diseases or other factors (*e.g.*, weakened physical condition due to starvation) appeared to contribute to their deaths (NWHC 2015).

A preliminary study was undertaken in the Duckabush Valley, Washington, for a few days in June 2010 that combined radar and visual observations to detect collisions with powerlines. Of the targets (presumably murrelets) that flew in the space where collision was possible, none were observed to collide with the powerlines or support structures (Lewis County Community Development 2010, p. 2 Attachment B).

Summary - Energy Development, Production, and Associated Infrastructure. Based on the latest information, we find that murrelets may be highly vulnerable in localized areas from energy development and production. This includes direct mortality from strikes, as well as loss of habitat and fragmentation, and impacts to reproductive success through changes in prey base, marine habitat, and disturbance.

Disturbance in the Marine Environment

Subsequent to McShane *et al*. (2004), the Service began considering impacts to murrelets from activities in the marine environment. These impacts could be experienced underwater, on the surface, or both and could result in mortality, injury, or disturbance. There is little empirical data regarding the probability of lethal responses, sublethal injuries, physiological responses (particularly stress responses), behavioral responses, or social responses by murrelets to human activities in the marine environment. However, for the Service's analyses, we reviewed the best scientific and commercial data on the probable responses of other species and then used this information to make inferences about the probable responses of murrelets. Based on best available information, we consider murrelets

to be potentially affected by exposure to elevated sound levels (both underwater and above water), boat traffic, and reductions of prey or prey habitat.

Most of these impacts occur in Puget Sound and Grays Harbor in Washington State. Similar activities either do not take place along the outer coasts of Washington, Oregon, and California or have not yet been analyzed. For example, boat traffic is known to occur all along the coast where murrelets occur, but the impacts have not yet been analyzed.

Exposure to Elevated Sound Levels**.** High underwater sound pressure levels (SPLs) are known to have negative neurological, physiological, and behavioral effects on a wide variety of vertebrate species including fishes, mammals, and birds (Cudahy and Ellison 2002; Fothergill *et al*. 2001; Halvorsen *et al*. 2012; Ryals *et al*. 1999; Steevens *et al*. 1999; U.S. Department of Defense 2002; Yelverton and Richmond 1981; Yelverton *et al*. 1973). However, direct evidence regarding the effects of high underwater SPLs on murrelets is not available. In 2011 and 2012, the Service convened a series of multi-disciplinary science panels to evaluate evidence regarding the effects of elevated SPLs on other species and make recommendations about how to interpret that evidence to understand effects to murrelets (Science Applications International Corporation [SAIC] 2011; SAIC 2012).

Exposure to elevated SPLs from sources such as underwater explosions, pile driving, or sonar can cause auditory injury. Exposure to loud sounds can cause "threshold shift" (TS), which is a decrease in hearing capability at specific frequencies, which may last hours or days, or may be permanent. The onset and degree of TS resulting from noise exposure varies among species. In fish, hearing loss may result in only a short-term fatiguing of the auditory system, without cellular damage; this is often called "temporary threshold shift" and categorized as non-injurious (Popper *et al*. 2005). In birds, however, exposure to SPLs resulting in TS has been shown to lead to inner ear injuries resulting in hair cell loss, which may be reversible in some cases and permanent in others (Ryals *et al*. 1999). Hearing damage is expected to significantly impair a murrelet's ability to carry out essential life functions such as avoiding predators or communicating with other murrelets during foraging or breeding. This type of injury is expected when murrelets are exposed to cumulative sound exposure level (SEL) of 202 decibels (dB re 1 μPa^2-sec, the standard unit of underwater SPLs) (SAIC 2011, p. 20).

Exposure to elevated SPLs may also result in another kind of injury, called barotrauma, which results from changes in pressure within the air-filled spaces inside of an animal. Barotrauma may be mild or severe, ranging from bruising to hemorrhage of internal organs (Halvorsen *et al*. 2012; Hastings and Popper 2005; Turnpenny and Nedwell 1994; Yelverton and Richmond 1981; Yelverton *et al*. 1973; Yelverton *et al*. 1975). Sublethal barotrauma injuries that do not immediately result in mortality could include internal organ damage, loss of vision, or hearing loss, all of which can significantly impair an individual's ability to carry out essential life functions such as flying, diving, breeding, feeding, and predator avoidance. Activities that we consider to potentially result in these effects include, but are not limited to, underwater detonations and pile driving. This type of injury is expected when murrelets are exposed to cumulative SEL of 208 dB re 1 μPa^2-sec (SAIC 2011, p. 22).

As in the terrestrial environment, murrelets may be exposed and respond to noise in the marine environment, including both underwater and in-air noise. In the marine environment, in-air noise in particular is expected to interfere with murrelet foraging when the sound overlaps in frequency with

the frequency of murrelet calls, and is much louder than background noise levels. This situation can lead to "masking," in which murrelets cannot hear one another's calls above the noise. Murrelets frequently forage in pairs, perhaps engaging in cooperative foraging, and often call upon re-surfacing, apparently to assist in relocating one another. Activities that may lead to significant masking in the marine environment include pile driving and naval aircraft overflights.

While there are no known studies or data available that evaluate the behavioral response of murrelets (or other alcids) to noise in the marine environment, behaviors that we believe could indicate disturbance of murrelets in the marine environment include disrupted or aborted feeding attempts; multiple delayed feeding attempts within a single day or across multiple days, multiple interrupted resting attempts, and precluded access to suitable foraging habitat. Since our 2009 5-year status review, the Service has exempted incidental take in the form of harm of 176 murrelets and all murrelets associated with 194,342 ac (78,648 ha) of marine habitat, primarily in Conservation Zones 1 and 2. In addition, the Service has authorized incidental take in the form of harassment of 65 murrelets and all murrelets associated with 64,292 ac (26,158 ha) of marine habitat within Conservation Zones 1 and 2. In some instances multiple years of harm and harassment occur, depending upon the duration of the project.

Boat Traffic**.** Our 2009 5-year status review presented information regarding murrelet behavioral response to boat traffic, which can interfere with foraging and cause energetic costs, especially to juveniles. Research on this topic has continued since 2009, and offers further support to the conclusion that murrelets are vulnerable to disturbance by traffic in the marine environment.

As discussed in our 2009 5-year status review, murrelets often fly or dive in response to boats. Whether and how murrelets respond to boats depends on a number of factors including the size, distance, and speed of the boat, boat density, and time of year (Agness *et al*. 2008, p. 349; Bellefleur *et al*. 2009, pp. 531, 536; Hentze 2006, p. 12; Strachan *et al*. 1995, p. 252; Strong 1995, p. 102). In Glacier Bay, Alaska, when a large cruise ship passes within 2,789 feet (850 meters) of murrelets (including marbled murrelets and the closely related Kittlitz's murrelets [*Brachyramphus brevirostris*]), the vast majority of the birds fly or dive, with a slightly higher probability of flying than diving (Marcella *et al*. 2017, p. 13). Murrelets in Glacier Bay become more sensitive to cruise ship traffic as the season progresses, showing no evidence of habituation (Marcella *et al*. 2017, p. 13). This result contrasts with earlier reports showing that marbled murrelets in areas with regular boat traffic, like the San Juan Islands, Washington, in Conservation Zone 1, are reported to respond to vessels at much shorter distances, which may be a sign of habituation (Bellefleur *et al*. 2009, p. 536; Strachan *et al*. 1995, p. 252). However, the shorter distance for response may simply be due to the smaller size of boats used in the previous studies, or could indicate that murrelets are more committed to foraging in these areas in spite of the boat traffic (Marcella 2014, pp. 41-42).

As discussed in our 2009 5-year status review, vessel disturbance is expected to have energetic consequence for murrelets. These costs come from reductions in foraging and increases in energetically costly flight and diving behaviors (Agness *et al*. 2008; Bellefleur *et al*. 2009; Korschgen *et al*. 1985; Pennycuik 1987; Schummer and Eddleman 2003). In addition, when vessels disturb a fish-holding murrelet, presumably a breeder preparing to fly inland to feed a nestling, the murrelet may drop or swallow the fish (Speckman *et al*. 2004, p. 33). It is not known whether a bird that swallows fish in response to disturbance subsequently forages more to obtain another fish for the

chick, incurring energetic costs to the adult, or simply forgoes a delivery of food, potentially leading to underfeeding of the chick.

A recent study of Kittlitz's murrelet reactions to boats illustrates some of the energetic consequences of vessel disturbance (Agness *et al*. 2013). Based on bird flight models and data regarding boat traffic and Kittlitz's murrelet response, the authors estimated that non-breeding Kittlitz's murrelets would spend 30 percent more energy on peak boat traffic days, and 50 percent more energy on some peak traffic days, all due to increases in flights in response to boat traffic (Agness *et al*. 2013, p. 16). Breeding murrelets, which are more likely to dive than fly, were estimated to spend only 10 percent more energy on some peak traffic days, but this estimate accounted only for additional costs from flying and not from diving (Agness *et al*. 2013, p. 16). Even without considering vessel disturbance, when rearing chicks, Kittlitz's murrelets must consume about two-thirds of their body weight in Pacific sand lance to maintain their typical metabolic rate, and even non-breeding adults must consume over one-third of their body weight in Pacific sand lance (Hatch 2011, pp. 75, 81). As a result, when energy expenditures are greater than average or when medium- to high-quality prey is unavailable, Kittlitz's murrelets may be unable to consume enough prey to meet their energy needs (Hatch 2011, pp. 87-88). Adding in the energetic costs of flight in response to boats, Agness *et al*. (2013, p. 189) estimated that Kittlitz's murrelets would need to consume 83 to 107 percent of their body weight in fish every day. Because the two species are very similar, Kittlitz's murrelet energetics offer a good proxy for marbled murrelet energetics.

The costs of additional diving in response to boats may also be considerable. For some seabirds, diving metabolic rates may be up to nine times higher than resting metabolic rates, though other seabirds may be able to spend only slightly more energy while diving than while resting (Ponganis 2016, p. 170). The thick-billed murre, another alcid species, triples its metabolic rate while diving (Croll *et al*. 1992, p. 351). Diving birds can use either aerobic or anaerobic metabolism to fuel their dives (Croll *et al*. 1992, p. 351; Butler and Jones 1997, p. 840; Jodice and Collopy 1999, p. 1,410). Anaerobic metabolism is less efficient, and therefore more energetically costly, than aerobic metabolism (Jodice and Collopy 1999, p. 1,410), and recovering from dives fueled by anaerobic metabolism requires longer rest time (Butler and Jones 1997, p. 879). Increased dive duration or shorter periods between individual dives may necessitate anaerobic metabolism, and longer periods between diving bouts may suggest that anaerobic metabolism has been in use (Jodice and Collopy 1999, pp. 1,412, 1,416). Although murrelets most likely use aerobic metabolism more often while foraging (Peery *et al*. 2009, p. 129), they may sometimes dive repeatedly in response to boats (Speckman *et al*. 2004, p. 33), potentially necessitating anaerobic metabolism. If marbled murrelets use anaerobic metabolism to fuel their disturbance response dives, birds will have to compensate for the energy lost to extra activity while also spending more time at the surface to recover from those anaerobic dives.

These energetic expenses could have significant impacts on marbled murrelet fitness, especially during times of high energetic expenditure, such as breeding or winter survival, or at times of low forage abundance resulting from poor ocean conditions (Agness *et al*. 2013, p. 19; Morgan and Bishop 2011, pp. 7, 16; Ronconi and Burger 2008, p. 256). Murrelets generally spend less than 25 percent of daylight hours foraging underwater, which indicates some potential for flexibility in their activity budgets (Henkel *et al*. 2004, p. 11; Pontius and Kirchoff 2009, p. 154). Despite this apparent flexibility, in periods of low prey availability, many murrelets are unable to meet the energetic

demands of successful breeding (Peery *et al*. 2004, pp. 1,094-1,095; Ronconi and Burger 2008, pp. 252, 256), and additional energy expenditure on disturbance responses can only increase the energy deficit birds experience in these conditions. Marbled murrelet energy expenditures are especially high when they must fly long distances inland to reach nesting sites, or long distances at sea to reach suitable foraging areas, or both, as is frequently the case in Washington (Conservation Zones 1 and 2) (Hull *et al*. 2001, p. 1040; Lorenz *et al*. 2017, p. 313).

Marbled murrelet response to vessel traffic likely results in more than a momentary move away from the immediate area of the vessel and the energetic consequences of that movement. Fewer murrelets were observed along transects in Alaska that had higher numbers of boats on or near the transect (Kuletz 1996, p. 776). Research on Kittlitz's murrelets also showed that vessel activity caused declines in density that lasted at least 30 minutes, but no longer than a day (Agness *et al*. 2008, p. 349). In Conservation Zone 1, murrelet densities were higher in areas with lower marine human footprint; only the proximity to nesting habitat is more influential (Raphael *et al*. 2016b, p. 109). Nonetheless, murrelets can be found in areas with relatively high boat densities, such as the San Juan Islands in Conservation Zone 1 (Strachan *et al*. 1995, p. 252). It is not clear whether their presence in these areas represents true habituation, or simply indicates dependence on foraging habitat there (Stankowich and Blumstein 2005, p. 2,631). If the quality of foraging habitat is higher in the San Juan Islands than in surrounding areas – a conjecture supported by this area's disproportionate use by radio-tagged murrelets (Lorenz *et al*. 2017, p. 312) – murrelets could be continuing to forage there by necessity, despite the stress associated with boat traffic.

If murrelets must continue to forage in areas with high boat densities, they could be vulnerable to a form of physiological stress called allostatic overload, which involves the alteration of hormonal signaling. This type of stress response has been shown to occur and in some cases to have fitness consequences for other avian species subjected to inescapable anthropogenic stressors (Arlettaz *et al*. 2015, p. 1,208; Bonier *et al*. 2009, p. 635; Busch and Hayward 2009, pp. 2,847-2,850; Kleist *et al*. 2018, E650-E653). The study of how allostatic loading affects fitness is a developing field, and there is debate among scientists regarding the most useful methods for collecting data and making inferences related to these stress responses, but numerous studies have been conducted recently regarding stress hormones and seabirds (Hansen 2017, p. 44). No information is available specifically addressing murrelet vulnerability to allostatic overload.

As was the case in 2009, research regarding disturbance in the marine environment has not been empirically correlated with effects on reproductive success or Conservation Zone populations, although it has now been correlated with distribution within Conservation Zone 1 (Raphael *et al*. 2016b, p. 109). This and other recent studies continue to provide evidence that within areas with high boat density or large or fast-moving boats, murrelets are more likely to move away, possibly to a less desirable foraging location. Within the three-state area, there are areas (such as Puget Sound and Monterey Bay) where murrelets co-occur with substantial boat traffic, recreational and commercial. Recent studies have also provided additional evidence that within such areas, boat traffic may be causing energetic impacts on murrelets that they are unable to compensate for, especially during the pre-breeding and breeding seasons.

Disturbance in the Terrestrial Environment:

In our 2009 5-year status review, we concluded that human presence was tied to increased predation in nesting habitat, but further research throughout the range was necessary to determine the severity of disturbance on murrelets. For further information regarding predation, see the "Predation" section above.

Since the analysis for our 2009 5-year status review, no new studies have been conducted that address the impacts to murrelets from disturbance caused by humans. One study, which was partially reported on in our 2009 5-year status review and has since been published, determined that in Washington, murrelets preferred areas close to shore but selected areas further from shore where the human terrestrial footprint (human populations density, light pollution, and transportation infrastructure) was high (Lorenz *et al*. 2016, p. 10). A potential new source of disturbance is the recreational use of personal un-manned aerial vehicles (drones). While as yet little literature is available on the impacts to wildlife from this newly-emerging technology, one study looked at three bird species and documented some reactions by all three species (Vas *et al*. 2015, pp. 2-3). Further work on the potential impacts to murrelets is needed if the use of this technology continues to expand.

Since the analysis for our 2009 5-year status review, the Service has authorized incidental take in the form of harm and harassment of murrelets due to noise-related effects associated with activities in Washington, Oregon, and California. The take authorized by the Service is summarized by Conservation Zone in Table 6. The total acres of take in the form of harassment represent effects associated with both individual site-specific projects and large-scale programmatic consultations (*e.g.*, multiple activities at the scale of an entire National Forest or National Park). While the cumulative total of habitat exposed is substantial, most of the acres of nesting habitat potentially exposed to disturbance effects are associated with existing roads, trails, and campgrounds, and in some instances may represent the same habitat areas exposed to disturbance effects year after year.

Table 6. Summary of incidental take of marbled murrelets authorized by the Service since 2008.

State	Conservation Zone	Individual Murrelets		Acres of Suitable Habitat	
		Harm	Harass	Harm	Harass
WA	1 Puget Sound	35	167	905	66,765
WA	2 Western Washington	0	50	881	54,239
WA	7 marine - outside CZ	2	0	0	6,840
OR	3 Oregon Coast Range	0	188	0	634
OR	4 Siskiyou Coast Range	0	30	648	7,267
CA	4 Siskiyou Coast Range	0	1	0	33,684
CA	5	0	0	0	0
CA	6 Santa Cruz	0	0	0	0
CA	9 Outside CZ in CA	0	0	0	1,176
Totals		**37**	**436**	**2,434**	**170,605**

Marine and Terrestrial Disturbance Summary. The potential for mortality, injury, and disturbance due to exposure to elevated sound levels in the marine environment, underwater or in the air, continues to be a threat. While there are no known studies or data available that evaluate the behavioral response of murrelets (or other alcids) to noise in the marine environment, behaviors that we believe could indicate disturbance of murrelets in the marine environment include disrupted or aborted feeding attempts; multiple delayed feeding attempts within a single day or across multiple days, multiple interrupted resting attempts, and precluded access to suitable foraging habitat. New information regarding disturbances from boat traffic corroborates the information provided in our previous 5-year status reviews. These impacts can occur wherever murrelets are found, but are more concentrated in areas of higher human presence, such as Puget Sound and Monterey Bay. As the human population continues to grow and shipping traffic increases in the coastal areas used by murrelets (See Factor A), the foraging areas used by murrelets may become further restricted. There have been no additional regulations or changes to regulations to minimize impacts, nor have recovery actions reduced the impacts.

Our 2004 5-year status review did not address disturbance in the terrestrial environment; however, McShane *et al*. (2004) indicated noise disturbance may affect murrelet fitness and reproductive success, but further research was needed. In our 2009 5-year status review, we concluded that human presence was tied to increased predation in nesting habitat, but further research throughout the range was necessary to determine the severity of disturbance on murrelets. No new studies have been conducted that address the impacts to murrelets from disturbance caused by humans; however, one study negatively correlates use of the marine environment to higher human use in terrestrial areas. Further research throughout the range is necessary to determine the severity of disturbance on murrelets.

Other Natural or Manmade Factors Summary. Since the analyses for our 2004 and 2009 5-year status reviews, we have determined the scope, severity and magnitude of the threat to murrelets from oil spills has not changed; however, the magnitude of this threat in Washington may be increasing. The scope and severity of the threat to murrelets from bycatch in gill nets, purse seines, and recreational fisheries has not changed; however, bycatch can occur wherever these fisheries take place in murrelet marine habitat. New information indicates murrelets may be at risk of mortality in some trawl gear. The scope and severity of the threat to murrelets of entanglement in derelict fishing gear has not changed. The magnitude of this threat may have decreased due to a significant gear removal effort and gear loss reporting requirements in Puget Sound. However, gear will continue to accumulate and entanglement remains a threat. The scope of the threat to murrelets from energy development, production, and associated infrastructure has not changed, but may be increased if proposed projects are installed in the marine and terrestrial habitats used by murrelets and the severity and magnitude of these threats may be high where they occur. The scope and severity of disturbances in the marine and terrestrial environments remains unchanged or unknown, but is expected to be high in areas with concentrated human use.

2.4 Synthesis

The murrelet is a small seabird of the family Alcidae. Murrelets spend most of their lives in the marine environment where they forage in near-shore areas and consume a diversity of prey species, including small fish and invertebrates. In their terrestrial environment, the presence of platforms (large branches or deformities) used for nesting is the most important characteristic of their nesting habitat. Murrelet habitat use during the breeding season is positively associated with the presence and abundance of mature and old-growth forests, large core areas of old-growth, low amounts of edge habitat, reduced habitat fragmentation, proximity to the marine environment, and forests that are increasing in stand age and height.

The murrelet population estimate for Conservation Zones 1 through 6 was approximately 23,260 birds in 2016 (most recent year with data for all zones). This estimate is higher than the 2008 estimate (18,000 birds) available for our 2009 5-year status review, and slightly lower than the estimate (24,400 birds) in our 2004 5-year status review. While there continues to be significant declines in the murrelet population in Washington State, there does not appear to be a trend (negative or positive) at the listed-range scale.

Since our 2009 5-year status review, there is little or no additional data to suggest there has been an improvement in nesting success in Washington, Oregon, and California. New information indicates that a greater amount of nesting habitat occurs on non-federal lands than previously thought and the habitat on those lands continues to be harvested, while remaining habitat on all landownerships is fragmented and subject to human disturbance and predation by corvids. Climate change is likely to exacerbate the impacts of continued nesting habitat loss and fragmentation. In particular, anthropogenic climate change has the potential to substantially affect the coast redwood forests in California and Oregon by the late 21st century, in which this forest type is projected to experience a reduction of nearly one fourth of its range. Therefore, the available new information suggests the level of threats in the terrestrial environment is not reduced and may be greater than documented in previous reviews.

New information indicates threats in their marine environment continue to impact murrelets and some sources, such as HABs, prey availability, and oil spills may become more severe in the foreseeable future. While some changes in fishing practices may benefit murrelets by reducing bycatch and enabling prey species to rebound, climate change is projected to result in changes throughout the marine food web, further reducing prey quality and quantity. Murrelets may not be able to overcome the changes in their marine environment as there is already a disconnection of nesting habitat from foraging areas that is contributing to sustained low recruitment of new adults into the population.

The recovery criteria for this species have not been met. The recovery plan indicated that the recovery criteria could be updated when additional information was available. This information included murrelet population size, trends, and demographic goals for each Conservation Zone; the quantity, quality, and distribution of nesting and marine habitats and prey populations within each zone necessary to achieve recovery goals; and detailed studies of the survivorship and productivity of murrelets. While data collection and research has been ongoing in these areas, it needs to continue, and further information is still needed for marine habitats and prey populations, as well as survivorship and productivity. When available, this information should be used to revise the recovery criteria.

Based on the evaluation of the threats and the murrelet's population status and trends we have determined that the murrelet should remain listed as threatened. However, we remain concerned about the apparent substantial downward trend of the population in Washington and the species' continued vulnerability from a broad range of threats across its entire listed range. Although some threats have been reduced, most continue unabated and new threats now strain the ability of the murrelet to successfully reproduce. In summary, if reproductive success continues to be too low to sustain the population, the observed population trends continue to decline significantly, and manmade and natural threats continue at current or increased levels, a change in listing status to endangered may be warranted in the future.

3.0 RESULTS

3.1 Recommended Classification:

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
_X_ No change is needed

3.2 New Recovery Priority Number: No change

Brief Rationale: None needed.

3.3 Listing and Reclassification Priority Number.

Reclassification (from Threatened to Endangered) Priority Number: ____
Reclassification (from Endangered to Threatened) Priority Number: ____
Delisting (regardless of current classification) Priority Number: ____

Brief Rationale: None needed.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

- Because the recovery plan is greater than 10 years old and information regarding threats and population has changed, a revision of the recovery plan is warranted.
- Information regarding marine threats, and general life history including reproduction is lacking, therefore research on these topics is needed.
- Further examine marbled murrelet population trends in the coastal redwood zone, given the magnitude and imminence of threats

5.0 REFERENCES –Follows Signature Page

U.S. FISH AND WILDLIFE SERVICE

5-YEAR REVIEW OF MARBLED MURRELET *(Brachyramphus marmoratus)*

Current Classification: Threatened Species

Recommendation resulting from the 5-Year Review:

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
_X_ No change needed

Appropriate Listing/Reclassification Priority Number, if applicable: N/A

Review Conducted By: Washington Fish and Wildlife Office staff in collaboration with staff from the Oregon Fish and Wildlife Office, Arcata Fish and Wildlife Office, and the Ventura Fish and Wildlife Office.

REGIONAL OFFICE APPROVAL:

Date 5/31/2019

Assistant Regional Director, Ecological Services

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APPENDIX A

Climate change analysis excerpt from Biological Opinion on the Puget Sound Fisheries 2017-2037. U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office, Lacey, Washington.

Global Climate Change

Our analyses under the Endangered Species Act include consideration of ongoing and projected changes in climate. The term "climate" refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2014a, pp. 119-120). The term "climate change" thus refers to a change in the mean or variability of one or more measures of climate (*e.g.*, temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2014a, p. 119).

Measurements spanning several decades demonstrate that changes in climate are occurring, and that the rate of change since the 1950s is unprecedented (IPCC 2014a, p. 40). Examples include warming of the atmosphere and the oceans, melting of glaciers and sea ice, and substantial increases in precipitation in some regions of the world with decreases in other regions (*e.g.*, IPCC 2014a, pp. 40-42; Solomon *et al*. 2007, pp. 35–54, 82–85). Analyses presented by the IPCC show that most of the observed increase in global average temperature since the mid-20th century cannot be explained by natural variability in climate, and is "extremely likely" (defined by the IPCC as 95 percent or higher probability) due to the observed increase in greenhouse gas (GHG) concentrations in the atmosphere as a result of human activities, particularly carbon dioxide emissions from use of fossil fuels (IPCC 2014a, pp. 47-49; Solomon *et al*. 2007, pp. 21–35). Further confirmation of the role of GHGs comes from analyses by Huber and Knutti (2011, p. 4), who concluded it is extremely likely that approximately 75 percent of global warming since 1950 is caused by human activities.

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of GHG emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions (*e.g.*, Meehl *et al*. 2007, entire; Ganguly *et al*. 2009, pp. 11555, 15558; Prinn *et al*. 2011, pp. 527, 529; van Vuuren *et al*. 2014, entire). All combinations of models and emissions scenarios yield very similar projections of increases in the most common measure of climate change, average global surface temperature (commonly known as global warming), until about 2035. After 2035, model projections diverge depending on initial assumptions about greenhouse gas emissions (Kirtman *et al*. 2013, pp. 978-980, 1004-1012; Collins *et al*. 2013, p. 1093). Although projections of the magnitude and rate of warming differ after about 2035, the overall trajectory of all the projections is one of increased global warming through the end of this century, even for the projections based on scenarios that assume that GHG emissions will stabilize or decline. Thus, there is strong scientific support for projections that warming will continue through the 21st century, and that the magnitude and rate of change will be influenced substantially by the amount of GHG emissions (IPCC 2014a, pp. 56-63; Meehl *et al*. 2007, pp. 760–764 and 797–811; Ganguly *et al*. 2009, pp. 15555–15558; Prinn *et al*. 2011, pp. 527, 529). Other changes in the global climate are likely to include longer and more frequent heat waves, extreme precipitation events over mid-latitude land masses, intensified precipitation variability related to El Niño-Southern Oscillation (ENSO), reductions in spring snow

cover and summer sea ice, sea level rise, ocean acidification, and decreases in the dissolved oxygen content of the ocean (IPCC 2014a, pp. 60-62).

Various changes in climate may have direct or indirect effects on listed species. These effects may be positive, neutral, or negative, and they may change over time. Identifying likely effects involves aspects of climate change vulnerability analysis. Vulnerability refers to the degree to which a species (or system) is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the type, magnitude, and rate of climate change and variation to which a species is exposed, its sensitivity, and its adaptive capacity (IPCC 2007, p. 89; see also Glick *et al*. 2011, pp. 19–22). There is no single method for conducting such analyses that applies to all situations (Glick *et al*. 2011, p. 3). We use our expert judgment and appropriate analytical approaches to weigh relevant information, including uncertainty, in our consideration of various aspects of climate change. In general, many species are projected to face increased extinction risk as the climate changes in the future, especially when climate changes are combined with other factors like habitat modification; but this risk can be reduced through management actions, including those that reduce the impacts of non-climate change stressors (IPCC 2014b, pp. 14-15).

Regional and Local Climate Projections

Global climate projections are informative, and in some cases, the only or the best scientific information available for us to use. However, projected changes in climate and related impacts can vary substantially across and within different regions of the world (*e.g.*, IPCC 2007, pp. 8-12). We therefore use "downscaled" projections when they are available, and have been developed through appropriate scientific procedures, because such projections provide higher resolution information that is more relevant to spatial scales used for analyses of a given species (see Glick *et al.* 2011, pp. 58–61, for a discussion of downscaling). With regard to our analysis of the action area, downscaled projections are available in some cases. The spatial scales addressed by the climate studies reviewed here range from the entire Northeast Pacific to specific areas of Puget Sound.

Many of the reports discussing downscaled or regional projections of climate change for the action area use a suite of climate models along with one or more scenarios for anthropogenic carbon emissions over time. The exact suite of models and scenarios varies among reports, but the climate models generally encompass a range of sensitivities to climate scenarios, and the emissions scenarios typically include a lower-emissions scenario and a higher-emissions scenario. A few studies report results of projections for the 2030s, within the timeframe of the proposed action. However, most are reported in terms of a range of potential outcomes by the mid- or late 21st century, outside of the timeframe of the proposed action. These projections indicate the direction of various environmental changes (*i.e.*, increases vs. decreases), but are not informative about the magnitude of the expected change within the timeframe of the proposed action, because some changes may accelerate over time, while others may approach a new equilibrium during the timeframe of the projections.

Projected Changes in the Physical Environment

Projected changes to the climate within the action area include air and sea surface temperature increases, changes in precipitation seasonality, and increases in the frequency and intensity of extreme

rainfall events (Mauger *et al*. 2015, pp. 2-1 – 2-18). Air temperature warming is already underway, and is expected to continue, with the mid-21st century projected to be approximately 4 to 6 ºF (2.2 to 3.3 ºC) warmer than the late 20th century (Mauger *et al*. 2015, p. 2-5). Similarly, sea surface temperatures are already rising and the warming is expected to continue, with an increase of 2.2 °F (1.2 °C) projected for Puget Sound between the late 20th century and mid-21st century (Mote and Salathe 2010, p. 16). For the Strait of Georgia, projections suggest an increase of between 2.7 and 5.4 °F (1.5-3 °C) by the end of the 21st century (Riche *et al*. 2014, p. 41). Summer precipitation is expected to decrease by 22 percent (averaged across models, relative to the late 20th century) by the mid-21st century, while winter precipitation is expected to increase (Mauger *et al*. 2015, p. 2-7). In particular, heavy rainfall events are projected to occur approximately three times as frequently and to be about 19 percent more intense, on average, in the late 21st century than they were during the late 20th century (Warner *et al*. 2015, pp. 123-124).

The warming trend and trends in rainfall may be masked by naturally-occurring climate cycles, such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Reeder *et al*. 2013, p. 76). These oscillations have similar effects in the Pacific Northwest, with relatively warm coastal water and warm, dry winter conditions during a "positive" warm phase, followed by cooler coastal water and cooler, wetter winter conditions during the cool "negative" phase (Moore *et al*. 2008, p. 1747). They differ in that one phase of the ENSO cycle typically lasts between 6 and 18 months (one to three years for a full cycle), whereas, during the 20th century, each phase of the PDO cycle lasted approximately 20 to 30 years (approximately 40 to 60 years for a full cycle) (Mantua and Hare 2002, p. 36). Some studies break the PDO into two components, one with a full cycle length between 16 and 20 years and the other with a 50 to 70 year period, with the longer component referred to as the Pacific Multidecadal Oscillation (PMO) (Steinman *et al*. 2015, p. 988). Another recent study has identified a 60-year cycle separate from the longer-term component of the PDO, also referring to this as the PMO (Chen *et al*. 2016, p. 319). An additional pattern, the North Pacific Gyre Oscillation, is associated with changes in the alongshore winds that drive upwelling, and appears to complete approximately one cycle per decade (Di Lorenzo *et al*. 2008, pp. 2-3).

The overall warming projections described above for the action area will be superimposed over the natural climate oscillations. The climate models used to project future trends account for naturally occurring cycles (IPCC 2014a, p. 56). Therefore, the projected trend combined with the existing cycles mean that temperatures during a cool phase will be less cool than they would be without climate change, and warm phases will be warmer. During the winter of 2014-2015, the climate shifted from a negative cool phase of the PDO to a positive warm phase (Peterson *et al*. 2016, p. 46). Additionally, one study predicts that the PMO will enter a positive warm phase around the year 2025 (Chen *et al*. 2016, p. 322). The phases of these long-term climate cycles in addition to the projected warming trend imply that we should expect sea surface temperatures during the period from 2017 through 2037 to be especially warm. However, climate change may also alter the patterns of these oscillations, for example, by shortening the cycle length of the PDO (Zhang and Delworth 2016, pp. 6007-6008).-. Many studies of climate effects to marine species and ecosystems use indices of these climate oscillations, rather than individual climate variables such as sea surface temperature, as their measures of the climatic state (*e.g.*, Becker and Beissenger 2006, p. 473). Therefore, if climate factors that covary with a given oscillation become decoupled, the relationships inferred from these studies may no longer be valid in the future.

These changes in temperature and the seasonality of precipitation affect the freshwater inflows to Puget Sound. Spring and summer freshwater inflows are expected to be warmer and reduced in volume, whereas winter freshwater inflows are expected to increase (Lee and Hamlet 2011, p. 110; Mauger *et al*. 2015, p. 3-8; Moore *et al*. 2015, p. 6; Mote *et al*. 2003, p. 56). Many watersheds draining to Puget Sound have historically been fed by a mix of rain and snowmelt, but are expected to be increasingly dominated by rainfall, which will cause the timing of peak flows to shift from spring to winter (Elsner *et al*. 2010, pp. 248-249; Hamlet *et al*. 2001, pp. 9-11; Hamlet *et al*. 2013, pp. 401-404; Mauger *et al*. 2015, pp. 3-4 – 3-5). With winter warming and increases in heavy rainfall events, flooding has increased, and this increase is expected to continue (Hamlet and Lettenmaier 2007, pp. 25-16; Lee and Hamlet 2011, p. 113; Mauger *et al*. 2015, pp. 3-6 – 3-7). Increased winter freshwater inflows, in combination with melting glaciers, are expected to bring increased sediments to Puget Sound; however, it is uncertain whether these sediments are more likely to enter the Sound or to be deposited in estuaries (Czuba *et al*. 2011, p. 2; Lee and Hamlet 2011, pp. 129-134; Mauger *et al*. 2015, pp. 5-7 – 5-10).

These changes in seasonal freshwater inflows are expected to alter water circulation and stratification within the action area, and to affect the rate and timing of exchange of waters through the Strait of Juan de Fuca between the action area and the North Pacific Ocean (Babson *et al*. 2006, pp. 29-30; MacReady and Banas 2016, p. 13; Mauger *et al*. 2015, p. 6-2, Riche *et al*. 2014, pp. 37-39, 44-45, 49-50). This exchange occurs in two layers, with fresh water at the surface flowing toward the ocean, and denser, saltier ocean waters flowing from the ocean at greater depths (Babson *et al*. 2006, p. 30). With the projected changes in timing of freshwater inflows, the rate of exchange is expected to increase during winter and decrease during summer (Mauger *et al*. 2015, pp. 6-2 – 6-3). The effect of changes in freshwater inflow on stratification is likely to vary by location within the action area, with greater potential for effect in, for example, Budd Inlet and Commencement Bay than in well-mixed channels like Admiralty Inlet and Dana Passage (Newton *et al*. 2003, p. 721).

If changes in upwelling occur along the outer coast of Washington, these changes will also affect the interchange of waters through the Strait of Juan de Fuca (Babson *et al*. 2006, p. 30; Newton *et al*. 2003, p. 718). It has been hypothesized that as climate change accentuates greater warming of air over land areas than of air over the ocean, alongshore winds will intensify, which will lead to an increase in upwelling (Bakun 1990, entire). Historical records show that these winds have intensified over the past several decades (Bylhower *et al*. 2013, p. 2572; Sydeman *et al*. 2014, p. 78-79). Projections for future changes in upwelling offer some support for this hypothesis, but are more equivocal (Foreman *et al*. 2011, p. 10; Moore *et al*. 2015, p. 5; Mote and Mantua 2002, p. 53-3; Rykaczewski *et al*. 2015, p. 6426; Wang *et al*. 2010, pp. 263, 265). Some studies indicate a trend toward a later, shorter (but in some cases, more intense) upwelling season (Bograd *et al*. 2009, p. 2; Bylhower *et al*. 2013, p. 2572; Foreman *et al*. 2011, p. 8). Within the action area, upwelling leads to an influx of waters rich in nutrients such as nitrates, phosphates, and silicates, but that are also acidic (due to high dissolved carbon dioxide content) and low in dissolved oxygen (Johannessen *et al*. 2014, p. 220; Krembs 2012, p. 109; Riche *et al*. 2014, pp. 45-46, 48; Sutton *et al*. 2013, p. 7191).

Regardless of potential changes in the timing or intensity of upwelling, the dissolved oxygen content of the waters in the action area is expected to decrease. The solubility of oxygen in water decreases with increasing temperature, so as the climate becomes warmer, the dissolved oxygen content of the marine environment is expected to decrease (IPCC 2014a, p. 62; Mauger *et al*. 2015, pp. 7-3, 7-8).

The oxygen content in the North Pacific Ocean just outside of the action area has declined significantly since measurements began in 1987 (Whitney *et al*. 2007, p. 184), and this decline is projected to continue (Whitney *et al*. 2013, p. 2204). As these waters flow into the action area, they drive down the oxygen content of action area waters, although there is considerable variation over time, space, and depth, due to patterns of circulation and mixing within the action area (Bassin *et al*. 2011, Section 3.2; Johannessen *et al*. 2014, pp. 214-220). For example, Hood Canal is particularly susceptible to hypoxic conditions, partly because circulation of water through Hood Canal is slow (Babson *et al*. 2006, p. 30), whereas the vigorous tidal currents in Haro Strait allow for the mixing of oxygen-rich surface water throughout the water column (Johannessen *et al*. 2014, p. 216). Increased stratification, as is expected during winter with the larger freshwater inflows, can lead to hypoxic conditions in deeper waters (Mauger *et al*. 2015, p. 6-3; Whitney *et al*. 2007, p. 189). On the other hand, weaker stratification, as expected in the summer, may decrease the probability of low oxygen due to greater mixing, or increase the probability of low oxygen due to slower circulation (Newton *et al*. 2003, p. 725). If upwelling does increase in intensity, the effect would likely be to further reduce the oxygen content of action area waters, but these changes are not likely to be consistent throughout the action area or throughout the year. Changes in oxygen content, or in the timing of low-oxygen periods, may have important biological consequences (see below). Oxygen content also responds to biological activity. In addition to climate change-induced effects, some locations will likely experience reductions in oxygen content stemming from biological responses to eutrophication in areas that receive (and do not quickly flush) nutrient inputs from human activities (Cope and Roberts 2013, pp. 20-23; Mackas and Harrison 1997, p. 14; Roberts *et al*. 2014, pp. 103-104, 108; Sutton *et al*. 2013, p. 7191).

Similarly, acidification of waters in the action area is expected to increase, regardless of any changes in upwelling. Acidification results when carbon dioxide in the air dissolves in surface water, and is the direct consequence of increasing carbon dioxide emissions (IPCC 2014a, pp. 41, 49). Marine waters are projected to continue becoming more acidic, although if carbon emissions are stringently and immediately curtailed, this trend may reverse during the late 21st century (IPCC 2014a, pp. 8-9, 49). Both the surface and upwelled waters of North Pacific Ocean just outside of the action area have become more acidic due to carbon dioxide emissions (Feely *et al*. 2008, pp. 1491-1492, Murray *et al*. 2015, pp. 962-963), and this trend is expected to continue (Byrne *et al*. 2010, p. L02601; Feely *et al*. 2009, pp. 40-46). These waters contribute to acidification of the action area as they flow in through the Strait of Juan de Fuca (Feely *et al*. 2010, p. 446, Murray *et al*. 2015, p. 961), and any changes in upwelling intensity or seasonality would respectively increase acidification or change the timing of pH changes in the action area. It is unknown whether regional carbon dioxide emissions cause additional localized acidification within the action area (Newton *et al*. 2012, p. 36), but it is likely that other products of fossil fuel combustion, such as sulfuric acid, do contribute (Doney *et al*. 2007, pp. 14582-14583). Linked to reductions in dissolved oxygen (Riche *et al*. 2014, p. 49), acidification has important biological consequences (see below), and also responds to biological activity. For example, local areas of eutrophication are likely to experience additional acidification beyond that caused directly or indirectly by carbon dioxide emissions (Newton *et al*. 2012, pp. 32-33).

Sea level rise is also expected to affect the action area. Sea level rise is a consequence of the melting of glaciers and ice sheets combined with the expansion of water as it warms (IPCC 2014a, p. 42). At regional and local scales, numerous factors affect sea level rise, including ocean currents, wind patterns, and plate tectonics (Mauger *et al*. 2015, p. 4-1; Dalrymple 2012, p. 81; Petersen *et al*. 2015,

p. 21). Sea level is rising at most locations in the action area (Mauger *et al*. 2015, p. 4-2; Dalrymple 2012, pp. 79-81; Shaw *et al*. 1998, p. 37). These increases in sea level are likely to continue and may accelerate in the near future (Bromirski *et al*. 2011, pp. 9-10; Mauger *et al*. 2015, pp. 4-3 – 4-5; Mote *et al*. 2008, p. 10; Dalrymple 2012, p. 71; Petersen *et al*. 2015, pp. 21, 29, and Appendix D). However, in some places, such as Neah Bay, plate tectonics are causing upward land movement that is currently outpacing sea level rise (Mote *et al*. 2008, pp. 7-8; Dalrymple 2012, p. 80; Petersen *et al*. 2015, pp 24-26). In other places, sea-level rise is expected to have consequences for near-shore ecosystems (see below).

Projected Biological Consequences of Climate Change

Primary Productivity

Changes in temperature, carbon dioxide, and nutrient levels are likely to affect primary productivity by phytoplankton, macroalgae, kelp, eelgrass, and other marine photosynthesizers (Mauger *et al*. 2015, p. 11-5). In general, warmer temperatures, higher carbon dioxide concentrations, and higher nutrient levels lead to greater productivity (Gao and Campbell 2014, pp. 451, 454; Newton and Van Voorhis 2002, p. 10; Roberts *et al*. 2014, pp. 11, 22, 108; Thom 1996, pp. 386-387), but these effects vary by species and other environmental conditions, such as sunlight levels or the ratios of different nutrients (Gao and Campbell 2014, pp. 451, 454; Krembs 2012, p. 109, Low-Decarie *et al*. 2011, p. 2530). In particular, phytoplankton species that form calcium carbonate shells, such as coccolithophores, show weaker shell formation and alter their physiology in response to acidification (Feely *et al*. 2004, pp. 365-366; Kendall 2015, pp. 26-46). Due to changes in the seasonality of nutrient flows associated with upwelling and freshwater inputs, there may also be alterations in the timing, location, and species composition of bursts of primary productivity, for example, earlier phytoplankton blooms (Allen and Wolfe 2013, pp. 6, 8-9; MacCready and Banas 2016, p. 17; Mauger *et al*. 2015, p. 6-3). Changes in primary productivity are not expected to occur in every season: during winter, sunlight is the major limiting factor through most of the action area (Newton and Van Voorhis 2002, pp. 9, 12), and climate change is not expected to alter winter sunlight. Changes in primary productivity are also likely to vary across the action area; for example, primary productivity in Possession Sound is more sensitive to nutrient inputs than other areas within Puget Sound (Newton and Van Voorhis 2002, pp. 10-11). In sum, we expect an overall increase in primary productivity, but there are likely to be changes in the timing, location, and species dominance of primary producers.

Eelgrass (*Zostera marina*) is a particularly important primary producer in the action area. In some areas, such as Padilla Bay, sea level rise is expected to lead to larger areas of suitable depth for eelgrass meadows. In such areas, eelgrass cover, biomass, and net primary production are projected to increase during the next 20 years (Kairis 2008, pp. 92-102), but these effects will depend on the current and future topography of the tidal flats in a given area. In addition, eelgrass photosynthetic rates increase with increasing dissolved carbon dioxide concentrations (Short and Neckles 1999, pp. 184-186; Thom 1996, pp. 385-386). However, increasing temperatures are not likely to be beneficial for eelgrass, and in combination with increased nutrients, could favor algal competitors (Short and Neckles 1999, pp. 172, 174; Thom *et al*. 2014, p. 4). Between 1999 and 2013, eelgrass growth rates in Sequim Bay have increased, but at a site in central Puget Sound, shoot density over a similar time period was too variable to detect trends (Thom *et al*. 2014, pp. 5-6). Taken together, these studies indicate that climate change may benefit eelgrass over the next 20 years, particularly at some sites

within the action area, but there is the potential for negative effects to dominate at other sites (Thom *et al*. 2014, pp. 7-9).

Kelp forests also make important contributions to primary productivity in the action area, but are less well studied than eelgrass. Like eelgrass, bull kelp (*Nereocystis luetkeana*) responds to higher carbon dioxide concentrations with greater productivity (Thom 1996, pp. 385-386). Outside of the action area, warming waters (among other factors) have reduced the range of giant kelp (*Macrocystis pyrifera* [Agardh]) (Edwards and Estes 2006, pp. 79, 85; Ling 2008, p. 892), but it is not clear that the giant kelp populations within the action area will be negatively affected by the projected increase in temperature here. Within the action area, along the western portion of the Strait of Juan de Fuca, bull kelp and giant kelp canopy area increased between 1989 and 2004, but this increase is likely due to factors unrelated to climate change, such as harvesting of sea urchins, which graze on kelp (Berry *et al*. 2005, p. 4). It is unclear what the future effects of climate change might be on kelp in the action area.

In contrast, increases in toxic algae (also known as red tides or harmful algal blooms) have been documented over the past several decades, and these changes may be due to climate change (Trainer *et al*. 2003, pp. 216, 222). Future conditions are projected to favor higher growth rates and longer bloom seasons for these species. In the case of one species, *Alexandrium catanella,* increases in the length of bloom season are projected primarily due to increases in sea surface temperature (Moore *et al*. 2015, pp. 7-9). As with other climate change effects discussed above, increases in the length of the toxic algae bloom season is likely to vary across the action area. In the eastern end of the Strait of Juan de Fuca and the inlets of southern Puget Sound, the *A. catanella* bloom season is projected to increase by 30 days per year by 2069, in contrast with Whidbey basin, where little or no change in season length is projected (Moore *et al*. 2015, p. 8). In another species of toxic algae, *Pseudo-nitzschia fraudulenta*, toxin concentrations increase with increasing acidification of the water, especially in conditions in which silicic acid (used to construct the algal cell walls) is limiting (Tatters *et al*. 2012, pp. 2-3). This species also exhibits higher growth rates with higher carbon dioxide concentrations (Tatters *et al*. 2012, pp. 3-4). These results indicate that with future climate change, toxic algae blooms are likely to be more frequent, larger, and more toxic.

Higher Trophic Levels

There are several pathways by which climate change may affect species at higher trophic levels (*i.e*., consumers). Changing physical conditions, such as increasing temperatures, hypoxia, or acidification will have direct effects on some species. Other consumers will be affected via changes in the abundance, distribution, or other characteristics of their competitors or prey species. Changes in the timing of seasonal events may lead to mismatches in the timing of consumers' life history requirements with their habitat conditions (including prey availability as well as physical conditions) (Mackas *et al*. 2007, p. 249). The combination of these effects is likely to cause changes in community dynamics (*e.g.*, competitive interactions, predator-prey relationships, etc.), but the magnitude of these effects cannot be predicted with confidence (Busch *et al*. 2013, pp. 827- 831).

A wide variety of marine species are directly affected by ocean acidification. Like their phytoplankton counterparts, foraminiferans and other planktonic consumers that form calcium carbonate shells are less able to form and maintain their shells in acidified waters (Feely *et al*. 2004, pp. 356-366).

Similarly, chemical changes associated with acidification interfere with shell development or maintenance in pteropods (sea snails) and marine bivalves (Busch *et al*. 2014, pp. 5, 8; Waldbusser *et al*. 2015, pp. 273-278). These effects on bivalves can be exacerbated by hypoxic conditions (Gobler *et al*. 2014, p. 5), or ameliorated by very high or low temperatures (Kroeker *et al*. 2014, pp. 4-5), so it is not clear what the effect is likely to be in a future that includes acidification, hypoxia, and elevated temperatures. Acidification affects crustaceans, for example, slowing growth and development in Pacific krill (*Euphausia pacifica*) and Dungeness crabs (*Cancer magister*) (Cooper *et al*. 2016, p. 4; Miller *et al*. 2016, pp. 118-119). Salmon are also negatively affected by acidification, including negative growth rates and reduced metabolic rates in juvenile pink salmon (*Oncorhynchus gorbuscha*) at carbon dioxide concentrations comparable to those recently observed in the Strait of Georgia (Ou *et al*. 2015, pp. 951, 954).

Climate effects are expected to alter interactions within the marine food web. When prey items decrease in abundance, their consumers are also expected to decrease, and this can also create opportunities for other species to increase. In California's Farallon Islands, the recently increasing variance of climate drivers is leading to increased variability in abundance of prey species such as euphausiids and juvenile rockfish (*Sebastes* spp.), associated with corresponding variability in the demography of predators such as seabirds and salmon (Sydeman *et al*. 2013, pp. 1662, 1667-1672). In future scenarios with strong acidification effects to benthic prey in the California Current, euphausiids and several fish species are expected to decline, while other species are expected to increase (Kaplan *et al*. 2010, pp. 1973-1976). An investigation of the planktonic food web off of Oregon shows that sea surface temperature has contrasting effects on different types of zooplankton, and competitive interactions are much more prevalent during warm phases of ENSO or PDO than during cool phases (Francis *et al*. 2012, pp. 2502, 2505-2506). A food web model of Puget Sound shows that moderate or strong acidification effects to calcifying species are expected to result in reductions in fisheries yield for several species, including salmon and Pacific herring (*Clupea pallasii*), and increased yield for others (Busch *et al*. 2013, pp. 827-829). Additionally, the same model shows that these ocean acidification effects are expected to cause reductions in forage fish biomass, which are in turn expected to lead to reductions in diving bird biomass (Busch *et al*. 2013, p. 829). While Busch and coauthors (2013, p. 831) express confidence that this model is accurate in terms of the nature of ocean acidification effects to the Puget Sound food web of the future, they are careful to note that there is a great deal of uncertainty when it comes to the magnitude of the changes. The model also illustrates that some of the effects to the food web will dampen or make up for other effects to the food web, so that changes in abundance of a given prey species will not always correspond directly to changes in the abundance of their consumers (Busch *et al*. 2013, pp. 827, 830).

Changes in seasonality at lower trophic levels may lead to changes in population dynamics or in interactions between species at higher trophic levels. For example, just outside of the action area in British Columbia, earlier spring phytoplankton blooms are associated with lower pink salmon productivity, likely mediated by zooplankton grazers, and this effect is likely to apply to the action area as well (Malick *et al*. 2015, pp. 703-706). Similarly, if salmon hatchery release dates are not adjusted to account for changes in peak timing of phytoplankton blooms, this can lead to a mismatch between release dates and marine productivity peaks, which has been shown to reduce smolt-to-adult survival in the Strait of Georgia (Chittenden *et al*. 2010, pp. 8-9). At Triangle Island in British Columbia, Cassin's auklet (*Ptychoramphus aleuticus*) breeding success is reduced during years when the peak in copepod prey availability comes earlier than the birds' hatch date, and this mismatch is

associated with warm sea surface temperatures (Hipfner 2008, pp. 298-302). However, piscivorous seabirds (*i.e.*, tufted puffins [*Fratercula cirrhata*], rhinoceros auklets [*Cerorhinca monocerata*], and common murres [*Uria aalge*]) breeding at the same Triangle Island site have, at least to some extent, been able to adjust their breeding dates according to ocean conditions (Bertram *et al*. 2001, pp. 292-293; Gjerdrum *et al*. 2003, p. 9379), as have Cassin's auklets breeding in the Farallon Islands of California (Abraham and Sydeman 2004, p. 240). Because of the changes in tufted puffin, rhinoceros auklet, and common murre hatch dates at Triangle Island, the breeding periods of these species have converged to substantially overlap with one another and with that of Cassin's auklet (Bertram *et al*. 2001, pp. 293-294), but studies have not addressed whether this overlap has consequences for competitive interactions among the four species. Note that all four of these bird species are in the family Alcidae, which also contains marbled murrelets. All these species also breed in, or just outside, the action area and forage within the action area. However, we did not locate any studies addressing these types of effects within the action area.

Several studies have suggested that climate change is one of several factors allowing jellyfish to increase their ecological dominance, at the expense of forage fish (Parsons and Lalli 2002, pp. 117-118; Purcell *et al*. 2007, pp. 154, 163, 167-168; Richardson *et al*. 2009, pp. 314-216). Many (though not all) species of jellyfish increase in abundance and reproductive rate in response to ocean warming, and jellyfish are also more tolerant of hypoxic conditions than fish are (Purcell 2005, p. 472; Purcell *et al*. 2007, pp. 160, 163; see Suchman *et al*. 2012, pp. 119-120 for a Northeastern Pacific counterexample). Jellyfish may also be more tolerant of acidification than fish are (Atrill *et al*. 2007, p. 483; Lesniowski *et al*. 2015, p. 1380). Jellyfish abundance in southern and central Puget Sound has increased since the 1970s (Greene *et al*. 2015, p. 164). Over the same time period, herring abundance has decreased in south and central Puget Sound, and surf smelt (*Hypomesus pretiosus*) abundance has also decreased in south Puget Sound, although other Puget Sound forage fish populations have been stable or increasing (Greene *et al*. 2015, pp. 160-162). Forage fish abundance and jellyfish abundance were negatively correlated within Puget Sound and Rosario Strait (Greene *et al*. 2015, p. 164). It is not clear whether there is a causal relationship between forage fish and jellyfish abundance, or whether the two groups are simply responding in opposite ways to climate and other anthropogenic factors.

Many species of forage fish are expected to fare poorly in the changing climate, regardless of any competitive effects of jellyfish. In the Gulf of Alaska, Anderson and Piatt (1999, pp. 119-120) documented the crash of capelin (*Mallotus villosus*), Pacific herring, and species of Irish lord (*Hemilepidotus* spp.), prickleback (Stichaeidae family), greenlings and mackerel (*Hexagrammos* and *Pleurogrammus* spp.),as well as several shrimp species, as part of a major community reorganization following a climate regime shift from a cool phase to a warm phase in the 1970s. In the northeastern Pacific Ocean, capelin, sand lance (Ammodytidae family), and rockfish abundance are all negatively correlated with seasonal sea surface temperatures (Thayer *et al*. 2008, p. 1616). A model of multiple climate change effects (*e.g.*, acidification and deoxygenation) to marine food webs in the Northeast Pacific consistently projects future declines in small pelagic fish abundance (Ainsworth *et al*. 2011, pp. 1219, 1224). Within the action area, abundance of surf smelt and Pacific herring in the Skagit River estuary are positively associated with coastal upwelling during the spring and early summer, likely because nutrient-rich upwelled water increases food availability (Reum *et al*. 2011, pp. 210-212). If projections of later, shorter upwelling seasons are correct (see above), the delays may lead to declines in these stocks of herring and surf smelt, as happened in 2005 (Reum *et al*. 2011, p. 212). Similarly, delayed upwelling in 2005 led to reduced growth rates, increased mortality, and recruitment

failure of juvenile northern anchovies (*Engraulis mordax*) off of the Oregon and Washington coasts (Takahashi *et al*. 2012, pp. 397-403). In the northeastern Pacific, Chavez and coauthors (2003, pp. 217-220) have described a shift between an "anchovy regime" during the cool negative phase of the PDO and a "sardine regime" during the warm positive phase, where the two regimes are associated with contrasting physical and biological states. However, global warming may disrupt the ecological response to the naturally-occurring oscillation, or alter the pattern of the oscillation itself (Chavez *et al*. 2003, p. 221; Zhang and Delworth 2016, entire).

Marbled Murrelets

Marbled murrelets are likely to experience changes in foraging and breeding ecology as the climate continues to change. Within the action area, there is no research attempting to measure or project the effects of climate change on the marbled murrelet. However, several related studies have been conducted outside of the action area, and the results are likely to be applicable to marbled murrelets within the action area as well. Additionally, numerous studies of other alcids from Mexico to British Columbia indicate that alcids as a group are vulnerable to climate change in the northeastern Pacific.

These studies suggest that the effects of climate change will be to reduce marbled murrelet reproductive success, likely mediated through climate change effects to prey. In British Columbia, there is a strong negative correlation between sea surface temperature and the number of marbled murrelets observed at inland sites displaying behaviors associated with nesting (Burger 2000, p. 728). In central California, marbled murrelet diets vary depending on ocean conditions, and there is a trend toward greater reproductive success during cool water years, likely due to the abundant availability of prey items such as euphausiids and juvenile rockfish (Becker *et al*. 2007, pp. 273-274). In the Georgia Basin, just north of the action area, much of the yearly variation in marbled murrelet abundance from 1958 through 2000 can be explained by the proportion of fish (as opposed to euphausiids or amphipods) in the birds' diet (Norris *et al*. 2007, p. 879). If climate change leads to further declines in forage fish populations (see above), those declines are likely to be reflected in marbled murrelet populations.

The conclusion that climate change is likely to reduce marbled murrelet breeding success via changes in prey availability is further supported by several studies of other alcid species in British Columbia and California. Common murres, Cassin's auklets, rhinoceros auklets, and tufted puffins in British Columbia; pigeon guillemots (*Cepphus columba*), common murres, and Cassin's auklets in California; and even Cassin's auklets in Mexico all show altered reproductive rates, altered chick growth rates, or changes in the timing of the breeding season, depending on sea surface temperature or other climatic variables, prey abundance, prey type, or the timing of peaks in prey availability (Abraham and Sydeman 2004, pp. 239-243; Ainley *et al*. 1995, pp. 73-77; Albores-Barajas 2007, pp. 85-96; Bertram *et al*. 2001, pp. 292-301; Borstad *et al*. 2011, pp. 291-299; Gjerdrum *et al*. 2003, pp. 9378-9380; Hedd *et al*. 2006, pp. 266-275). The abundance of Cassin's auklets and rhinoceros auklets off southern California declined by 75 and 94 percent, respectively, over a period of ocean warming between 1987 and 1998 (Hyrenbach and Veit 2003, pp. 2546, 2551). Although the details of the relationships between climate variables, prey, and demography vary between bird species and locations, the consistent demonstration of such relationships indicates that alcids as a group are sensitive to climate-related changes in prey availability, prompting some researchers to consider them indicator species for climate change (Hedd *et al*. 2006, p. 275; Hyrenbach and Veit 2003, p. 2551).

In addition to effects on foraging ecology and breeding success, climate change may expose adult marbled murrelets to health risks. For example, it is likely that they will experience more frequent domoic acid poisoning, as this toxin originates from harmful algae blooms that are expected to become more prevalent in the action area (see above). In central California, domoic acid poisoning was determined to be the cause of death for at least two marbled murrelets recovered during a harmful algae bloom in 1998 (Peery *et al*. 2006, p. 84). During this study, which took place between 1997 and 2003, the mortality rate of radio-tagged marbled murrelets was highest during the algae bloom (Peery *et al*. 2006, p. 83). Domoic acid poisoning has previously been shown to travel through the food chain to seabirds via forage fish that feed on the toxic algae (Work *et al*. 1993, p. 59). A different species of harmful algae produces a foam that led to plumage fouling and subsequent mortality of common murres and other seabird species off of Oregon and Washington during October of 2009, and similar events may become more frequent with climate change (Phillips *et al*. 2011, pp. 120, 122-124). Climate change may also promote conditions in which alcids become exposed to novel pathogens, as occurred in Alaska during 2013, when crested auklets (*Aethia cristatella*) and thick-billed murres (*Uria lomvia*) washed ashore after dying of avian cholera (Bodenstein *et al*. 2015, p. 935). Counterintuitively, in the 1997-2003 study of radio tagged marbled murrelets in California, marbled murrelet adult survival was higher during warm-water years and lower during cold-water years, likely because they did not breed and therefore avoided the associated physiological stresses and additional predator risk (Peery *et al*. 2006, pp. 83-85).

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