2.2.1.3.1.10 Ocean Acidification

Approach in 2008 FCRPS BiOp and AMIP:

Increasing acidification and decreased carbonate ion availability from the increasing concentration of CO2 dissolved in ocean waters was discussed generally in ISAB (2007a) and the 2008 SCA (Section 5.7.3).

New Information Relevant to the FCRPS BiOp and AMIP:

Since the start of the industrial revolution, the oceans have absorbed about a third of anthropogenic carbon dioxide emissions (Sabine et al. 2004). New information indicates that, globally, ocean pH has dropped about 0.1 due to ocean acidification (reviewed in Feely et al. 2008). Samples from the continental shelf of North America have confirmed this 0.1 pH drop (Feely et al. 2008; Hauri et al. 2009). Ocean acidification also decreases the amount of carbonate ions available to organisms that build calcium carbonate shells. The saturation state for one type of calcium carbonate widely used by marine organisms has decreased 0.5 in the California Current System (Hauri et al. 2009). Ocean acidification is expected to accelerate in the near-term future given continued carbon dioxide emissions (Byrne et al. 2010; Caldeira and Wickett 2003; Doney et al. 2009).

2.2.1.3.2 Recent Observations and Future Expectations of Biological Effects of Climate Change in the Pacific Northwest On Listed Columbia River Basin Salmon and Steelhead

2.2.1.3.2.1 Impacts of Climate Change on Salmon in Columbia Basin Tributaries (Spawning and Egg-to-Emergence Survival)

Approach in 2008 FCRPS BiOp and AMIP:

ISAB (2007a), summarized in the 2008 SCA (Section 5.7.3), noted that increased winter flooding can reduce egg survival, some redds might be dewatered, spawners may change to less productive timing or areas for spawning, there may be earlier fry emergence which may cause lower survival, there may be smaller fry size at emergence, and increased temperatures could cause direct egg mortality or susceptibility to disease.

New Information Relevant to the 2008 FCRPS BiOp and AMIP:

Spawner Distribution:
Geist et al. (2008) determined that chum salmon and fall Chinook spawning distribution below Bonneville Dam is influenced by hyporheic temperatures and gradients. Variability of temperature was increased by load-following (fluctuations in power production). Connor et al. (2003) found that Snake River fall Chinook egg development time was well-predicted by thermal units, and sites outside the current spawning distribution appeared limited by cold temperature. If cold winters are the primary limiting factor for these populations, new sites might become suitable with warmer winters. Angilletta et al. (2008) examined how dams changed thermal regimes on the Willamette, Rogue, and Cowlitz Rivers (cooler summer, warmer fall and winter),

and postulated that resultant changes in emergence time could drive evolution in spawn timing. Hanrahan (2008) found that variation in operations at Hells Canyon Dam had minimal impact on hydraulic and temperature gradients between the river and riverbed at nearby Snake River fall Chinook spawning sites.

Spawner Success:
Yates et al. (2008) determined that climate change will exacerbate effects of warm temperatures on poor spawning success in the Sacramento River, but reservoirs such as Shasta provide a cool-water pool through the summer that may help counter this effect.

Methods for Assessing Climate Change:
Groves et al. (2008) found that surface water temperature predicts intra-redd temperatures for salmon embryo developmental timing in the Snake River, facilitating models of development time and potential spawning distribution.

2.2.1.3.2.2 Impacts of Climate Change on Salmon in Columbia Basin Tributaries (Fry-Smolt Rearing)

Approach in 2008 FCRPS BiOp and AMIP:

ISAB (2007a), summarized in the 2008 SCA (Section 5.7.3), noted that reduced flows may impact quality and quantity of rearing habitat, strand fish, or make fish more susceptible to predation. Warmer spring-fall temps may reduce quality and quantity of rearing habitat, cause a reduction in size (hence survival) if habitats are food-limited or an increase in size if habitats are not food-limited, and increase predation rates. In colder high-elevation streams, higher temperatures may be beneficial and result in larger fish. Higher winter temperatures may increase fish size and survival, but may also increase predation rates. Higher winter flows are likely to increase mortality if winter flood refuge habitat is not available.

Crozier et al. (2008a; 7-14, 2008 SCA) predicted an 18-34% decline in parr-smolt survival of SR spring/summer Chinook populations by 2040. This information was not used to adjust quantitative 2008 BiOp metrics because the time period was outside that of 2008 BiOp, there was uncertainty about direct comparison to the 2008 BiOp base condition, and uncertainty about the way to treat partial density-dependent compensation described by Crozier et al. (2008a).

New Information Relevant to the 2008 FCRPS BiOp and AMIP:

Survival:
Geist et al. (2010) described mainstem temperature tolerances of juvenile Snake River fall Chinook, finding high survival over 30 days at constant temperatures up to 22ºC, and moderately high survival (83-88% over 30 days) when daily maximum temperatures reached 27ºC.

Growth:
Crozier et al. (2010) found positive effects of warmer temperatures on parr growth in Salmon River Basin Chinook at low fish densities, but the effect reversed at higher densities. Boughton et al. (2007) found negative effects of warm temperatures on growth in California steelhead in field enclosures, and an interaction with food availability, although in some analyses these

effects were not significant. Rundio and Lindley (2008) found that, unlike many temperate streams where terrestrial inputs provide an alternate prey source when aquatic invertebrate abundance is low, terrestrial inputs to two California streams with Mediterranean climate apparently provide a year-round additional source of prey. The terrestrial prey (like aquatic prey) peaks when water temperature is warmest and hence when fish growth potential is high. Beauchamp (2009) analyzed the bioenergetics of allometric relationships between fish size, temperature, and ration, and found that smaller fish have higher optimal and maximum temperatures for growth relative to larger fish, and that improving food quality (composite energy density) can raise the optimal temperature for growth. Beauchamp concluded that juveniles are more likely to be limited by prey quality and quantity than temperature directly, whereas adults will be more sensitive to temperature change. McCarthy et al. (2009) predicted decreased steelhead growth rate in the Trinity River under three climate scenarios based on bioenergetic analyses.

Behavior:

Spina (2007) showed that California steelhead occupy relatively hot pools and remain active over summer. Apparently thermal refugia cannot be found or are not available.

Disease:

Dionne et al. (2007) found that among Atlantic salmon in eastern Canada along 12º of latitude, allelic diversity within the Major Histocompatibility Complex is correlated with pathogen and bacterial diversity, which in turn is correlated with thermal regimes. Thus warmer temperatures are associated with more diverse and virulent pathogen communities, which in turn has presumably selected for greater immune resistance. Bowden (2008) found that an increase in temperature, salinity, pH, particulates, oxygen and light increases immune function. Kocan et al. (2009) found that swimming stamina was reduced above 15ºC in rainbow trout exposed to ichthyophoniasis infection, and argue that the high migration mortality observed in Yukon River Chinook might be caused by this interaction between disease and high temperature exposure.

2.2.1.3.2.3 Impacts of Climate Changes on Multiple Life Stages in Tributaries

New Information Relevant to the 2008 FCRPS BiOp and AMIP

Nelitz et al. (2009) modeled climate change impacts on potential Chinook habitat in the Cariboo-Chilcotin region of southern British Columbia. They generated climate change scenarios by inputting downscaled temperature and precipitation projections into a hydrological model, and classifying historic and future potential habitat using temperature and flow criteria, as well as other habitat criteria, such as access barriers, channel characteristics, etc. They found that habitat suitability is likely to decrease due to rising temperatures and decreasing flow in the northeastern portion of the study region, but increase in the southern section, where certain areas are currently considered too cold for Chinook. Although the results are site-specific, the methods are relevant to studies in the Columbia Basin.

Some ongoing studies of tributary restoration and recovery potential are also of interest. NWFSC staff (T.Cooney and D. Holzer) are working with R. Carmichael (Oregon Department of Fish and Wildlife) to develop maps of vulnerability to climate change for interior Columbia steelhead populations. Cooney and Holzer have developed relatively simple models to relate summer stream temperatures in steelhead rearing habitats to projections based on the general climate change models. Carmichael has adapted available regional assessments of stream flow characteristics to incorporate into the assessment. The combined analyses will be used to identify sensitivity of recovery strategies to current climate model projections, highlight watersheds within each population that are particularly vulnerable, and compare these with recovery strategies.

Christine Petersen with the Moore Foundation/ NCEAS workgroup is working on population viability analyses of the Wenatchee Basin and the Grande Ronde Basin, identifying critical life history stages threatened by climate change. Preliminary results suggest that for Wenatchee Basin Chinook, mainstem Columbia summer temperatures are likely to have negative impacts on summer runs, although probably not in the next 25 years, whereas spawning habitat is more likely to constrain some spring Chinook populations. For Grande Ronde populations, thermally suitable summer holding areas may already be limiting population recovery, and this constraint will intensify with warmer temperatures.

Tributary Habitat Effects:

Dunham et al. (2007) showed that physical stream habitats can remain altered (for example, increased temperature) for many years following wildfire, which is predicted to increase with climate change, but native aquatic vertebrates can be resilient. Pollock et al. (2009) showed that stream temperatures are significantly correlated with the percent of harvest in watersheds.

Thermal Refugia for Multiple Life Stages:

Reid (2007) described thermal refugia for adult spring Chinook and juvenile Chinook and steelhead in the Rogue River. Refugia were approximately 2° C cooler than adjacent areas and current levels of motor boat activity had minor effects on water temperature, fish behavior, and fish metabolism.

Effects of Temperature on Population Distribution:

Lindley et al. (2007) used results of downscaled global climate models, linked to a regional hydrologic model, to predict that the forecast rise in summer stream temperatures may allow spring-run Chinook salmon to persist in some California streams, but make other areas unsuitable. At the upper end of predictions, very little spring-run Chinook habitat is expected to remain suitable.

2.2.1.3.2.4 Impacts of Climate Change on Mainstem Juvenile Migrations and Mainstem Spawning

Approach in 2008 FCRPS BiOp and AMIP:

ISAB (2007a), summarized in the 2008 SCA (Section 5.7.3), noted that fall Chinook and chum salmon will have similar egg-fry effects in the mainstem as described above for warmer, low-elevation, streams. Yearling smolts may reach the estuary earlier because of high spring flows and warm temperatures and there may be mismatch with ocean conditions and predators. Higher temperatures may cause earlier migration (which could be an advantage or disadvantage), may