Comments to the National Marine Fisheries Service (NMFS) regarding the Draft Environmental Assessment (DEA) for Amendment 21 to the Pacific Coast Salmon Fishery Management Plan (FMP).

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Great Old Broads for Wilderness
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We appreciate the opportunity to provide comments to NMFS on the Draft Environmental Assessment (DEA) and the Amendment 21 Alternatives proposed by NMFS. We recognize and appreciate the considerable amount of time and effort devoted by the Southern Resident Killer Whale (SRKW) Working Group (WG) to develop the May 2020 Risk Assessment and the recommendations in its Draft Range of Alternatives and Recommendations of August 2020 ("Draft Recommendations") that formed the basis for the Alternative considered in the DEA.

We, among many other concerned conservation organizations, have in the past two years (2019 and 2020) provided detailed comment to NMFS, the Council, and the WG, including comments on the very alternatives that NMFS has chosen to consider in the DEA. Consequently, we include several of those comment documents together with this Letter for the Administrative Record, rather than undertake a completely new, and ultimately repetitive, analysis of the alternatives in the DEA.

First, we wish to bring to NMFS' attention a serious matter concerning the public process for the WG in developing alternatives for Amendment 21. WFC, RCF and WO, along with other colleagues advocating for better management and protection of SRKWs in Council fisheries, have participated in and provided substantive feedback and comments to the WG process as requested by the Council and NMFS. We have, to the best of our knowledge, received no written responses to any of the comments submitted over the past two years. This failure represents a violation of the Public Trust. At the very least, the Council and NMFS should make it clear at the outset of any public comment period or other request for written public input that commenters should have no expectation of receiving written responses from representatives or individuals to whom the comments were addressed. In other words, if it is the policy of NMFS, the Council, or the WG not to provide written responses to the public comments requested, that should be stated at the outset. At least then, the public would have appropriate expectations that they are dropping their comments into a black box.

We hope and expect that such a policy will not befall the comments we and others submit herein.

Reflecting the failure to respond to previous comments pertaining to the development of the alternatives contained in the DEA, we bring attention to a substantive approach to identifying an appropriate Alternative that we submitted with our October 27 2020 Comments (attached) that was not included in the DEA, including in DEA Section 2.4 ("Alternatives considered but not further analyzed"). This is the alternative approach to specify a TS1 NOF Chinook abundance threshold *below which* no marine commercial or recreational fishing occurs. This would secure a minimum Chinook abundance in NOF upon which SRKW may forage (either in the NOF region or in marine waters where Chinook that escaped the NOF harvest may migrate). Such an alternative places the burden of proof regarding fishery actions that may adversely affect SRKWs primarily on the Council fisheries, and not on endangered Southern Residents.

Management policies that restrict commercial and recreational fishery openings until some abundance threshold is attained are not uncommon in the Pacific Northwest. We note two examples. Collie and Peterman (2012) conducted a management strategy evaluation of chum salmon in the Arctic–Yukon–Kuskokwim region of Alaska. They note that Alaska Department of Fish and Game (ADF&G) manage fishery openings using the following priorities: first meet spawner escapement goals; second, meet subsistence fishery harvest objects; and third, provide commercial harvest opportunity. Price et al. (2021) analyzed changes in the diversity of sockeye salmon populations in the Skeena River since the early years of the twentieth century. They note that Department of Fisheries and Oceans Canada (DFO)'s management policy for Skeena sockeye is to open commercial fisheries after an aggregate abundance target of 1.05 million is attained. The 1.05 million target includes a spawner escapement goal of 900,000, and an "indigenous fisheries" allocation of 150,000.

Clearly, it is conceivable to determine a similar management control rule (Alternative) for the FMP that prioritizes securing minimal levels of Chinook abundance in NOF for SRKW below which no commercial or recreational marine fisheries occur. At the very least, such an Alternative should be included in the Final Recommendations. As a point of departure for developing such an alternative, we suggest that the Alternative 2 threshold of 966,000 Chinook in NOF at TS1 be a starting point for determination of an appropriately risk-averse Chinook abundance threshold below which no commercial or recreational Chinook fishery may occur.

The importance of evaluating alternatives of the minimum abundance/fishery closure alternative (described in our October 27 2020 submission to the WG) also underscores our call for an Environmental Impact Statement pursuant to NEPA, and not an EA. The restricted list of Alternatives (#s 1 to 3 in the DEA) and in the list of alternatives considered but not further analyzed, fail to capture a reasonable range of alternatives that encompass different scientifically credible approaches to determining an appropriate harvest control rule that is likely to be compatible with the maintenance and recovery of the SRKW DPS. The restricted range of alternatives in the DEA, all of which are variants of the same general approach, is itself controversial, as is the inherent assumption of these approaches that the burden of proof ultimately falls on the SRKW to show that alternative approaches are necessary. Considerable controversy also attends the very conduct of coastal mixed-stock Chinook salmon fisheries in the EEZ, including issues of age-over-fishing and mortality of immature Chinook, an issue we also raised in our October 27 2020 comments to the WG. For these reasons alone, we believe that NEPA requires NMFS to undertake a full EIS analysis. Any thought of producing a final EA should be dropped and our comments, and likely those of others conservation groups commenting on the DEA, should be transferred to producing a DEIS.

Finally, we draw attention to several recent developments that cast serious doubt on the DEA's assumption that Chinook stock dynamics encountered by Council fisheries during the next ten years will more or less mirror those of the past ten years. Climate change phenomena that impact Chinook, other Pacific salmon, their food webs, and their marine and freshwater ecosystems are clearly changing at a greater rate than in the recent past. In the ocean, this includes measurable changes to structure, such as stratification and trophic composition (including prey quality shifts in zooplankton), to function, including the role of carbonate ions, and to processes like pH buffering, nutrient cycling, and primary production. In freshwater, it includes changes to precipitation (falling as rain instead of snow, rainfall and drought extremes), changes to snow pack, changes to watershed hydrology, and changes to stream and river temperatures that inhibit downstream and upstream Chinook migration, reduce year round habitat, and generally increase Chinook salmon mortality at all life stages. Many of these conditions and events lie outside of those that SRKW whales evolved with, but must now recover within.

We note two recent phenomena of importance. First, the massive Pacific Northwest heat wave at the end of June: This utterly unexpected sudden increase in surface air temperatures that lasted for several days pushed temperatures in Oregon, Washington, and British Columbia well above 100 degrees Fahrenheit (F). Among several harmful and lethal consequences for many species, this caused a rapid increase in snow melt that rapidly increased discharge in the Skeena and Fraser rivers followed by marked increases in water temperatures of these two large rivers as well as every river and stream regardless of size. Numerous stream and river levels are now flowing below recent normal levels with water temperatures one to several degrees F above average. All of these related events bode ill for salmon and SRKW.

Second, is the closure of 57% of commercial fisheries in British Columbia. DFO closed essentially all sockeye, pink, and chum fisheries and two coho troll fisheries based on abundance and conservation concerns. These closures were additionally motivated by conservation concerns and by catch of Fraser River and other BC coastal Chinook salmon populations (although surprisingly, only one commercial Chinook fishery was included in these permanent closures). This action was entirely unexpected a year ago. This set of closures is largely the result of increased warming of coastal waters and associated declines in marine food web composition and productivity which leads to bottom-up negative effects on higher trophic level taxa, including salmon and SRKW.

These climate change-related developments (among many others that could be cited) provide significant evidence that Council's assumption that environmental conditions affecting salmon and SRKW in the next 10 years will be similar to the past, is decidedly improbable; the next 10 years are more likely than not to be worse than the previous ten years (see, Phillip et al. 2021, attached). This requires pro-active and strongly precautionary fisheries management actions (among others) if not only for SRKW but for many vulnerable Chinook and other salmon populations. If these populations are to survive, much less (in the case of SRKW) preserve the capacity to rebuild and retain their evolutionary potential in a rapidly changing climate, a rethink on exploitation rates and conventional approaches is urgently required.

NMFS and Council fisheries management policies have been far too reactive, and insufficiently anticipatory of environmental changes that likely bode ill for salmon and SRKW. The list of alternatives considered in the DEA exhibit just this reactive character. An EIS is required to appropriately evaluate the effect these changes have (many of which, if not all, are increasingly difficult to predict) on Chinook and SRKW that are affected by Council fisheries.

In conclusion, we re-iterate the substantive comments that we have previously provided to NMFS, Council, and the WG (attached), and look forward to having the DEA replaced by a DEIS, with a presentation of a range of substantive alternatives that will enable the public and the relevant agencies to determine an appropriately precautionary and anticipatory Amendment to the FMP.

Sincerely,

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Friends of the Earth

Pam Conley, Great Old Broads for Wilderness

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Citations.

Collie, J.S., Peterman, R.M., and Zuehlke, B.M. 2012. A fisheries risk-assessment framework to evaluate trade-offs among management options in the presence of time-varying productivity. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*(2), 209-223.

Price, M.H., Moore, J.W., Connors, B.M., Wilson, K.L., and Reynolds, J.D. 2021. Portfolio simplification arising from a century of change in salmon population diversity and artificial production. *Journal of Applied Ecology*.

Phillip, S.Y. and 26 co-authors. 2021. Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021. World Weather Attribution Initiative. https://www.worldweatherattribution.org/

Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021.

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Main findings

- Based on observations and modeling, the occurrence of a heatwave with maximum daily temperatures (TXx) as observed in the area 45–52 ºN, 119–123 ºW, was virtually impossible without human-caused climate change.
- The observed temperatures were so extreme that they lie far outside the range of historically observed temperatures. This makes it hard to quantify with confidence how rare the event was. In the most realistic statistical analysis the event is estimated to be about a 1 in 1000 year event in today's climate.

- There are two possible sources of this extreme jump in peak temperatures. The first is that this is a very low probability event, even in the current climate which already includes about 1.2°C of global warming -- the statistical equivalent of really bad luck, albeit aggravated by climate change. The second option is that nonlinear interactions in the climate have substantially increased the probability of such extreme heat, much beyond the gradual increase in heat extremes that has been observed up to now. We need to investigate the second possibility further, although we note the climate models do not show it. All numbers below assume that the heatwave was a very low probability event that was not caused by new nonlinearities.
- With this assumption and combining the results from the analysis of climate models and weather observations, an event, defined as daily maximum temperatures (TXx) in the heatwave region, as rare as 1 in a 1000 years would have been at least 150 times rarer without human-induced climate change.
- Also, this heatwave was about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 1.2°C cooler than today).
- Looking into the future, in a world with 2°C of global warming (0.8°C warmer than today which at current emission levels would be reached as early as the 2040s), this event would have been another degree hotter. An event like this -- currently estimated to occur only once every 1000 years, would occur roughly every 5 to 10 years in that future world with 2°C of global warming.

In summary, an event such as the Pacific Northwest 2021 heatwave is still rare or extremely rare in today's climate, yet would be virtually impossible without human-caused climate change. As warming continues, it will become a lot less rare.

Our results provide a strong warning: our rapidly warming climate is bringing us into uncharted territory that has significant consequences for health, well-being, and livelihoods. Adaptation and mitigation are urgently needed to prepare societies for a very different future. Adaptation measures need to be much more ambitious and take account of the rising risk of heatwaves around the world, including surprises such as this unexpected extreme. Deaths from extreme heat can be dramatically reduced with adequate preparedness action. Heat action plans that incorporate heatwave early warning systems can strengthen the resilience of cities and people. In addition, longer-term plans are needed to modify our built environments to be more adequate for the hotter climate that we already experience today and the additional warming that we expect in future. In addition, greenhouse gas mitigation goals should take into account the increasing risks associated with unprecedented climate conditions if warming would be allowed to continue

1 Introduction

During the last days of June 2021, Pacific northwest areas of the U.S. and Canada experienced temperatures never previously observed, with records broken in multiple cities by several degrees Celsius. Temperatures far above 40 ºC (104 ºF) occurred on Sunday 27 to Tuesday 29 June (Figs 1a,b for Monday) in the Pacific northwest areas of the U.S. and western Provinces of Canada, with the maximum warmth moving from the western to the eastern part of the domain from Monday to Tuesday. The anomalies relative to normal maximum temperatures for the time of year reached 16°C to 20 ºC (Figs 1c,d). It is noteworthy that these record temperatures occurred one whole month before the climatologically warmest part of the year (end of July, early August), making them particularly exceptional. Even compared to the maximum temperatures in other years independent of the considered month, the recent event exceeds those temperatures by about 5 ºC (Figure 2). Records were shattered in a very large area, including setting a new all-time Canadian temperature record in the village of Lytton, at which a temperature of 49.6 ºC was measured on June 29[1,2,3,4], and where wildfires spread on the following day[3]

[1] https://public.wmo.int/en/media/news/june-ends-exceptional-heat
[2] https://www.cbc.ca/news/canada/british-columbia/canada-bc-alberta-heat-wave-heat-dome-temperature-records-1.6084203
[3] https://www.cbc.ca/news/canada/british-columbia/bc-wildfires-june-30-2021-1.6085919
[4] https://www.reuters.com/business/environment/wildfire-forces-evacuation-residents-small-western-canada-town-2021-07-01/

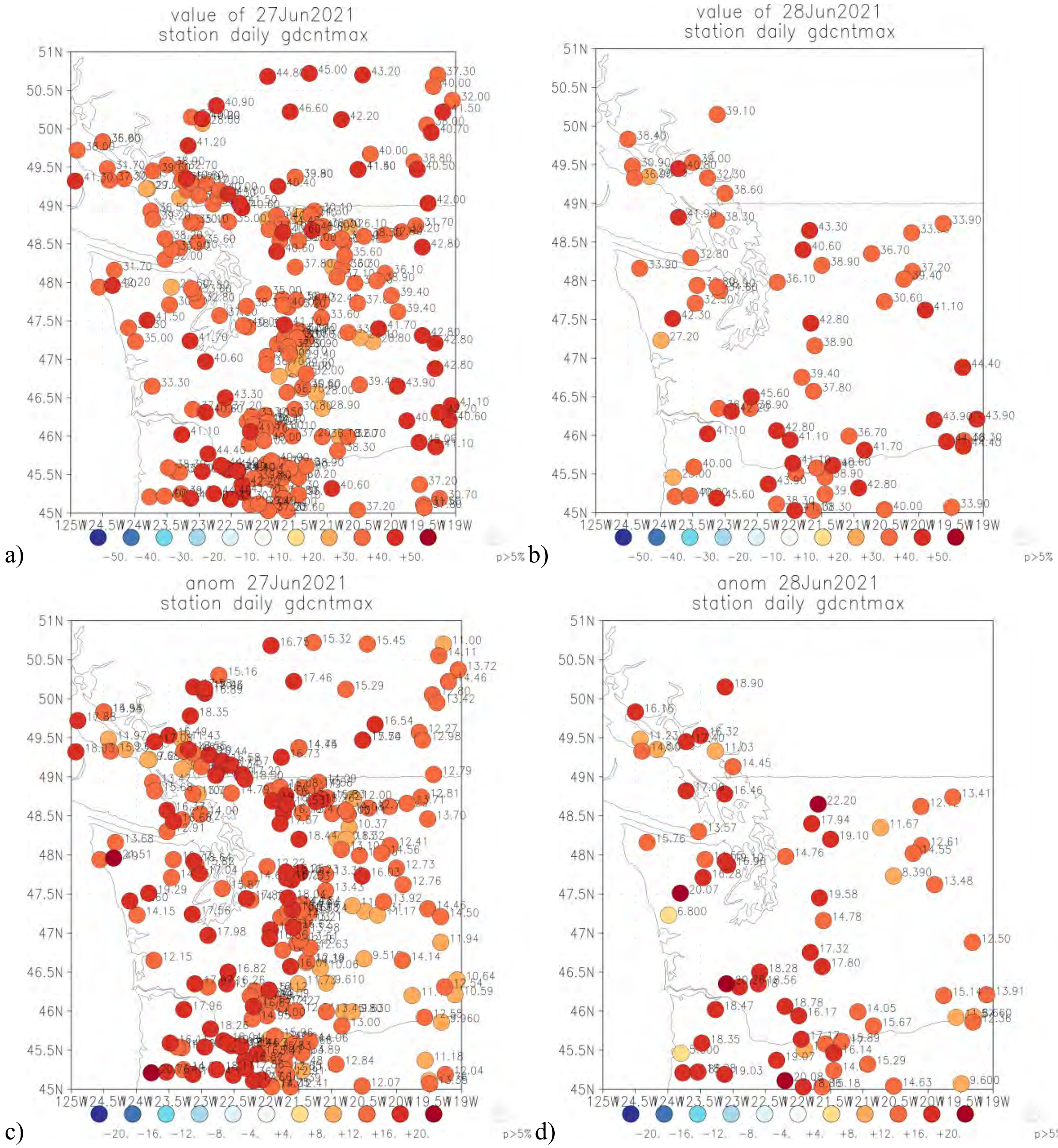


Figure 1. a) observed temperatures on 27 June 2021, b) 28 June 2021, c,d) same for anomalies relative to the whole station records.

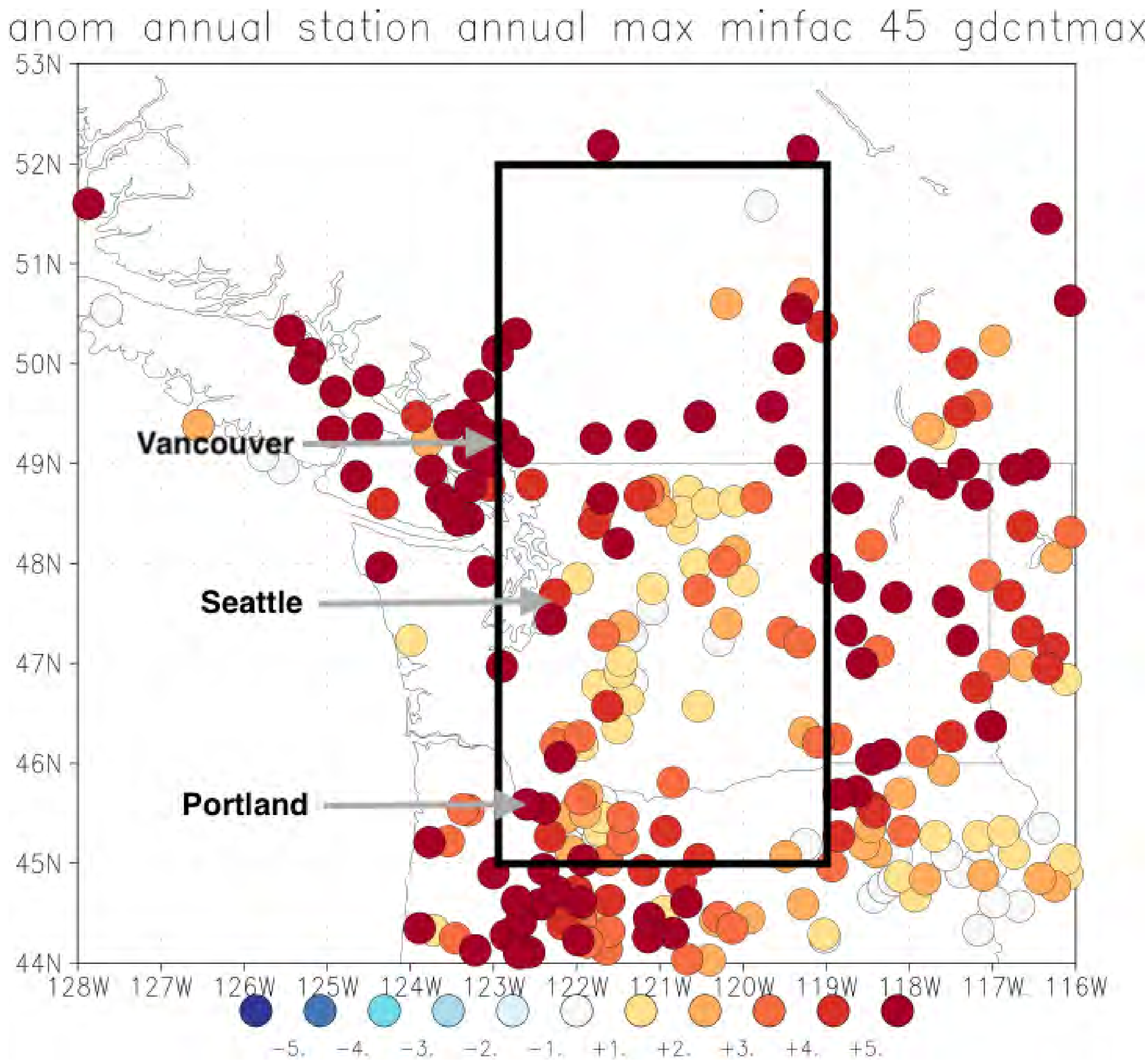


Figure 2. Anomalies of 2021 highest daily maximum temperature (TXx) relative to the whole time series, assuming the rest of the summer is cooler than this heatwave. Note that some stations do not have data up to the peak of the heatwave yet and hence underestimate the event. Negative values certainly do not include the heatwave and have therefore been deleted. The black box indicates the study region. Source: GHCN-D downloaded 4 July 2021.

Given that the observed temperatures were so far outside historical experiences and in a region with only about 50% household air conditioning penetration, we expect large impacts on health. The excess deaths numbers will only be available in 3–6 months (Canada) or a year (US), but preliminary indications from Canada are that it has already caused at least several hundreds of extra deaths[5,6].

[5] https://www.bbc.com/news/world-us-canada-57668738
[6] https://www.washingtonpost.com/world/2021/06/29/canada-heat-dome-deaths/

The present report aims to investigate the role of human-induced climate change in the likelihood and intensity of this extreme heatwave, following the established methods of multi-model multi-method approach of extreme event attribution (Philip et al., 2020; van Oldenborgh et al., 2021). We focus the analysis on the maximum temperatures in the region where most people have been affected by the heat (45 °N–52 ºN, 119 °W–123 ºW) including the cities of Seattle, Portland, and Vancouver. While the extreme heat was an important driver of the observed impacts, it is important to highlight that the meteorological extremes assessed here only partly represent one component of these described impacts, the hazard, whereas the impacts strongly depend on exposure and vulnerability too, as well as other climatological components of the hazard. In addition to the attribution of the extreme temperatures we qualitatively assess whether meteorological drivers and antecedent conditions played an important role in the observed extreme temperatures in section 7.

1.1 Event definition

Daily maximum temperatures were the headline figure in the large number of media reports describing the heatwave and the impacts associated with the event. Furthermore, daily maximum temperature was the primary extreme characteristic of the event. We therefore defined the event based on the annual maximum of daily maximum temperature, TXx. There is some evidence that longer time scales, e.g. 3-day average, better describe the health impacts (e.g., D'Ippoliti et al, 2010). However, TXx is a standard heat impact index and thus the results can easily be compared to other studies. High minimum temperatures also have strong impacts on human health. However, here we intentionally focus on one event definition to keep this rapid analysis succinct, choosing TXx, which not only characterises the extreme character of the event but is also readily available in climate models allowing us to use a large range of different models.

As the spatial scale of the event we consider the area 45°N-52°N, 119°W-123°W. This covers the more populated region around Portland, Seattle and Vancouver that were impacted heavily by the heat (with a total population of over 9.4 million in their combined metropolitan areas), but excludes the rainforest to the west and arid areas to the east. Note that this spatial event definition is based on the expected and reported human impacts rather than on the meteorological extremity. Besides this main definition we also analysed the observations for three stations in Portland, Seattle and Vancouver with long homogeneous time series.

1.2 Previous trends in heatwaves

Figure 3 shows the observed trends in TXx in the GHCN-D dataset over 1900–2019. The stations were selected on the basis of long time series, at least 50 years of data, and being at least 2º apart. The trend is defined as the regression on the global mean temperature, so the numbers represent how much slower or faster than the global mean the temperature has changed. Individual stations with different trends than nearby stations usually have inhomogeneities in the observational method or local environment.The negative trends in eastern North America and parts of California are well-understood to be the result of land use changes, irrigation and changes in agricultural practice (Cook et al., 2011; Donat et al., 2016, 2017; Thiery et al., 2017, Cowan et al., 2020). The large trends in heatwaves in Europe are not yet understood (Vautard et al, 2020). The Pacific Northwest showed trends of about two times the global temperature trend up to 2019.

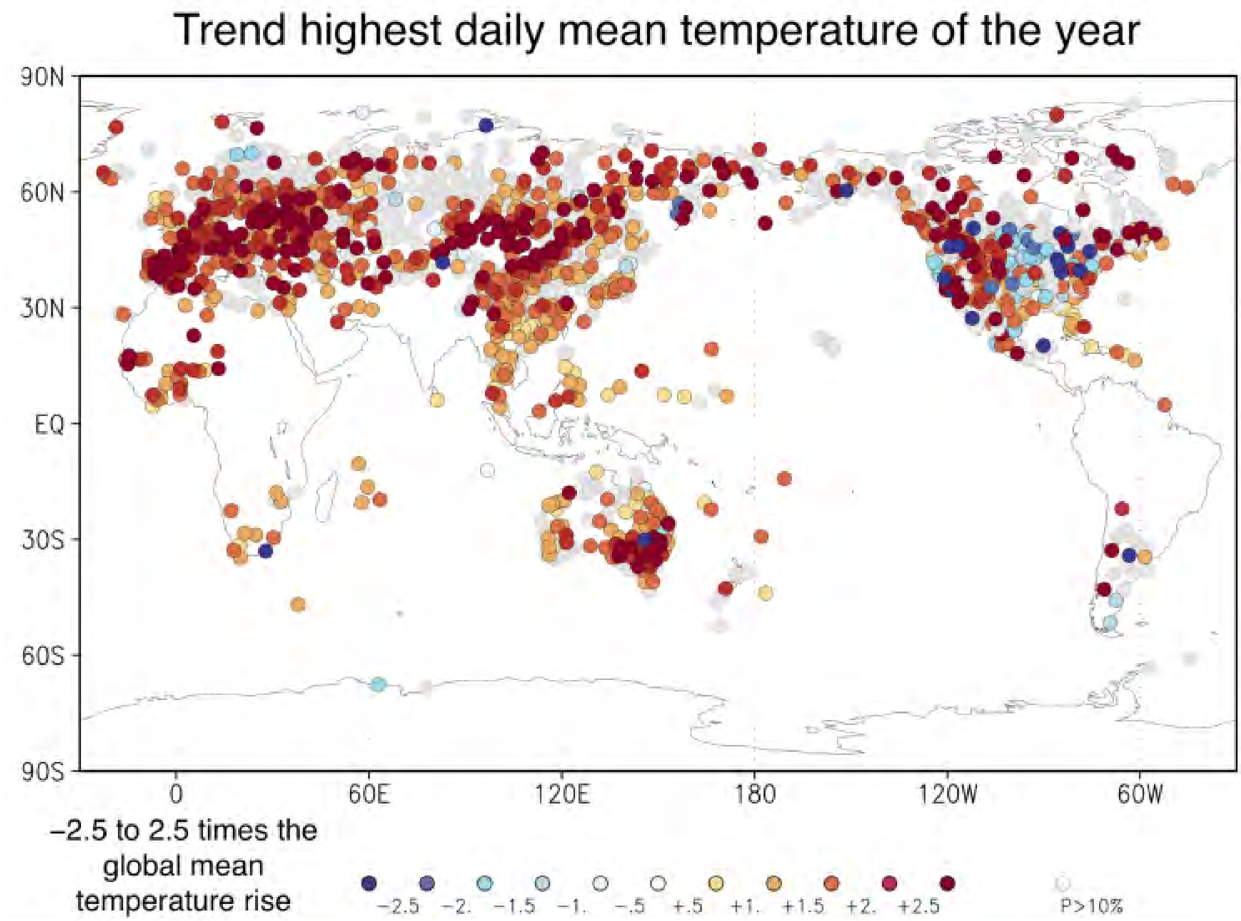


Figure 3. Trends in the highest daily maximum temperature of the year in the GHCN-D station data. Stations are selected to have at least 50 years of data and at least 2º apart. The trend is defined by the regression on the global mean temperature.

2 Data and methods

2.1 Observational data

The main dataset used to represent the heatwave is the ERA5 reanalysis (Hersbach et al., 2020), extended to the time of the heatwave by ECMWF operational analyses produced using a later version of the same model. All fields were downloaded at 0.25º resolution from the ECMWF. Both products are the optimal combination of observations, including near-surface temperature observations from meteorological stations, and the high-resolution ECMWF weather forecast model IFS. Due to the constraints of the surface temperature observations, we expect no large biases between the main dataset and the extension, although some differences may be possible under these extreme conditions.

Temperature observations were collected to directly assess the probability ratios and return periods associated with the event for the three major cities in the study area; Portland, Seattle, and Vancouver. Observing sites were chosen that had long homogenized historical records and were representative of the severity of the event by avoiding exposure to nearby large water bodies. Sites were also chosen to be representative of the populous areas of each city to better illuminate impact on inhabitants.

For Portland, the Portland International Airport National Weather Service station was used, which has continuous observations over 1938–2021. The airport is located close to the city centre, adjacent to the Columbia River. The river's influence is thought to be small and the water temperature is warm by June. For Seattle, Seattle-Tacoma International Airport was chosen, which has almost continuous observations 1948–2021, among the longest records in the Seattle area. This location is further inland and lacks the influence of Lake Washington that downtown Seattle has. Two long records exist adjacent to downtown Vancouver, but they are both very exposed to the Georgia Strait that influenced observations due to local onshore flow during the peak of the event. A record was chosen further inland at New Westminster. The observations start in 1875 but here are data gaps 1882–1893, 1928, 1980–1993.

The data for Portland International Airport and Seattle-Tacoma International Airport were gathered from the Global Historical Climatology Network Daily (GHCN-D; Menne et al., 2012) while data for New Westminster were gathered from the Adjusted Homogenized Canadian Climate Dataset (AHCCD) for daily temperature (Vincent et al., 2020). The AHCCD dataset is updated annually and ends in 2020. Data for 2021 were appended from unhomogenized recent records from Environment and Climate Change Canada. Overlapping data for 2020 were compared between the two sources and found to be identical except several duplicate/missing observations which would not cause error in the present analysis because the records are complete for June, 2021.

As a measure of anthropogenic climate change we use the global mean surface temperature (GMST), where GMST is taken from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Science (GISS) surface temperature analysis (GISTEMP, Hansen et al., 2010 and Lenssen et al. 2019). We apply a 4-yr running mean low-pass filter to suppress the influence of ENSO and winter variability at high northern latitudes as these are unforced variations.

2.2 Model and experiment descriptions

Model simulations from the 6th Coupled Model Intercomparison Project (CMIP6; Eyring et al., 2016) are assessed. We combine the historical simulations (1850 to 2015) with the Shared Socioeconomic Pathway (SSP) projections (O'Neill et al., 2016) for the years 2016 to 2100. Here, we only use data from SSP5-8.5, although the pathways are very similar to each other over the period 2015–2021. Models are excluded if they do not provide the relevant variables, do not run from 1850 to 2100, or include duplicate time steps or missing time steps. All available ensemble members are used. A total of 18 models (88 ensemble members), which fulfill these criteria and passed the validation tests (Section 4), are used.

In addition to the CMIP6 simulations, the ensemble of extended historical simulations from the IPSL-CM6A-LR model is used (see Boucher et al., 2020 for a description of the model). It is composed of 32 members, following the CMIP6 protocol (Eyring et al., 2016) over the historical period (1850-2014) and extended until 2029 using all forcings from the SSP2-4.5 scenario, except for the ozone concentration which has been kept constant at its 2014 climatology (as it was not available at the time of performing the extensions). This ensemble is used to explore the influence of internal variability.

The GFDL-CM2.5/FLOR (Vecchi et al., 2014) is a fully coupled climate model developed at the Geophysical Fluid Dynamics Laboratory (GFDL). While the ocean and ice components have a horizontal resolution of only 1 degree, the resolution of the atmosphere and land is about 50 km and therefore might provide a better simulation of certain extreme weather events (Baldwin et al. 2019). The data used in this study cover the period from 1860 to 2100, and include both the historical and RCP4.5 experiments driven by transient radiative forcings from CMIP5 (Taylor et al., 2012).

We also examine five ensemble members of the AMIP experiment (1871-2019) from the GFDL-AM2.5C360 (Yang et al. 2021, Chan et al. 2021), which consists of the atmosphere and land components of the FLOR model but with horizontal resolution doubled to 25 km for a potentially better representation of extreme events.

The Climate of the 20th Century Plus project (C20C+) was designed specifically for event attribution studies (Stone et al. 2019). The experimental design uses models of the atmosphere and land with prescribed sea surface temperatures and sea ice concentrations, similar to the AMIP experiment. To quantify the impact, if any, on extreme events, participating models were run in two configurations. The first followed AMIP protocols to represent the actual world — "world as it was". The second represented a counterfactual "world that might have been" without the anthropogenic climate by suitably altering the prescribed sea surface temperature and ice boundary conditions as well as atmospheric trace gas compositions. The distributions of TXx in the study area were examined in three C20C+ models, CAM5.1, MIROC5 and HadGEM3-A-N216 and compared to that of the ERA5 reanalysis. Only the Community Atmospheric Model (CAM5.1), run at the default ~1º resolution, satisfied the requirements of this study in the statistical description of heat extremes. The model is described in Neale et al. (2010). The actual world ensemble consists of 99 simulations of mixed duration all ending in 2018 resulting in a sample size of 4090 years. A counterfactual world ensemble of similar size consists of 89 simulations resulting in a sample size of 3823 years.

2.3 Statistical methods

A full description of the statistical methods is given in Philip et al (2020) and van Oldenborgh et al (2021). Here we give a summary.

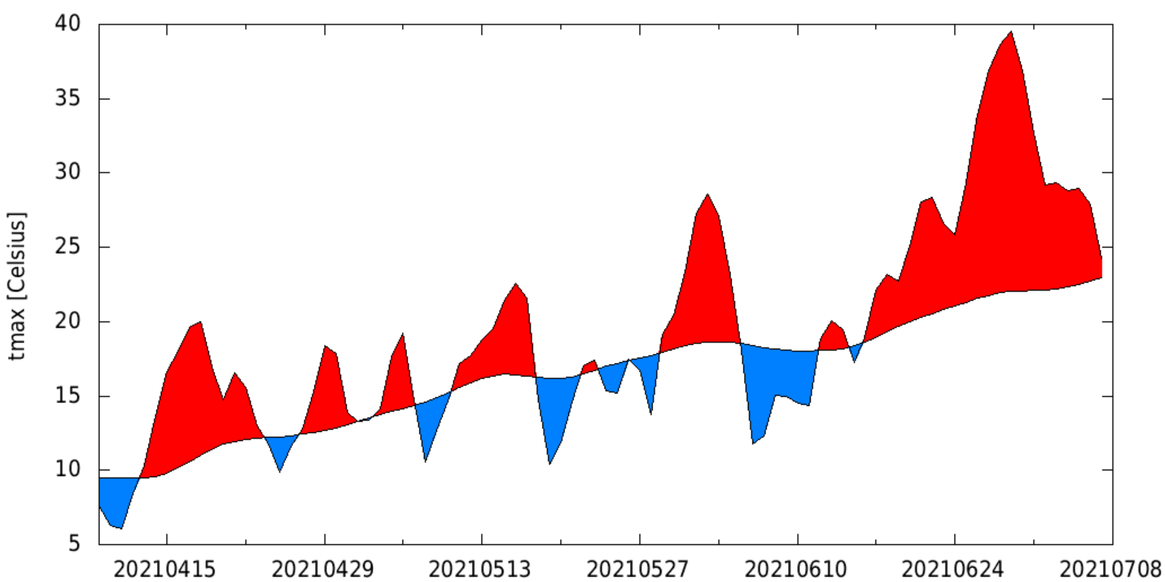
As discussed in section 1.2, we analyse the annual maximum of daily maximum temperatures (TXx) averaged over 45°N-52°N, 119°W-123°W. Initially, we analyse reanalysis data and station data from sites with long records. Next, we analyse climate model output for the same metric. We follow the steps outlined in the WWA protocol for event attribution. The analysis steps include: (i) trend calculation from observations; (ii) model validation; (iii) multi-method multi-model attribution and (iv) synthesis of the attribution statement.

For the event under investigation we calculate the return periods, probability ratio (PR) and change in intensity as a function of GMST. The two climates we compared are defined as the current 2021 event and a GMST value representative of the climate of late nineteenth century, −1.2 ºC relative to 2021 (1850-1900, based on the Global Warming Index https://www.globalwarmingindex.org). To statistically model the selected event, we use a GEV distribution that shifts with GMST, i.e., the location parameter has a term proportional to GMST and the scale and shape parameters are assumed constant. Next, results from observations and from the models are synthesized into a consistent attribution statement. For models (except for IPSL-CM6A-LR and CAM5.1), we additionally analyse the PR between a future climate at +2°C above the 1850-1900 reference, which is equivalent to +0.8°C above the current climate of 2021. For this analysis we use model data up to about 2050 or when the model GMST reaches +0.8 ºC compared to now.

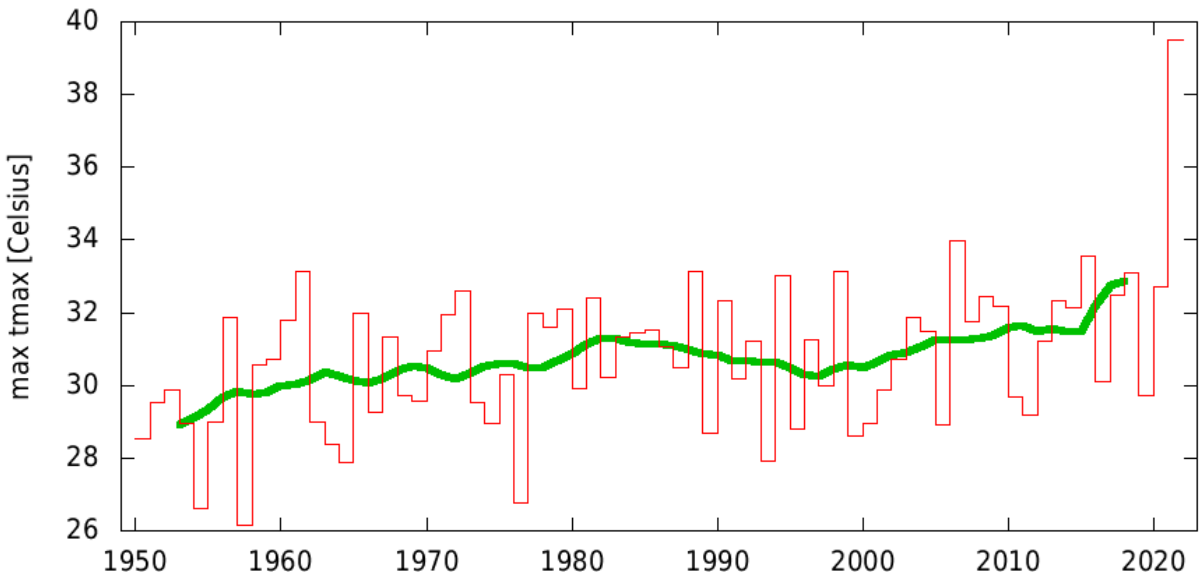
The CMIP6 data are analysed using the same statistical models as the main method. However, the parameter uncertainty is estimated in a Bayesian setting using a Markov Chain Monte Carlo (MCMC) sampler instead of a bootstrapping approach.

3 Observational analysis: return time and trend

Time series of various aspects of the main index are shown in Figure 4: a) the last 90 days combined from ERA5 up to 30 May, ECMWF analyses up to 29 June, ECMWF forecast up to 7 July; and b) annual max of the series. The value for 2021, 39.5 ºC, is 5.5 ºC above the previous record of 34.0 ºC, which is an extremely large increase that gives rise to difficulties in the statistical analysis described in Section 3.1.



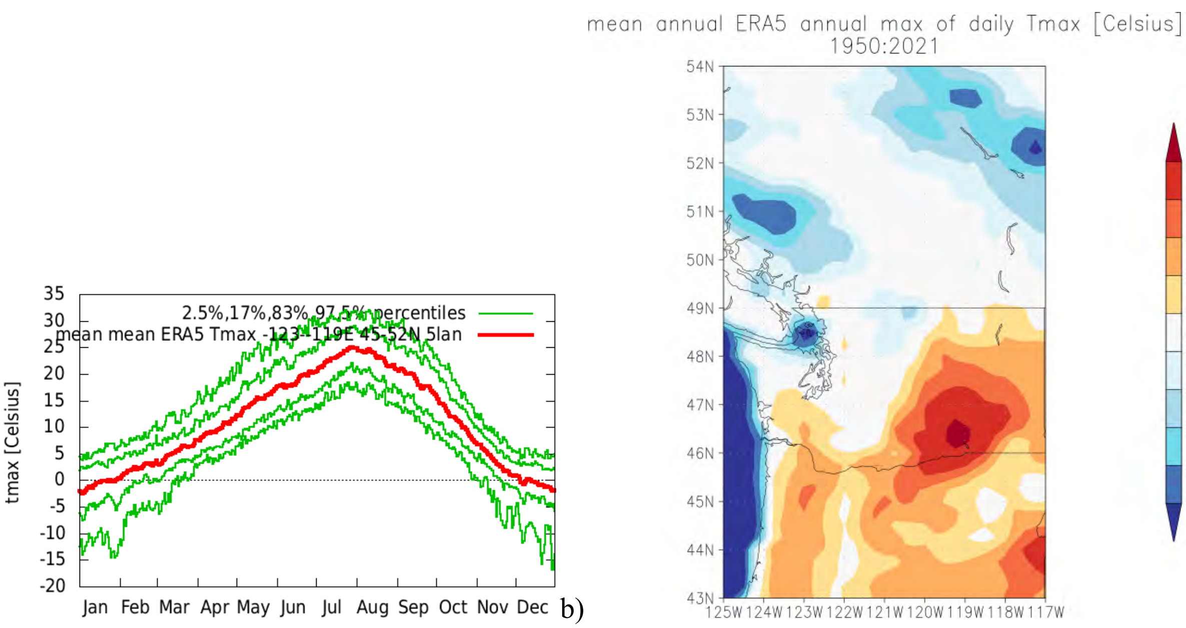
a)



b)

Figure 4. a) Last 90 days of the average temperature over the study area based on ERA5 (up to 30 May 2021), ECMWF analyses (up to 29 June 2021) and forecasts (up to 7 July 2021), with positive and negative departures from the 1991–2020 climatological mean of daily maximum temperature shaded red and blue, respectively. b) Annual maximum of the index series with a 10-yr running mean (green line).

In Figure 5a we show the seasonal cycle of the daily maximum temperature averaged over the index region and in Figure 5b the spatial pattern of the annual maximum of the daily maximum temperature at each grid point. These are also used in the model validation procedure.



a) b)

Figure 5. a) Seasonal cycle of Tmax averaged over the land points of 45–52 ºN, 119–123 ºW. b) Spatial pattern of the 1950–2021 mean of the annual maximum of Tmax at each grid point. Based on ERA5.

3.1 Analysis of point station data and gridded data

Figure 6a shows our standard extreme value analysis and the challenge of applying it to this event. The distribution of our index including data up to 2020 is described very well by a GEV distribution that has linearly warmed at a rate about twice as fast as the GMST. This is consistent with the general characteristic of global warming that summers over continents warm faster than the global mean. The fit has a negative shape parameter ξ, which implies a finite tail, and hence an upper bound. In this case it is at 35.5±1.3 ºC (2σ uncertainty). However, the observed value in 2021, 39.5 ºC, is far above this upper bound. Therefore, this GEV fit with constant shape and scale parameters that excludes all information about 2021 is not a valid description of the heatwaves in the area.

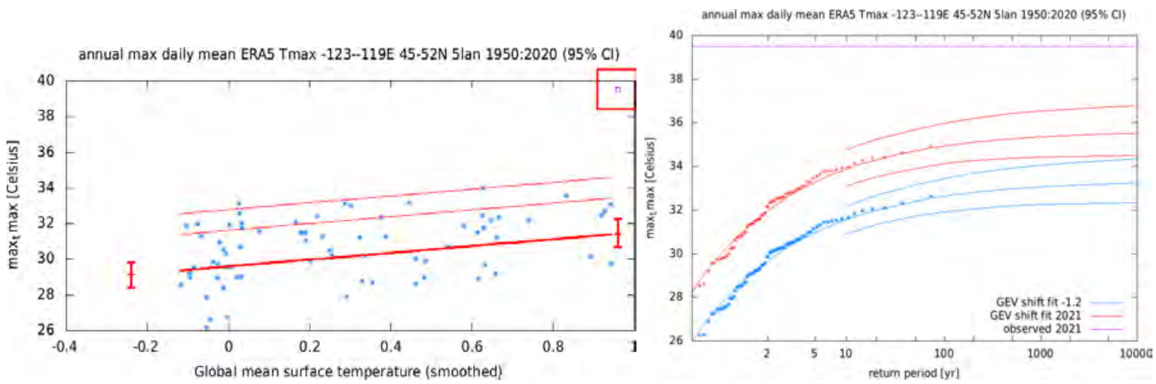


Figure 6. GEV fit with constant scale and shape parameters, and location parameter shifting proportional to GMST of the index series. No information from 2021 is included in the fit. Left: the observed TXx as a function of the smoothed GMST. The thick red line denotes the location parameter, the thin red lines the 6 and 40-yr return times. The June 2021 observation is highlighted with the red box and is not included in this fit. Right: Return time plots for the climate of 2021 (red) and a climate with GMST 1.2 ºC cooler (blue). The past observations are shown twice: once shifted up to the current climate and once shifted down to the climate of the late nineteenth century. Based on ERA5 extended with operational ECMWF analyses for June 2021.

An alternative to the standard approach of not using any information of the event under study to avoid a selection bias, is to use some of the information from the June 2021 heatwave, namely that it actually happened. Specifically, in the next fit we still assume that the data up to 2020 can be described by a GEV with constant scale and shape parameters, but we reject all GEV models in which the upper bound is below the value observed in 2021. In other words, we enforce a distribution that does not a priori reject the 2021 event as impossible. The result is shown in Figure 7. While the distribution now includes the 2021 event, the fit to the data up to and including the year 2020 is noticeably worse than when not taking 2021 into account. This suggests either a low-probability extreme or the contribution of non-linear effects to the event (Section 7). The return time for the 2021 event under these assumptions still has a lower bound of 10,000 years in the current climate. The fit differs from the previous one mainly in the shape parameter, which is now much less negative (about −0.2 instead of −0.4). This shifts the upper bound to higher values. The fit also gives a somewhat higher trend parameter.

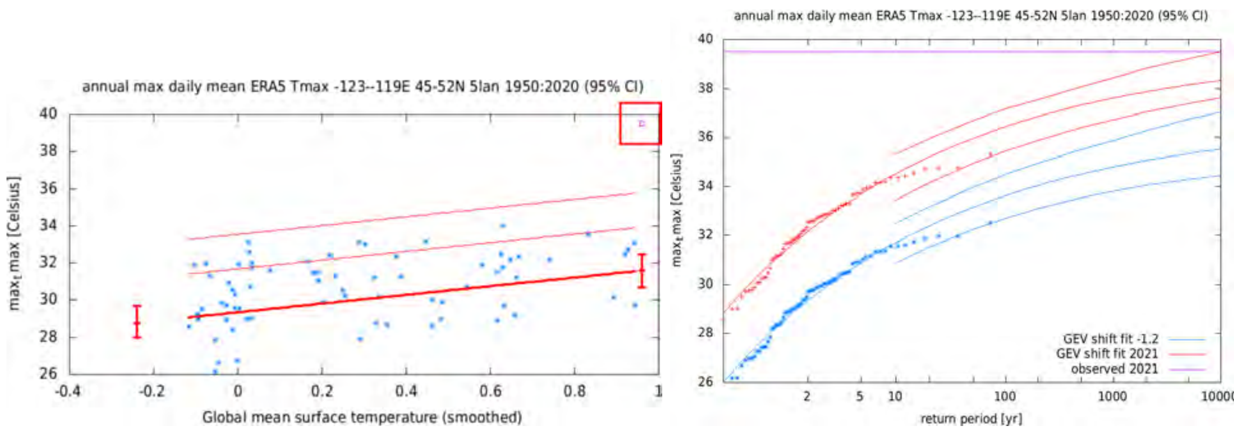


Figure 7. As Figure 6 but demanding the 2021 event is possible in the fitted GEV function, i.e., the upper bound is higher than the value observed in 2021.

The third possibility is to fit the GEV distribution over all available data, including 2021. This yields a return time of 1,000 years (95% CI >100 yr). This approach implicitly assumes that the 2021 event is drawn from the same distribution. This would not be the case if it would be selected from a large pool of time series to have as large a return time as possible. In that case it would be drawn from a larger distribution and could be expected to have a high extreme with a high return period due to selection bias. This is only partly the case here as we did choose the region because the heat was exceptional there. However, we also based our exact choice on population density and type of terrain, parameters that are more independent of the heatwave. The return time of 1000 yr is therefore possibly overestimated. However, this approach uses all information available and assumes this was just a chance event. We use this third approach thus as the best estimate, although follow-up research will be necessary to assess if possible non-linear effects could be consistent with the behaviour found with the other two fits (see also Section 7).
This fit gives a 95% CI of 1.4 to 1.9 K for the scale parameter σ and -0.5 to 0.0 for the shape parameter ξ. These values are used in section 4, the model validation.

The detection results, i.e., the comparison of the fit for 2021 and for a pre-industrial climate, show an increase in intensity of TXx of $\Delta T = 3.1$ ºC (95% CI: 1.1 to 4.7 ºC) and a probability ratio PR of 350 (3.2 to ∞).

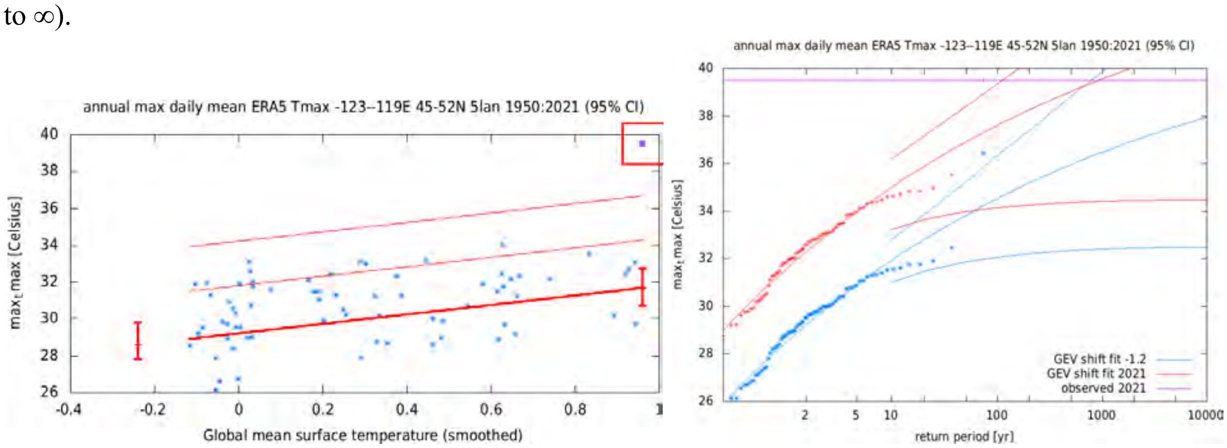


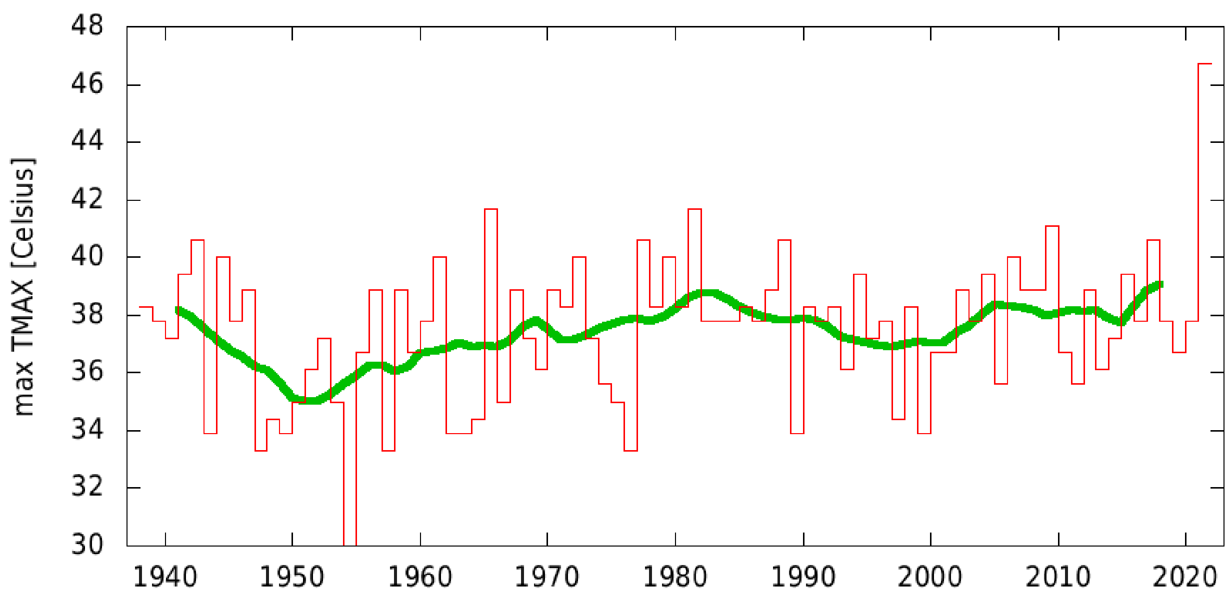
Figure 8. As for Figure 6 but including data from the 2021 heatwave into the fit.

We can give a very rough estimate of the global return time of a sudden jump in TXx with a similar return time. Assuming it was just a chance event, the heatwave covers an area of O(1500 km)², which is about 1.5% of the land area of the world. From this we can estimate the return time of a similar heatwave in terms of low probability and area covered, as there are about 1/(1.5%) ~ 60 independent areas in which it could have occurred. This implies that the return time of an event as rare as this one or rarer, somewhere over land, is 60 times larger than the O(1000 yr) that it occurred at the specific location that it did. This gives a very rough estimate of O(15 yr) with a lower bound of O(1.5 yr) to have such an improbable heatwave somewhere on the land of the earth. It is therefore conceivable that it was pure chance that it happened at this location. Further research on this and other exceptional heatwaves will be needed to determine whether this estimate is indeed realistic.

3.2 Analysis of temperature in Portland, Seattle and Vancouver

For Portland we choose the International Airport station, which is located on the northern edge of the city and has data starting in April 1938 and continuing until yesterday in the GHCN-D v2 database. Figure 9 (top panel) shows the annual maxima of the Portland station time series, assuming there will be no higher value during the rest of the summer. The record before this year was 41.7 ºC in 1965 and 1981, and TXx reached 46.7 °C this year, so the previous record was broken by 5.0 ºC.

We fit a GEV distribution to this data, including 2021 (Figure 9, lower panels). It gives a return time of 700 yr with a lower bound of 70 yr. For the PR we can only give a lower bound of 6, the best estimate is infinite. This corresponds to an increase in temperature of 3.4 ºC with a large uncertainty of 0.3 to 5.3 ºC. The large uncertainties are due to the somewhat shorter time series and large variability at this station.



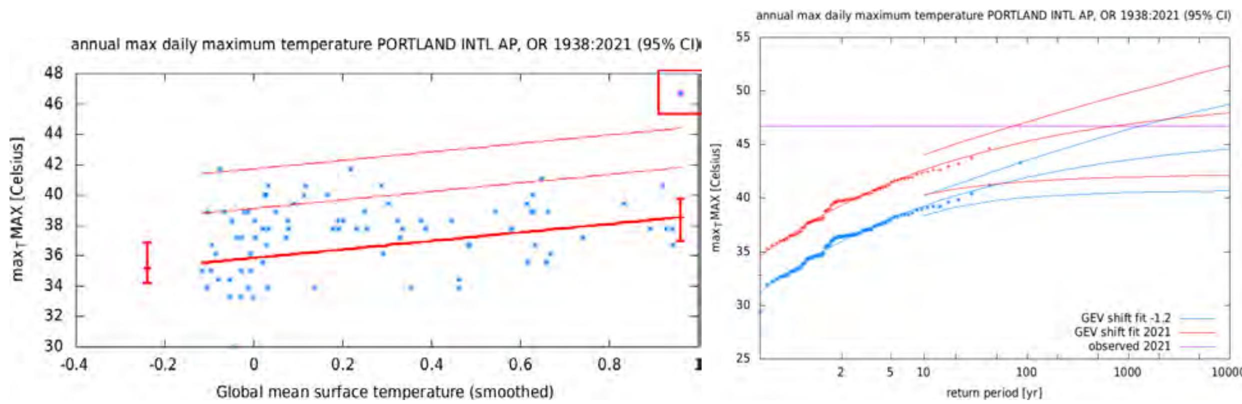
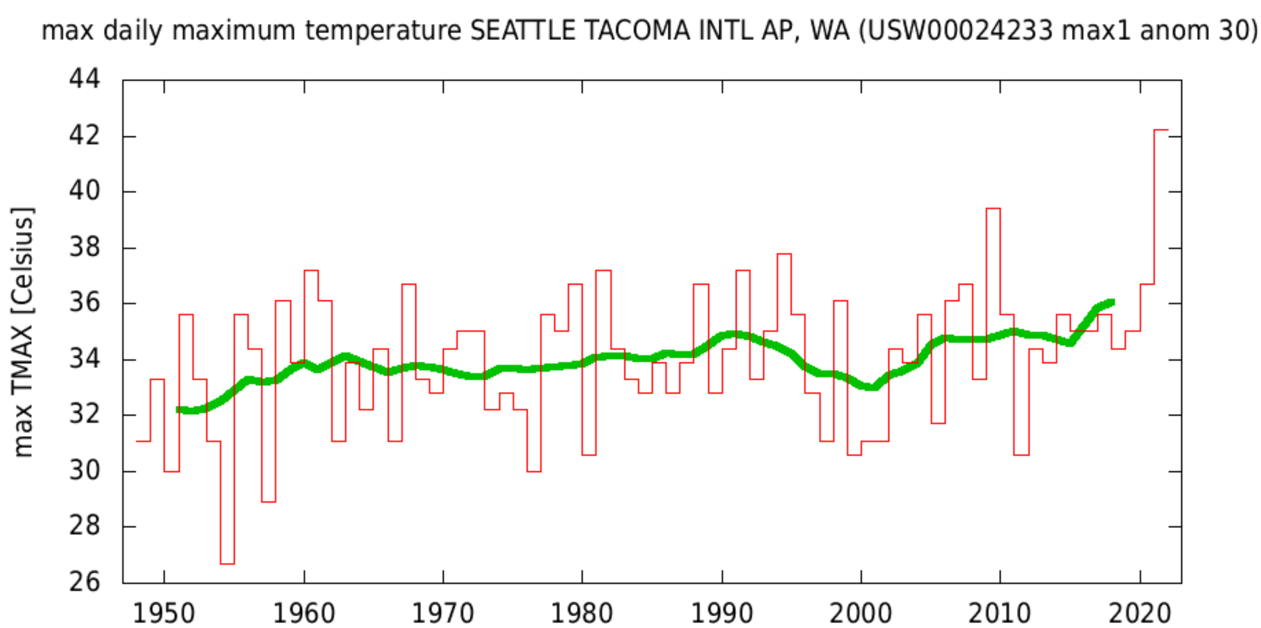


Figure 9: Top: time series of observed highest daily maximum temperature of the year at Portland International Airport. Bottom: as Figure 8 but for the station data at Portland International Airport. Source: data GHCN-D, fit: KNMI Climate Explorer.

In Seattle, the only station with a sufficiently long time series that includes 2021 is Seattle-Tacoma International Airport. It is located ~15 km south of the city but has similar terrain, without the upstream lakes of the city itself. The previous record was 39.4 ºC in 2009, and this year it reached 42.2 ºC. This is still a large increase of 2.8 ºC over the previous record. The event was also not quite as improbable, with a return time of 300 yr (lower bound 40 yr) in the current climate (Figure 10). The PR is again infinite with a lower bound of 7, and the increase in temperature from a late nineteen century climate is 3.8 ºC (0.7 to 5.7 ºC).



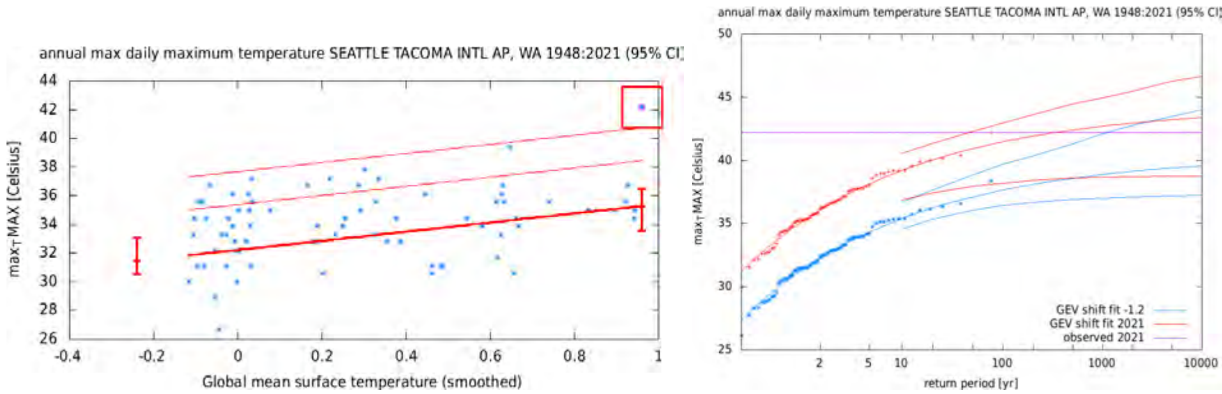
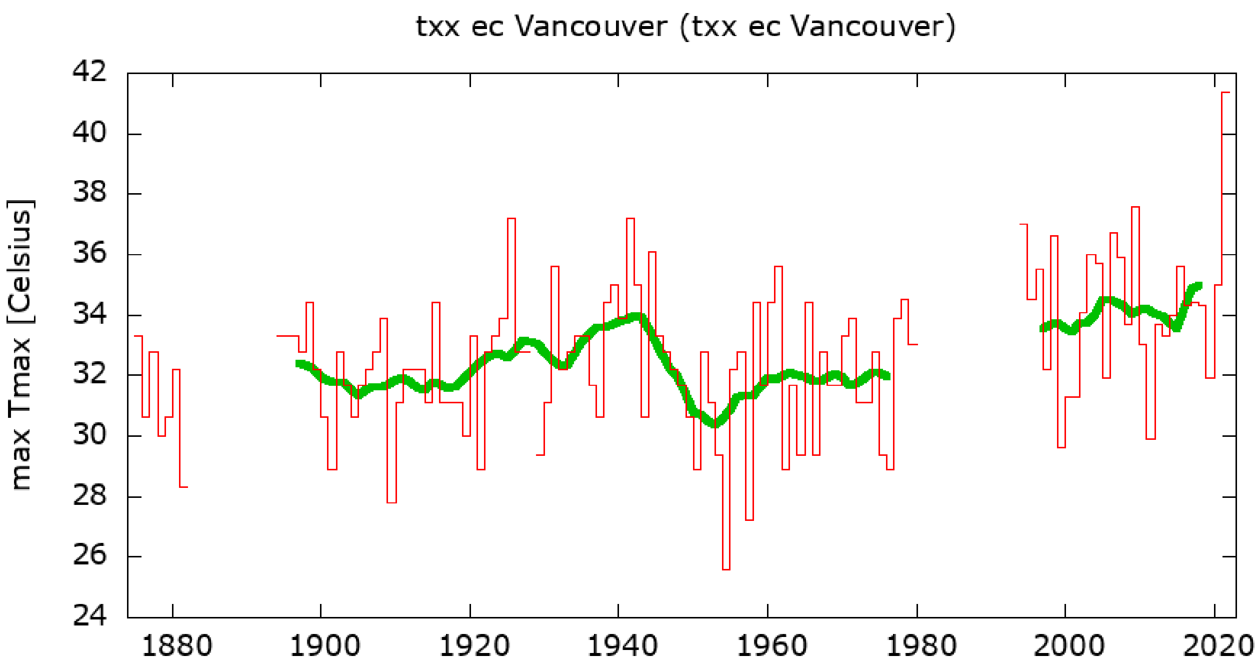


Figure 10: as Figure 9 but for the station data at Seattle-Tacoma International Airport. Source: data GHCN-D, fit: KNMI Climate Explorer.

In the Vancouver area the most representative station with fewest missing data is New Westminster. It has data from 1875 to 2021 with a few gaps. The previous record was 37.6 ºC in 2009, and in 2021 a temperature of 41.4 ºC was observed, 4.0 ºC warmer. A GEV fit including 2021 gives a return time of 1000 yrs with a lower bound of 70 yr (Figure 11). The PR is infinite with a lower bound of 170, and the temperature has increased by 3.4 (1.9 to 5.5) ºC.



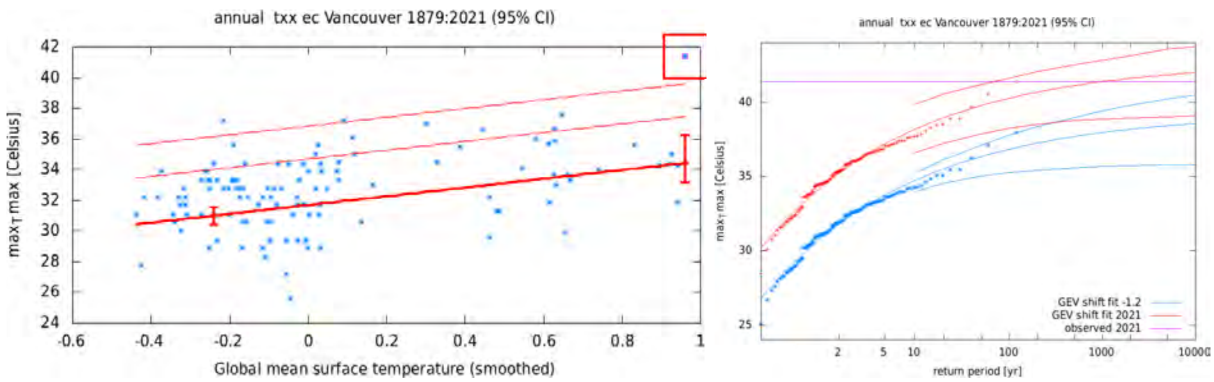


Figure 11: as Figure 9 but for the station data at New Westminster. Source: data EC, fit: KNMI Climate Explorer.

4 Model evaluation

In this section we show the results of the model validation. The validation criteria assess the similarity between the modelled and observed seasonal cycle, the spatial pattern of the climatology, and the scale and shape parameters of the GEV distribution. The assessment results in a label "good", "reasonable" or "bad", according to the criteria defined in Philip et al. 2020. In this study, we use models that are labelled "good" or "reasonable". However, if five or more models classify as "good" within a particular framing such as the CMIP6 models, then we do not include all of the "reasonable" models but only those that pass the test on fit parameters as "good". Table 1 shows the model validation results. The full table including also the models that did not pass the validation tests is given in Table 3. 21 models and a combined 224 ensemble members passed the validation test.

Table 1. Validation results for models that pass the validation tests on seasonal cycle, spatial pattern and GEV scale and shape fit parameters sigma. Observations in blue, models in black.

Model / Observations	**Seasonal cycle**	**Spatial pattern**	**Sigma**	**Shape parameter**	**Conclusion**
ERA5			1.70 (1.40 ... 1.90)	-0.200 (-0.500 ... 0.00)	
GFDL-CM2.5/FLOR historical-rcp45 (5)	good	good	2.01 (1.84 ... 2.17)	-0.201 (-0.272 ... -0.144)	reasonable, include as different experiment than most other models
ACCESS-CM2 historical-ssp585 (2)	good	good	1.86 (1.71 ... 2.02)	-0.200 (-0.260 ... -0.120)	good
AWI-CM-1-1-MR historical-ssp585 (1)	good	good	1.50 (1.35 ... 1.69)	-0.200 (-0.280 ... -0.110)	good
CNRM-CM6-1 historical-ssp585 (1)	good	good	1.54 (1.39 ... 1.72)	-0.210 (-0.290 ... -0.100)	good
CNRM-CM6-1-HR historical-ssp585 (1)	good	good	1.48 (1.33 ... 1.66)	-0.190 (-0.270 ... -0.100)	good

CNRM-ESM2-1 historical-ssp585 (1)	good	good	1.71 (1.54 ... 1.92)	-0.180 (-0.250 ... -0.0900)	good
CanESM5 historical-ssp585 (50)	good	reasonable	1.79 (1.76 ... 1.82)	-0.180 (-0.190 ... -0.170)	reasonable, include because statistical parameters good
EC-Earth3 historical-ssp585 (3)	good	good	1.87 (1.76 ... 2.00)	-0.220 (-0.270 ... -0.170)	good
FGOALS-g3 historical-ssp585 (3)	good	reasonable	1.80 (1.69 ... 1.92)	-0.180 (-0.210 ... -0.140)	reasonable, include because statistical parameters good
GFDL-CM4 historical-ssp585 (1)	good	good	1.43 (1.29 ... 1.62)	-0.210 (-0.300 ... -0.110)	good
INM-CM4-8 historical-ssp585 (1)	good	good	1.63 (1.46 ... 1.83)	-0.210 (-0.300 ... -0.110)	good
INM-CM5-0 historical-ssp585 (1)	good	good	1.80 (1.63 ... 2.03)	-0.240 (-0.310 ... -0.140)	good
IPSL-CM6A-LR historical-ssp585 (6)	good	reasonable	1.79 (1.71 ... 1.88)	-0.220 (-0.250 ... -0.180)	reasonable, include because statistical parameters good
MIROC-ES2L historical-ssp585 (1)	reasonable, peaks about a month early	reasonable	1.46 (1.31 ... 1.65)	-0.190 (-0.300 ... -0.0900)	reasonable, include because statistical parameters good
MPI-ESM1-2-HR historical-ssp585 (2)	good	good	1.49 (1.39 ... 1.62)	-0.250 (-0.310 ... -0.190)	good
MPI-ESM1-2-LR historical-ssp585 (10)	good	good	1.63 (1.58 ... 1.69)	-0.260 (-0.280 ... -0.230)	good
MRI-ESM2-0 historical-ssp585 (2)	reasonable, peak too flat	good	1.41 (1.30 ... 1.53)	-0.280 (-0.340 ... -0.220)	reasonable, include because statistical parameters good
NESM3 historical-ssp585 (1)	good	good	1.48 (1.34 ... 1.67)	-0.290 (-0.370 ... -0.200)	good
NorESM2-MM historical-ssp585 (1)	good	good	1.90 (1.70 ... 2.12)	-0.250 (-0.350 ... -0.140)	in between reasonable and good, include
IPSL-CM6A-LR historical-ssp245 (32)	good, from CMIP6	reasonable, from CMIP6	1.69 (1.64 ... 1.75)	-0.220 (-0.250 ... -0.200)	reasonable, obs covar used, different from CMIP6 as different ssp scenario. Use both
CAM5-1-1degree C20C historical (99)	NA	NA	1.70 (1.68 ... 1.72)	-0.176 (-0.172 ... -0.180)	good, values used with warming level 1.7

5 Multi-method multi-model attribution

This section shows probability ratios and change in intensity ΔT for models that pass the validation tests and also includes the values calculated from the fits to observations (Table 2). Results are given both for changes in current climate (1.2°C) compared to the past (pre-industrial conditions) and, when available, for a climate at +2˚C of global warming above pre-industrial climate compared with current climate. The results are visualized in Section 6.

Table 2. Analysis results showing the model threshold for a 1-in-1000 year event in the current climate, and the probability ratios and intensity changes for the present climate with respect to the past (labelled "past") and for the +2C GMST future climate with respect to the present (labelled "future").

Model / Observations	**Threshold**	**Probability ratio PR - past [-]**	**Change in intensity ΔT - past [˚C]**	**Probability ratio PR - future [-]**	**Change in intensity ΔT - future [˚C]**
ERA5	39.5 ˚C	3.5e+2 (3.2 ... ∞)	3.1 (1.1 ... 4.7)		
GFDL-CM2.5/FLOR historical-rcp45 (5)	34 ˚C	6.5e+2 (16 ... ∞)	1.6 (1.2 ... 2.1)	4.6 (3.4 ... 12)	1.2 (1.0 ... 1.3)
ACCESS-CM2 historical-ssp585 (2)	35 ˚C	25 (2.3 ... ∞)	1.1 (0.41 ... 1.9)	45 (4.5 ... ∞)	1.2 (0.96 ... 1.4)
AWI-CM-1-1-MR historical-ssp585 (1)	36 ˚C	1.1e+4 (6.6 ... ∞)	1.6 (0.84 ... 2.3)	2.8e+2 (5.5 ... ∞)	1.3 (1.1 ... 1.6)
CNRM-CM6-1 historical-ssp585 (1)	34 ˚C	1.9 (0.0 ... ∞)	0.22 (-0.51 ... 0.95)	69 (3.4 ... ∞)	1.1 (0.76 ... 1.3)
CNRM-CM6-1-HR historical-ssp585 (1)	35 ˚C	5.2e+2 (5.4 ... ∞)	1.5 (0.73 ... 2.2)	56 (4.1 ... ∞)	1.3 (1.0 ... 1.5)
CNRM-ESM2-1 historical-ssp585 (1)	38 ˚C	1.5e+2 (3.6 ... ∞)	1.6 (0.68 ... 2.6)	15 (2.8 ... ∞)	0.97 (0.64 ... 1.3)
CanESM5 historical-ssp585 (50)	38 ˚C	1.6e+3 (2.6e+2 ... 6.7e+4)	2.0 (1.9 ... 2.1)	62 (32 ... 1.5e+2)	1.5 (1.4 ... 1.5)
EC-Earth3 historical-ssp585 (3)	38 ˚C	3.2e+2 (8.2 ... ∞)	1.3 (0.88 ... 1.7)	20 (5.2 ... 5.8e+2)	1.2 (1.1 ... 1.4)
FGOALS-g3 historical-ssp585 (3)	41 ˚C	71 (8.5 ... 2.1e+8)	1.5 (1.0 ... 2.0)	17 (5.2 ... 2.2e+2)	1.1 (0.87 ... 1.3)
GFDL-CM4 historical-ssp585 (1)	31 ˚C	∞ (14 ... ∞)	2.1 (1.3 ... 3.0)	∞ (16 ... ∞)	1.7 (1.4 ... 1.9)
INM-CM4-8 historical-ssp585 (1)	42 ˚C	∞ (28 ... ∞)	2.6 (1.7 ... 3.6)	2.7e+3 (6.5 ... ∞)	1.7 (1.4 ... 2.0)
INM-CM5-0 historical-ssp585 (1)	41 ˚C	∞ (14 ... ∞)	2.2 (0.95 ... 3.3)	∞ (12 ... ∞)	1.6 (1.3 ... 2.0)
IPSL-CM6A-LR historical-ssp585 (6)	34 ˚C	1.5e+5 (50 ... ∞)	1.7 (1.4 ... 2.0)	2.4e+2 (16 ... ∞)	1.3 (1.1 ... 1.4)
MIROC-ES2L historical-ssp585 (1)	33 ˚C	75 (1.3 ... ∞)	1.2 (0.040 ... 2.3)	12 (2.2 ... ∞)	0.71 (0.41 ... 1.0)
MPI-ESM1-2-HR historical-ssp585 (2)	34 ˚C	∞ (27 ... ∞)	1.4 (0.82 ... 1.9)	4.8e+4 (12 ... ∞)	1.2 (0.96 ... 1.4)

MPI-ESM1-2-LR historical-ssp585 (10)	32 ˚C	∞ (1.1e+11 ... ∞)	1.6 (1.4 ... 1.9)	∞ (1.8e+3 ... ∞)	1.3 (1.2 ... 1.4)
MRI-ESM2-0 historical-ssp585 (2)	32 ˚C	∞ (1.3e+2 ... ∞)	1.4 (0.86 ... 1.9)	13 (4.9 ... 54)	1.0 (0.84 ... 1.2)
NESM3 historical-ssp585 (1)	30 ˚C	∞ (1.1e+5 ... ∞)	2.5 (1.9 ... 3.2)	∞ (66 ... ∞)	1.5 (1.3 ... 1.7)
NorESM2-MM historical-ssp585 (1)	41 ˚C	∞ (11 ... ∞)	2.6 (1.3 ... 3.9)	4.3e+7 (7.0 ... ∞)	1.7 (1.3 ... 2.1)
IPSL-CM6A-LR historical-ssp585 (32)	34 ˚C	∞ (∞ ... ∞)	2.6 (2.4 ... 2.9)	-	-
CAM5-1-1degree C20C historical ()	43 ˚C	2.4e+2 (1.5e+2 ... 3.8e+2)	1.6 (1.5 ... 1.8)	-	-

6 Hazard synthesis

We calculate the probability ratio as well as the change in magnitude of the event in the observations and the models. We synthesise the models with the observations to give an overarching attribution statement (please see e.g. Kew et al. (2021) for details on the synthesis technique including how weighting is calculated for observations and for models). Observations and models are combined into a single result in two ways. Firstly, we neglect common model uncertainties beyond the averaged model spread that is depicted by the bright red bar, and compute the weighted average of models and observations: this is indicated by the magenta bar. The weighting applied is the inverse square of the variability (the width of the bright bars). As, due to common model uncertainties, model uncertainty can be larger than the model spread, secondly, we also show the more conservative estimate of an unweighted average of observations and models, indicated by the white box accompanying the magenta bar in the synthesis figures.

Figure 12 shows the synthesis results for the current vs. past climate; the results for the future vs. current climate are presented in Figure 13. Where the results for the probability ratio do not give a finite number we replace them by 10000, to allow all models to be included in the synthesis analysis. This means that the reported synthesized probability ratio gives a more conservative, lower value. For the intensity change we report the weighted synthesis value. For probability ratio we can only give a lower estimate of the range.

Results for current vs past climate, i.e. for 1.2°C of global warming vs pre-industrial conditions (1850-1900), indicate an increase in intensity of about 2.0 ˚C (1.2 ˚C to 2.8 ˚C) and a PR of at least 150. Model results for additional future changes if global warming reaches 2°C indicate another increase in intensity of about 1.3 ˚C (0.8 ˚C to 1.7 ˚C) and a PR of at least 3, with a best estimate of 175. This means that an event like the current one, that is currently estimated to occur only once every 1000 years, would occur roughly every 5 to 10 years in that future world with 2°C of global warming.

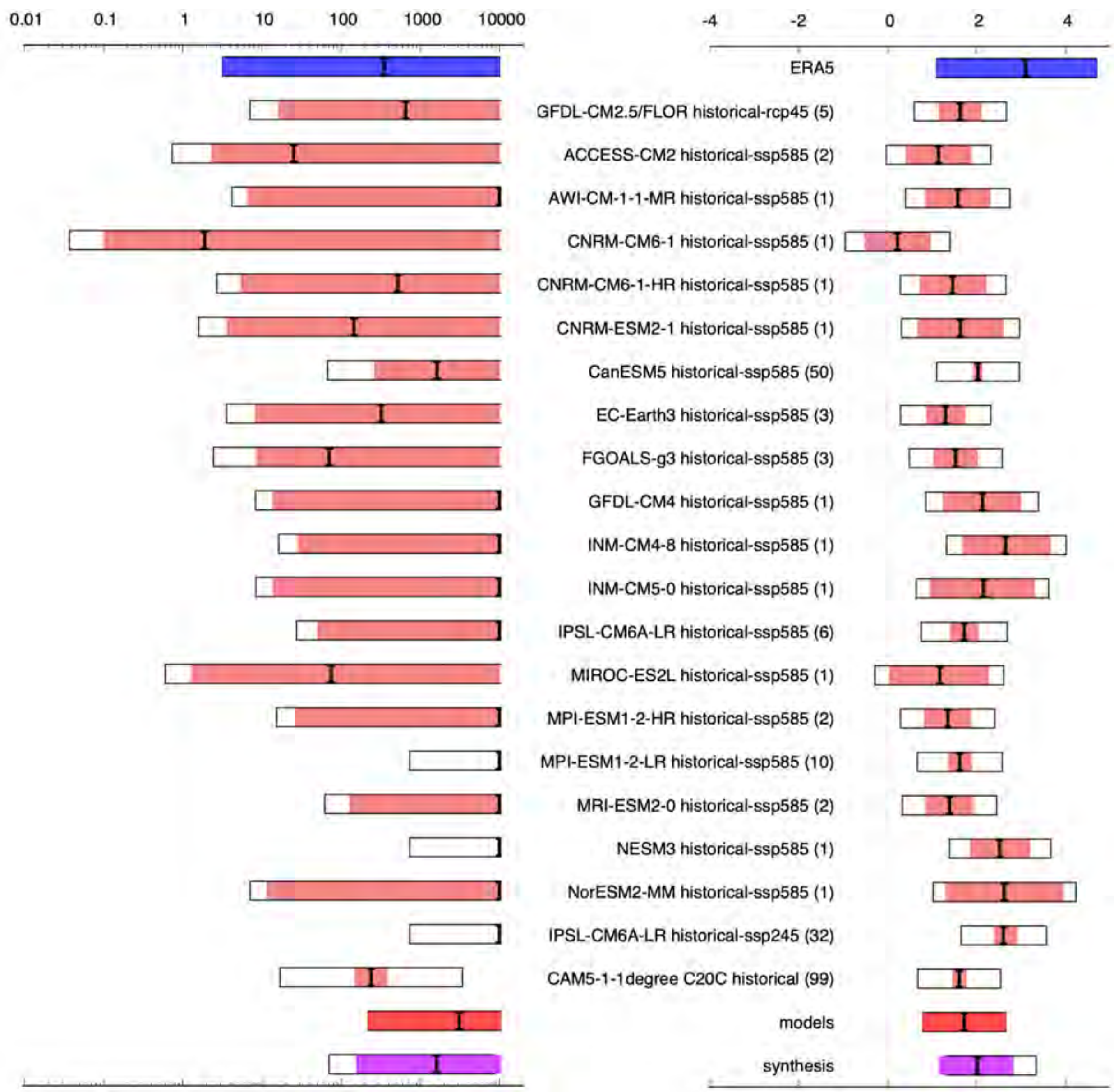


Figure 12. Synthesis of the past climate, showing probability ratios (left) and changes in intensity in ˚C (right), comparing the 2021 event with a pre-industrial climate.

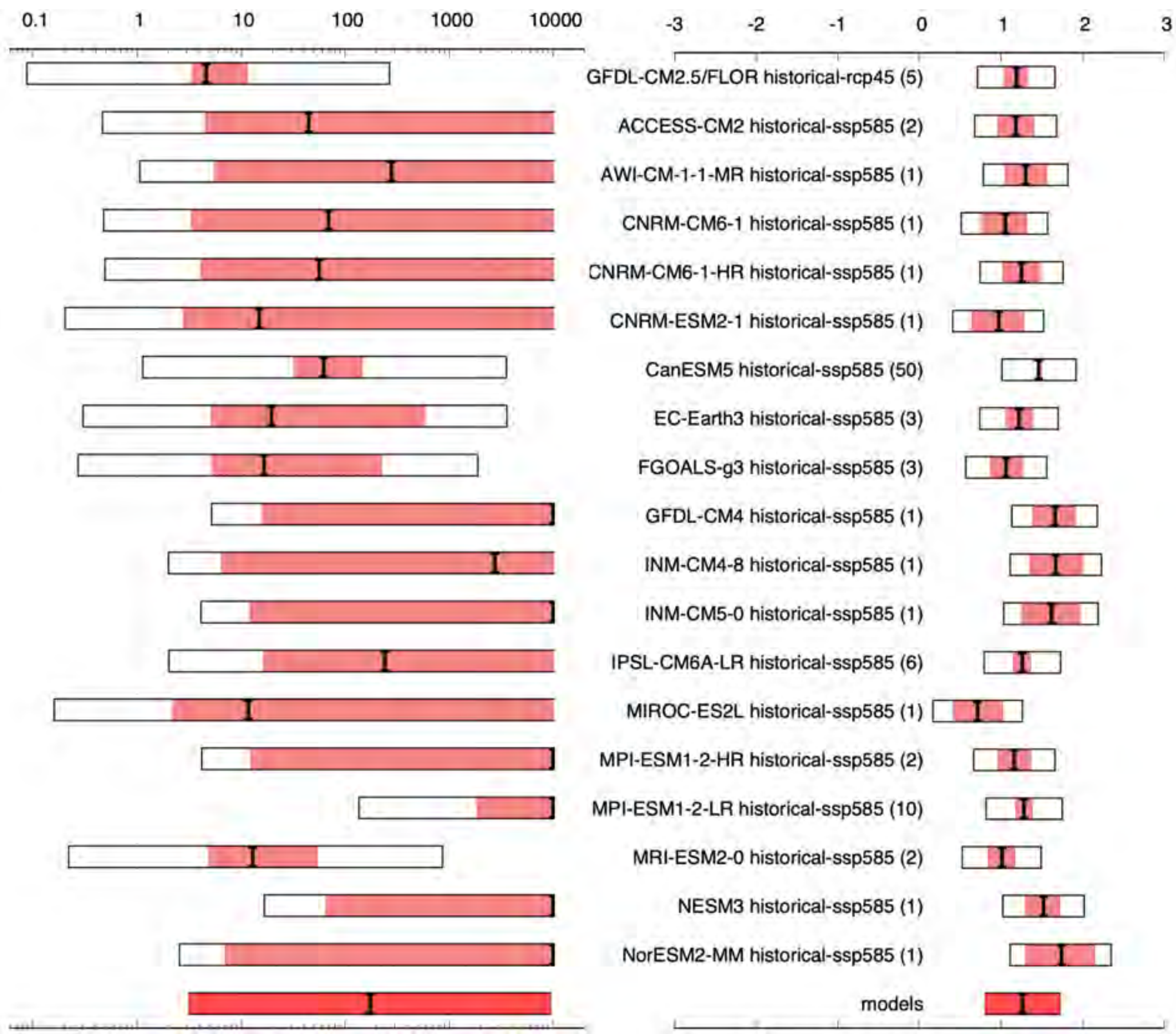


Figure 13. Same as Figure 12 but comparing 2°C of global warming (above pre-industrial) with present-day values.

7 Meteorological conditions and drivers

7.1 Meteorological analysis and dynamics

The evolution of this event can be explained by a confluence of meso- and synoptic-scale dynamical features, potentially including antecedent low-moisture conditions. At the synoptic scale, an omega-block developed over the study area beginning at roughly 00UTC on June 25th centred at ~125 ˚W, 52 ˚N, which then very slowly progressed eastward over subsequent days. This ridge featured a maximal 500 hpa geopotential height of ~5980 m, which is unprecedented for this area of western North America for the period from 1948 through to June 2021 at least (Figure 14).

Despite being a record, this extreme high pressure system – sometimes called a “Heat dome” – is not that anomalous given the long-term trend in 500 hPa driven by thermal expansion (Christidis and Stott, 2015). Also, comparing recent heatwaves in the Pacific NW to the extreme heatwave in Western Europe in 2019 (Vautard et al., 2020), the geopotential height reached similar anomalies and has a similar long-term trend (Figure 14).

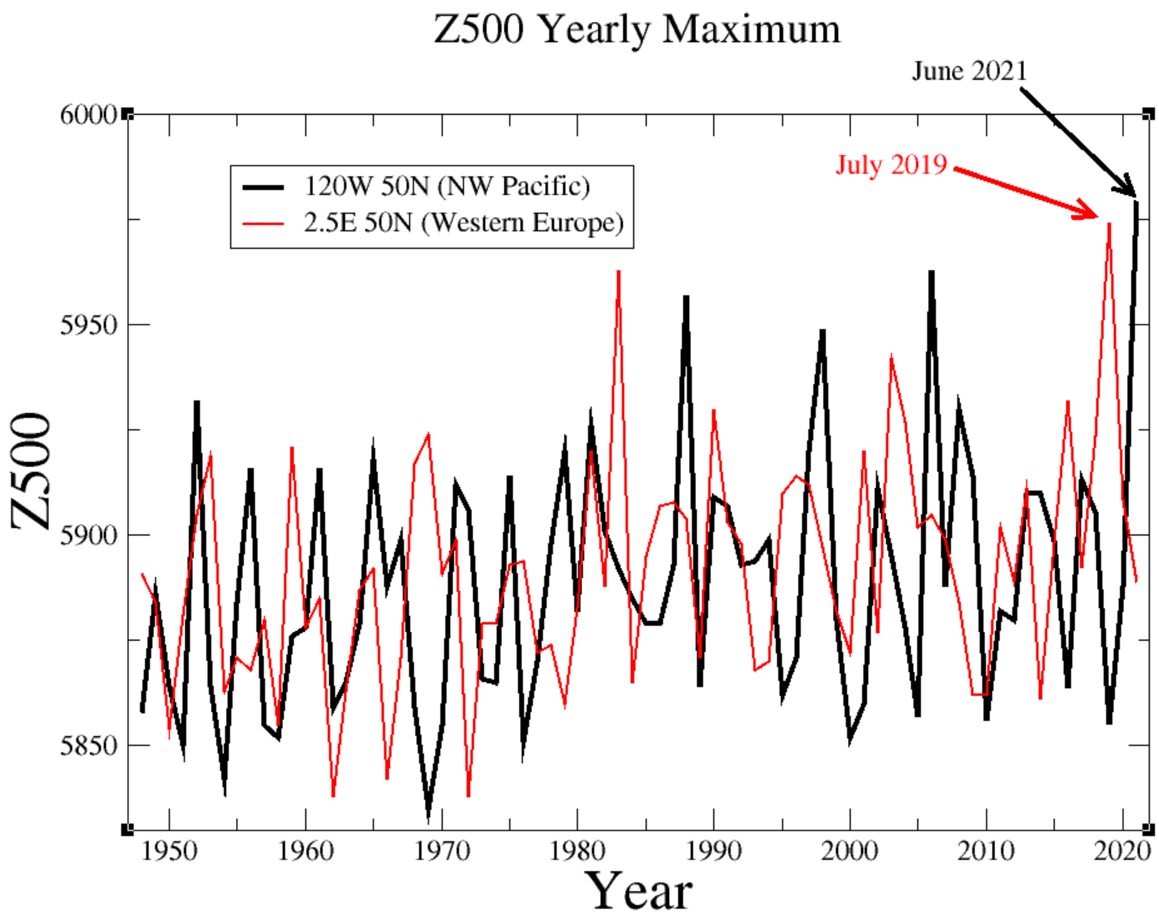


Figure 14: 500 hPa height (m) yearly maximum for two points at same latitude in two continents. Black: Pacific NW (as above) and red: Western Europe (2.5E; 50N).

The circulation pattern itself also appears not extremely anomalous: using analogues of 500 hPa and a pattern correlation metric to compare fields, we find that about 1% of June and July circulation patterns, defined as the 500 hPa geopotential height pattern within [160 ˚W-110 ˚W ; 35 ˚N-65 ˚N] in previous years have an anomaly correlation larger than 0.8 with the 28 June pattern. This degree of correlation is typical among days with this type of blocking pattern during the months of June and July., Roughly one third of June and July geopotential height fields have 1% or fewer analogues with an anomaly correlation larger than 0.8. We also find that this fraction does not change when restricting the analogues search within 3 distinct time periods between 1948 and 2020. We conclude that the 28 June circulation is likely not exceptional, while temperatures associated with it were.

At the meso-scale, high solar irradiance during the longest days of the year and strong subsidence increased near-surface air temperatures during the event. As is typical for summer heatwaves in the region

(Brewer et al., 2012; Brewer et al., 2013), a meso-scale thermal trough developed and reached southwest Oregon by 00UTC on the 28th June. This feature migrated northward reaching the northern tip of Washington State by 00UTC on the 29th. Further offshore, a small cut-off low travelled southwest to northeast around the synoptic-scale trough that made up the west arm of the omega block. The pressure gradients associated with the thermal trough and the cut-off low promoted moderate E-SE flow in the northern and eastern sectors of the feature and S-SW flow to the south. Near-surface winds with easterly components crossed the Cascade Range of Washington and Oregon and the southern Coast Mountains of British Columbia. The difference in elevation on the west and east sides of the mountain ranges contributed to more adiabatic heating than cooling, which helped drive the warmest temperatures observed in the event along the foot of the west slope of these mountains, at sea level. These dynamics are illustrated in Figure 15. By 12UTC on the 29th of June 2021, all but the eastern edge of the study area was under the influence of southerly to southwesterly near surface flows that advected marine air and forced marked cooling.

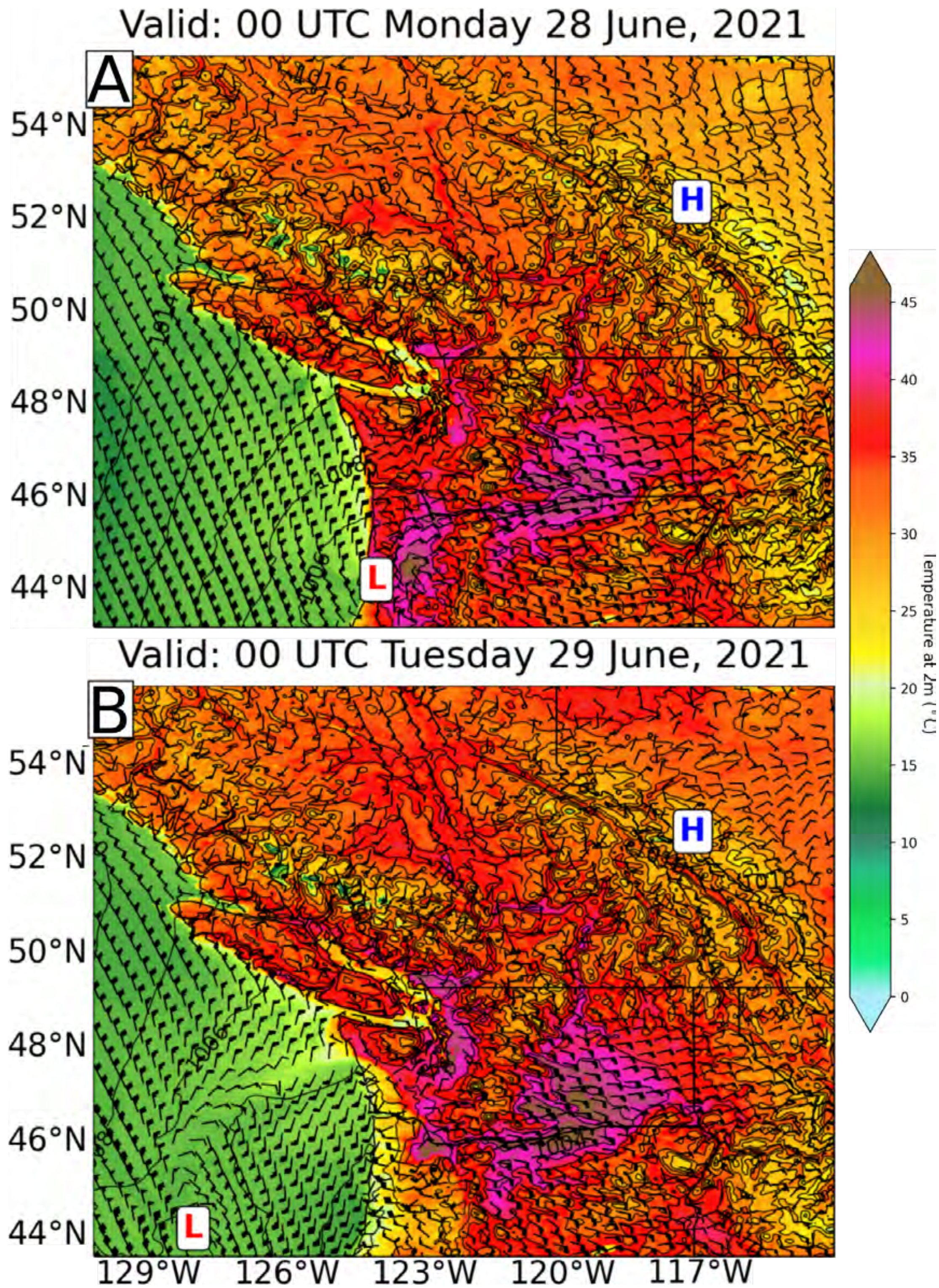


Figure 15. Regional simulation of sea level pressure, 2m air temperature, and 10m wind velocity in the region containing the study area using the Weather Research and Forecasting (WRF; Skamarock et al., 2019) model forced by the North American Mesoscale Forecast System (NAM). Panel (A) shows the situation during the peak of the event for the part of the study area south of Portland at 5PM local time.

Panel (B) as in (A) but for 5PM local time on the day of peak temperature for Portland, Seattle and Vancouver.

There is no scientific consensus whether blocking events are made more severe or persistent because of Arctic amplification or other mechanisms (i.e. Tang et al, 2014; Barnes and Screen, 2015; Vavrus, 2018).We contend that Arctic sea-ice was unlikely to have played a large role in this event largely due to the timing. In early summer, Arctic sea ice remains extensive, but is melting thus keeping near surface temperatures near 0 ºC. This causes summer trends in near-surface temperatures over the Arctic ocean to be lower than the midlatitudes. During recent months, the sea ice extent was below the 1981-2010 mean, but was similar to values observed from 2011 to 2020 (Fetterer et al., 2017). Instead, Arctic Amplification in summer is characterized by strong warming over high-latitude land areas (as can clearly be seen in Figure 16) and this warming signal reaches into the upper-troposphere. This enhanced warming is likely related to strong downward trends in early summer snow cover. There is evidence, from observations (Coumou et al, 2015; Chang et al, 2016), climate models (Harvey et al, 2020; Lehmann et al, 2014) and paleo-proxies (Routson et al, 2019), that this enhanced warming over high latitudes leads to a weakening of the jet and storm tracks in summer. This weakening could favour more persistent weather conditions (Pfleiderer et al, 2019; Kornhuber & Tamarin-Brodsky, 2021). Regional-scale interactions between loss of snow cover and low soil moisture associated with earlier snowmelt and rapid springtime soil moisture drying, may have had an enhanced warming impact into early summer in the Arctic. At mid-atmospheric levels there is some amplification remaining due to the winter season (Figure 16), but at the jet level (~250 hPa) the usual increase of the thermal gradient due to tropical upper tropospheric warming is advected North by the Hadley circulation (Haarsma et al, 2013). The final effect on the jet stream is therefore a competition between factors enhancing and decreasing the temperature gradient.

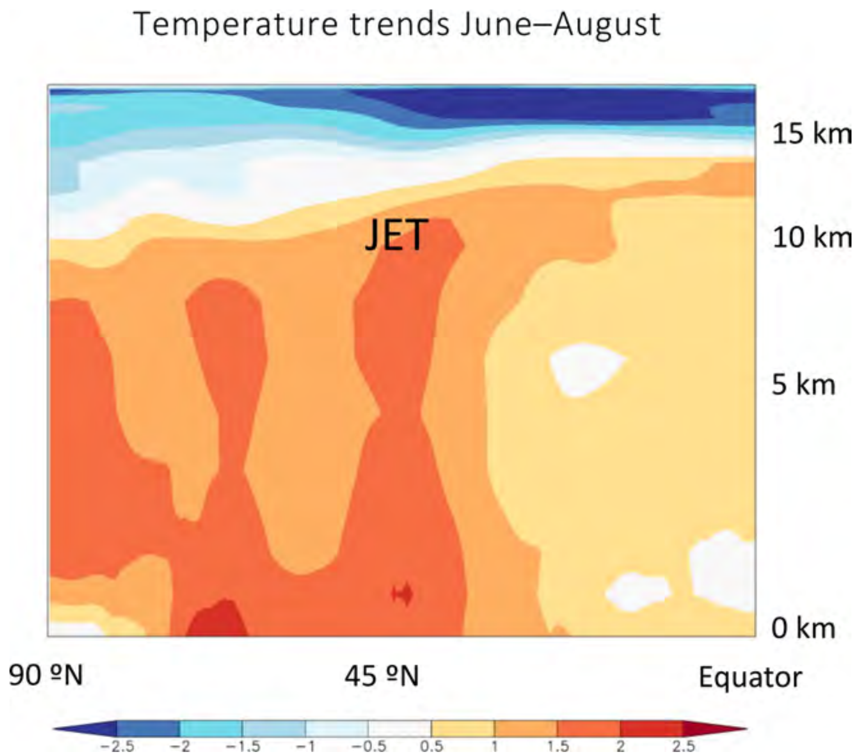


Figure 16. Zonal mean trends in temperature (ºC per degree global warming) as function of pressure in the ERA5 reanalysis 1979–2019 in the northern hemisphere.

7.2 Drought

An additional feature of the event is the very dry antecedent conditions that may have contributed to observed extreme temperatures through reduced latent cooling from low evapotranspiration rates. Low soil moisture conditions can lead to a strong amplification of temperature during heatwaves, including non-linear effects (Seneviratne et al. 2010, Mueller and Seneviratne 2012, Hauser et al. 2016, Wehrli et al. 2019). In addition, low spring snow level conditions can also further amplify this feedback (Hall et al. 2008). Integrated Multi-satellitE Retrievals for the Global Precipitation Mission (IMERG) estimates of precipitation during the period from March through June, 2021 indicate anomalously dry conditions from southern BC southward through California (Figure 17). The precipitation anomaly ranges from close to zero over the Puget Sound area including Seattle to values of between −0.6 and −0.8, meaning that only 20-40% of the average amount of precipitation fell in these locations, in Western Oregon. Note that in the northern parts of the area affected by the heatwave, i.e. in the coastal mountains north of Vancouver Island, large positive precipitation anomalies occurred over recent months.

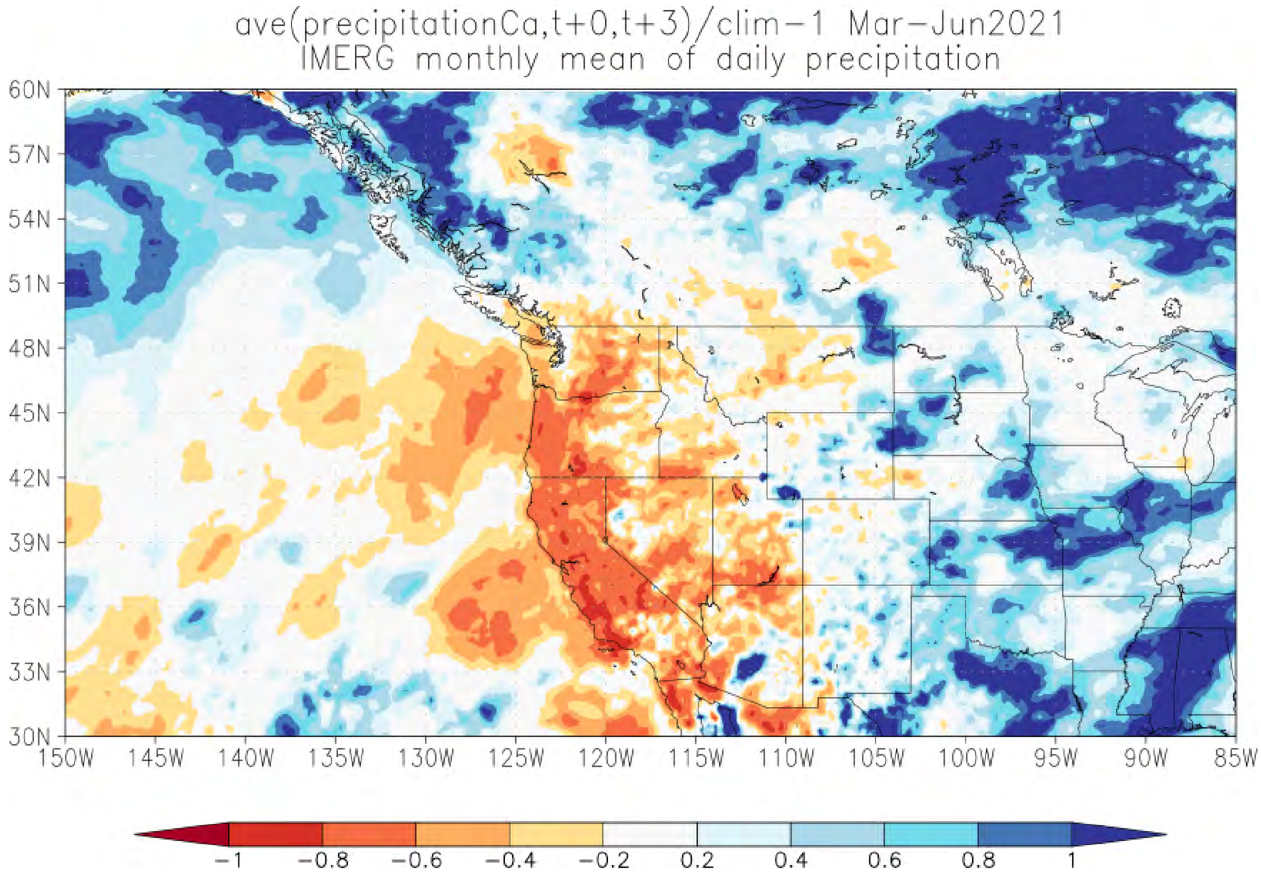


Figure 17. GPM/IMERG satellite estimates of relative precipitation anomalies in March–June 2021 relative to the whole record (2000-2020). The value –1 (dark red) denotes no precipitation, –0.5 (orange) 50% less than normal and zero (light grey) normal precipitation.

The available moisture is also influenced by evapotranspiration, which depends strongly on temperature, radiation and available atmospheric moisture. Evaporation was close to normal in the ERA5 reanalysis March–May in this area (not shown), so does not seem to have played a large role in setting the stage for the heatwave.

Satellite-based measurements of surface soil moisture based on microwave remote sensing from the European Space Agency (ESA) Climate Change Initiative (CCI) provided by the Copernicus service suggest that surface soil moisture was below normal in the region since the beginning of April and that the anomalous conditions persisted until June (https://dataviewer.geo.tuwien.ac.at/?state=88bf0c), in agreement with the decreased precipitation and close to normal evapotranspiration in the ERA5 reanalysis.

7.3 Influence of modes of natural variability

The El Niño Southern Oscillation is the dominant source of interannual variability in the region through the Pacific North American teleconnection. The influence is typically greatest in late winter and spring and has less clear impacts during summer and fall. Because ENSO was neutral during the preceding months and the impacts on TXx are minimal (r<0.1) we conclude that it had no influence on the occurrence of the heatwave.

The Pacific Decadal Oscillation (PDO) can affect some aspects of North American summer weather, although again the connections to heatwaves in this region are very weak. The strongly negative values of the PDO index, as they occurred in May, would slightly favor cooler conditions for this region. PDO thus also is unlikely to have played an important role in the event.

Altogether, external modes of variability appear to have played little to no role in the formation of the event.

8 Vulnerability and exposure

The Pacific Northwest region is not accustomed to very hot temperatures such as those observed during the June 2021 heatwave. Heatwaves are one of the deadliest natural hazards, resulting in high excess mortality through direct impacts of heat (e.g. heat stroke) and by exacerbating pre-existing medical conditions linked to respiratory and cardiovascular issues (Haines et al., 2006). News reports indicate that there was an increase in emergency calls, emergency department visits, and deaths linked to the heatwave.[7][8] In the following weeks and months, official data on excess deaths will become available to quantify the full extent of the human impacts on human health. The June 2021 heatwave also affected critical infrastructure such as roads and rail and caused power outages, agricultural impacts, and forced many businesses and schools to close[9] [10]. Rapid snowmelt in BC caused water levels to rise, also leading to evacuation orders north of Vancouver.[11] Furthermore, in some places, wildfires, the risk of which has increased due to climate change in this region (Kirchmeier-Young et al., 2018), have started and quickly spread requiring entire towns to evacuate[12]. The co-occurence of such events may result in compound risks, for example as households are advised to shut windows to keep outdoor wildfire smoke from getting inside, while simultaneously threatened by high indoor temperatures when lacking air conditioning.

Timely warnings were issued throughout the region by the US National Weather Service, Environment and Climate Change Canada and local governments. British Columbia has "Municipal Heat Response Planning", which gathers information on heat response plans throughout the province., including responses such as increasing access to cooling facilities and distribution of drinking water. In the long-term strategies, changes to the built environment are emphasized (Lubik et al., 2017). Not all municipalities throughout BC have formalized heat response plans, and others have limited planning,

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7 https://vancouversun.com/news/local-news/more-than-25-people-have-died-suddenly-in-burnaby-mostly-due-to-the-heat

8 https://www.cbc.ca/news/canada/british-columbia/heat-wave-719-deaths-1.6088793

9 https://apnews.com/article/canada-heat-waves-environment-and-nature-cc9d346d495caf2e245fc9ae923adae1

10 https://www.seattletimes.com/seattle-news/weather/pacific-northwests-record-smashing-heat-wave-primes-wildfire-buckles-roads-health-toll-not-yet-known

11 https://globalnews.ca/news/7994540/flooding-record-breaking-heat-rapid-snow-melt-bc-video/

12 https://www.washingtonpost.com/world/2021/07/01/lytton-canada-evacuated-wildfire-heatwave/

thought to be due to low heat risk perceptions throughout the area, as well as a lack of local data for risk assessments (Lubik et al., 2017).

The extremely high temperatures featured in this heat episode meant that everyone was vulnerable to its effects if exposed for a significant period of time. Although extreme heat affects everyone, some individuals are even more vulnerable, including the elderly, young children, individuals with pre-existing medical conditions, socially isolated individuals, homeless people, individuals without air-conditioning, and (outdoor) workers (Singh et al., 2019). Throughout Seattle's King County the number of vulnerable people is increasing as senior populations continue to rise (DeLaTorre & Neal, 2014; Washington State Department of Social and Health Services, 2019). In addition, Seattle's King County contains the third-largest population of homeless in the U.S, with the numbers increasing during the past decade (Stringfellow and Wagle, 2018). This group largely depends on governmental authorities to provide for sufficient and nearby cooling centers, and governmental authorities have done so by opening several cooling centers throughout Seattle, Portland, and Vancouver BC during the June 2021 heatwave. [13] [14] [15] In addition, electrolytes, food, and water were distributed to the homeless.[16] Governmental websites provided information on how and where to stay cool. Analyses will determine whether the numbers of centers were sufficient.

The lack of air conditioning is a significant factor contributing to heat risk. The Pacific Northwest has lower access to air-conditioned homes and buildings compared to other regions in the U.S., with the Seattle metropolitan area being the least air-conditioned metropolitan area of the United States (<50% air conditioning in residential areas) (U.S. Census Bureau, 2019). Portland and Vancouver also have comparably low percentages of air-conditioned households, 79% and 39% respectively (BC Hydro, 2020; U.S. Census Bureau, 2019). Still, a trend towards an increasing percentage of air conditioned homes is being observed in all three cities over the past years and this trend is expected to continue (ibid.).

Current estimates of the population health impacts of the event underestimate how many people died from the heat because of the lag between the event and when death certificates are available. The total mortality impact is determined by quantifying the number of excess deaths, or the numbers of deaths above what is expected for that time of year (without a heatwave). This difference is illustrated by an estimate from the U.S. Centers for Disease Control and Prevention that over the period 2004-2018, 702 Americans died annually from heat-related causes. An estimate of the numbers of excess heat-related deaths in 297 U.S. counties representing 61.9% of the U.S. population for the period 1997-2006 concluded that an average of 5,608 heat-attributable deaths occurred annually (Weinberger et al., 2020). Most deaths in a heatwave do not die from heat stroke but from cardiovascular, respiratory, and other diseases, with heat infrequently noted as a contributing cause on the death certificate.

Recommendations:

Although this extreme heat event is still rare in today's climate, the analysis above shows that the frequency is increasing with further warming. A number of adaptation and risk management priorities that

[13] https://durkan.seattle.gov/2021/06/city-of-seattle-opens-additional-cooling-centers-and-updated-guidance-for-staying-cool-in-extreme-heat%E2%80%AF/
[14] https://www.oregonlive.com/weather/2021/06/portland-cooling-centers-provide-relief-from-heat.html
[15] https://thebcarea.com/2021/06/26/cooling-stations-set-up-around-b-c-for-record-breaking-heat-wave-this-weekend/#comments
[16] https://edition.cnn.com/2021/06/29/weather/northwest-heat-illness-emergency-room/index.html

emerge as the risk of extreme heat continues to rise locally and around the globe. It is crucial that local governments and their emergency management partners establish heat action plans to ensure well coordinated response actions during an extreme heat event - tailored to high-risk groups (Ebi, 2019). Heatwave early warning systems also need to be improved, this includes tailoring messages to inform and motivate vulnerable groups, as well as providing tiered warnings that take into account vulnerable groups may have lower thresholds for risk (Hess and Ebi, 2016). In other words, starting to warn the most vulnerable early as temperatures start to rise, this can include temperatures at which the general population is not yet acutely at risk. In cases where heat action plans and heat early warning systems are already robust, it is important that they are reviewed and updated to capture the implications of rising risks - every five years or less (Hess and Ebi, 2016). Further, heatwave early warning systems should undergo stress tests to evaluate their robustness to temperature extremes beyond recent experience and to identify modifications to ensure continued effectiveness in a changing climate (Ebi et al., 2018).

Data availability

Data are available via the [KNMI Climate Explorer].

Validation tables

Table 3. As Table 1 but showing all model validation results.

Model / Observations	**Seasonal cycle**	**Spatial pattern**	**Sigma**	**Shape parameter**	**Conclusion**
ERA5			1.70 (1.40 ... 1.90)	-0.200 (-0.500 ... 0.00)	
GFDL-CM2.5/FLOR historical-rcp45 (5)	good	good	2.01 (1.84 ... 2.17)	-0.201 (-0.272 ... -0.144)	reasonable, include as different experiment than most other models
ACCESS-CM2 historical-ssp585 (2)	good	good	1.86 (1.71 ... 2.02)	-0.200 (-0.260 ... -0.120)	good
ACCESS-ESM1-5 historical-ssp585 (2)	good	good	2.69 (2.49 ... 2.90)	-0.240 (-0.290 ... -0.190)	bad
AWI-CM-1-1-MR historical-ssp585 (1)	good	good	1.50 (1.35 ... 1.69)	-0.200 (-0.280 ... -0.110)	good
BCC-CSM2-MR historical-ssp585 (1)	good	good	2.22 (2.00 ... 2.49)	-0.230 (-0.310 ... -0.140)	bad
CAMS-CSM1-0 historical-ssp585 (1)	good	good	1.98 (1.79 ... 2.23)	-0.200 (-0.290 ... -0.100)	reasonable, exclude because enough good CMIP5 models
CMCC-CM2-SR5 historical-ssp585 (1)	good	good	1.29 (1.15 ... 1.46)	-0.0800 (-0.160 ... 0.0300)	reasonable, exclude because enough good CMIP5 models
CNRM-CM6-1 historical-ssp585 (1)	good	good	1.54 (1.39 ... 1.72)	-0.210 (-0.290 ... -0.100)	good
CNRM-CM6-1-HR historical-ssp585 (1)	good	good	1.48 (1.33 ... 1.66)	-0.190 (-0.270 ... -0.100)	good
CNRM-ESM2-1	good	good	1.71 (1.54 ... 1.92)	-0.180 (-0.250 ...	good

historical-ssp585 (1)				-0.0900)	
CanESM5 historical-ssp585 (50)	good	reasonable	1.79 (1.76 ... 1.82)	-0.180 (-0.190 ... -0.170)	reasonable, include because statistical parameters good
EC-Earth3 historical-ssp585 (3)	good	good	1.87 (1.76 ... 2.00)	-0.220 (-0.270 ... -0.170)	good
EC-Earth3-Veg historical-ssp585 (4)	good	good	2.07 (1.95 ... 2.19)	-0.250 (-0.290 ... -0.210)	bad
FGOALS-g3 historical-ssp585 (3)	good	reasonable	1.80 (1.69 ... 1.92)	-0.180 (-0.210 ... -0.140)	reasonable, include because statistical parameters good
GFDL-CM4 historical-ssp585 (1)	good	good	1.43 (1.29 ... 1.62)	-0.210 (-0.300 ... -0.110)	good
GFDL-ESM4 historical-ssp585 (1)	good	good	1.37 (1.23 ... 1.55)	-0.170 (-0.260 ... -0.0700)	reasonable, exclude because enough good CMIP5 models
HadGEM3-GC31-LL historical-ssp585 (4)	good	good	2.00 (1.90 ... 2.12)	-0.210 (-0.250 ... -0.170)	reasonable, exclude because enough good CMIP5 models
HadGEM3-GC31-MM historical-ssp585 (3)	good	good	2.08 (1.96 ... 2.22)	-0.190 (-0.230 ... -0.140)	bad
INM-CM4-8 historical-ssp585 (1)	good	good	1.63 (1.46 ... 1.83)	-0.210 (-0.300 ... -0.110)	good
INM-CM5-0 historical-ssp585 (1)	good	good	1.80 (1.63 ... 2.03)	-0.240 (-0.310 ... -0.140)	good
IPSL-CM6A-LR historical-ssp585 (6)	good	reasonable	1.79 (1.71 ... 1.88)	-0.220 (-0.250 ... -0.180)	reasonable, include because statistical parameters good
KACE-1-0-G historical-ssp585 (3)	good	good	2.27 (2.13 ... 2.41)	-0.241 (-0.282 ... -0.196)	bad
MIROC-ES2L historical-ssp585 (1)	reasonable, peaks about a month early	reasonable	1.46 (1.31 ... 1.65)	-0.190 (-0.300 ... -0.0900)	reasonable, include because statistical parameters good
MIROC6 historical-ssp585 (50)	good	good	1.31 (1.29 ... 1.33)	-0.220 (-0.220 ... -0.210)	bad
MPI-ESM1-2-HR historical-ssp585 (2)	good	good	1.49 (1.39 ... 1.62)	-0.250 (-0.310 ... -0.190)	good
MPI-ESM1-2-LR historical-ssp585 (10)	good	good	1.63 (1.58 ... 1.69)	-0.260 (-0.280 ... -0.230)	good
MRI-ESM2-0 historical-ssp585 (2)	reasonable, peak too flat	good	1.41 (1.30 ... 1.53)	-0.280 (-0.340 ... -0.220)	reasonable, include because statistical parameters good
NESM3 historical-ssp585 (1)	good	good	1.48 (1.34 ... 1.67)	-0.290 (-0.370 ... -0.200)	good
NorESM2-MM historical-ssp585 (1)	good	good	1.90 (1.70 ... 2.12)	-0.250 (-0.350 ... -0.140)	in between reasonable and good, include
UKESM1-0-LL historical-ssp585 (5)	good	good	1.99 (1.90 ... 2.09)	-0.170 (-0.190 ... -0.140)	reasonable, exclude because enough good CMIP5 models
IPSL-CM6A-LR historical-ssp245 (32)	good, from CMIP6	reasonable, from CMIP6	1.69 (1.64 ... 1.75)	-0.220 (-0.250 ... -0.200)	reasonable, obs covar used, different from CMIP6 as different ssp scenario. Use both
GFDL-AM2.5C360 historical (5)	good	good	2.15 (1.99 ... 2.30)	-0.259 (-0.335 ... -0.197)	bad, variability too high

CAM5-1-1degree C20C historical (99)	NA	NA	1.70 (1.68 ... 1.72)	-0.176 (-0.172 ... -0.180)	good, values used with warming level 1.7
MIROC5 C20C historical ()	NA	NA	1.36 (1.33 ... 1.39)	-0.240 (-0.224 ... -0.256)	bad
HadGEM3-A-N216 C20C historical ()	NA	NA	2.00 (1.95 ... 2.05)	-0.240 (-0.218 ... -0.262)	bad

References

Baldwin, J. W., Dessy, J. B., Vecchi, G. A., & Oppenheimer, M. (2019). Temporally compound heat wave events and global warming: An emerging hazard. Earth's Future, 7. https://doi.org/10.1029/2018EF000989.

Barnes, E.A. and J.A. Screen: The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it? (2015) WIREs Clim Change, 6:277–286. doi: 10.1002/wcc.337.

BC Hydro, (2020, August). Not-so well-conditioned: How inefficient A/C use is leaving British Columbians out of pocket in the cold.

Boucher, O., Servonnat, J., Albright, A. L., Aumont, O., Balkanski, Y., Bastrikov, V., ... & Vuichard, N. (2020). Presentation and evaluation of the IPSL‐CM6A‐LR climate model. *Journal of Advances in Modeling Earth Systems*, *12*(7), e2019MS002010.

Chan D, GA Vecchi, W Yang, P Huybers (2021): Improved simulation of 19th- and 20th-century North Atlantic hurricane frequency after correcting historical sea surface temperatures. Sci. Adv. 2021. doi: 10.1126/sciadv.abg6931.

Coumou, D., Lehmann, J. & Beckmann, J. (2015) The weakening summer circulation in the Northern Hemisphere mid-latitudes. Science 348, 324–327 .

Chang, E. K. M., Ma, C., Zheng, C. & Yau, A. M. W. (2016). Observed and projected decrease in Northern Hemisphere extratropical cyclone activity in summer and its impacts on maximum temperature. Geophys. Res. Lett. 43, 2200–2208.

Christidis, N., and Stott, P. A. (2015), Changes in the geopotential height at 500 hPa under the influence of external climatic forcings, *Geophys. Res. Lett.*, 42, 10,798– 10,806, doi:10.1002/2015GL066669.

DeLaTorre, A. K., & Neal, M. B. (2014). Aging and equity in the greater Portland metropolitan region. Connections: Journal of the Coalition for a Livable Future, 12(1), 10–23.

Ebi KL, Berry P, Hayes K, Boyer C, Sellers S, Enright PM, Hess JJ. (2018) Stress Testing the Capacity of Health Systems to Manage Climate Change-Related Shocks and Stresses. Int J Environ Res Public Health. Oct 26;15(11):2370. doi: 10.3390/ijerph15112370. PMID: 30373158; PMCID: PMC6265916.

Ebi, KL (2019), Effective heat action plans: research to interventions, Environ. Res. Lett. 14 122001.

Fetterer, F., K. Knowles, W. N. Meier, M. Savoie, and A. K. Windnagel. (2017, updated daily). Sea Ice Index, Version 3. Ice Extent; Sea Ice Concentration. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.7265/N5K072F8. Accessed 2 July, 2021.

Haarsma, R.J., Selten, F. & van Oldenborgh, G.J. (2013). Anthropogenic changes of the thermal and zonal flow structure over Western Europe and Eastern North Atlantic in CMIP3 and CMIP5 models. Clim Dyn 41, 2577–2588. https://doi.org/10.1007/s00382-013-1734-8.

Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C. (2006). Climate change and human health: impacts, vulnerability, and mitigation. Lancet. 2006 Jun 24;367(9528):2101-9. doi: 10.1016/S0140-6736(06)68933-2. Erratum in: Lancet. 2006 Aug 19;368(9536):646. PMID: 16798393.

Hall, A., X. Qu, and J.D. Neelin (2008). Improving predictions of summer climate change in the United States. Geophys. Res. Lett., 35(1), L01702, doi:10.1029/2007GL032012.

Hansen, J., Ruedy, R., Sato, M., and Lo, K. (2010). Global surface temperature change. Rev. Geophys., 48, RG4004, https://doi.org/10.1029/2010RG000345.

Harvey, B.J, P. Cook, L.C. Shaffrey and R. Schiemann (2020). The Response of the Northern Hemisphere Storm Tracks and Jet Streams to Climate Change in the CMIP3, CMIP5, and CMIP6 Climate Models, Journal of Geophysical Research: Atmospheres, 125.

Hauser, M., R. Orth, and S. I. Seneviratne (2016). Role of soil moisture versus recent climate change for the 2010 heat wave in Russia. Geophys. Res. Lett., 43, 2819–2826, doi:10.1002/2016GL068036.

Hersbach, H, Bell, B, Berrisford, P, et al. (2020). The ERA5 global reanalysis. *Q J R Meteorol Soc*., 146: 1999– 2049. https://doi.org/10.1002/qj.3803.

Hess, J.J. and Ebi, K.L. (2016), Iterative management of heat early warning systems in a changing climate. Ann. N.Y. Acad. Sci., 1382: 21-30. https://doi.org/10.1111/nyas.13258

D'Ippoliti et al., (2010). The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project Environmental Health, 9–37.

Kew, S. F., Philip, S. Y., Hauser, M., Hobbins, M., Wanders, N., van Oldenborgh, G. J., van der Wiel, K., Veldkamp, T. I. E., Kimutai, J., Funk, C., and Otto, F. E. L. (2021). Impact of precipitation and increasing temperatures on drought trends in eastern Africa, Earth Syst. Dynam., 12, 17–35, https://doi.org/10.5194/esd-12-17-2021.

Kirchmeier-Young et al. (2018). Attribution of the influence of human-induced climate change on an extreme fire season, Earth's Future, 7, 2-10, doi:0.1029/2018EF001050.

Kornhuber, K and T. Tamarin-Brodsky, (2021). Future Changes in Northern Hemisphere Summer Weather Persistence Linked to Projected Arctic Warming, Geoph. Res Lett. 48.

Lehmann, J., Coumou, D., Frieler, K., Eliseev, A. V. & Levermann, A. (2014). Future changes in extratropical storm tracks and baroclinicity under climate change. Environ. Res. Lett. 9, 084002.

Lenssen, N., Schmidt, G., Hansen, J., Menne, M., Persin, A., Ruedy, R., and Zyss, D. (2019). Improvements in the GISTEMP uncertainty model. J. Geophys. Res. Atmos., 124(12), 6307-6326, doi:10.1029/2018JD029522.

Lucie A. Vincent , Megan M. Hartwell & Xiaolan L. Wang (2020): A Third Generation of Homogenized Temperature for Trend Analysis and Monitoring Changes in Canada's Climate, Atmosphere-Ocean, DOI: 10.1080/07055900.2020.1765728.

Lubik, A., McKee, G., Chen, T., & Kosatsky, T. (2017). Municipal Heat Response Planning in British Columbia, Canada 2017.

Menne, M.J., I. Durre, R.S. Vose, B.E. Gleason, and T.G. Houston, 2012: An overview of the Global Historical Climatology Network-Daily Database. Journal of Atmospheric and Oceanic Technology, 29, 897-910, doi.10.1175/JTECH-D-11-00103.1.

Mueller, B., and S.I. Seneviratne, (2012). Hot days induced by precipitation deficits at the global scale. *Proceedings of the National Academy of Sciences*, 109 (31), 12398-12403, doi: 10.1073/pnas.1204330109.

Neale et al. (2010) Description of the NCAR community atmosphere model (CAM 5.0). NCAR Tech. Note NCAR/TN-486+ STR, 1(1), 1-12.

Pfleiderer, P., Schleussner, C.-F., Kornhuber, K. and Coumou, D. (2019). Summer weather becomes more persistent in a 2C world, Nat. Clim. Chang., doi:10.1038/s41558-019-0555-0.

Philip, S., Kew, S., van Oldenborgh, G. J., Otto, F., Vautard, R., van der Wiel, K., King, A., Lott, F., Arrighi, J., Singh, R., and van Aalst, M. (2020). A protocol for probabilistic extreme event attribution analyses, Adv. Stat. Clim. Meteorol. Oceanogr., 6, 177–203, https://doi.org/10.5194/ascmo-6-177-2020.

Routson, CC, N.P. McKay, D.S. Kaufman, M.P. Erb, H. Goosse, B.N. Shuman, J.R. Rodysill & T. Ault (2019). Mid-latitude net precipitation decreased with Arctic warming during the Holocene, Nature, 568, 83-87.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, Z. Liu, J. Berner, W. Wang, J. G. Powers, M. G. Duda, D. M. Barker, and X.-Y. Huang (2019). A Description of the Advanced Research WRF Version 4. NCAR Tech. Note NCAR/TN-556+STR, 145 pp. doi:10.5065/1dfh-6p97.

Seneviratne, S.I., T. Corti, E.L. Davin, M. Hirschi, E.B. Jaeger, I. Lehner, B. Orlowsky, and A.J. Teuling (2010). Investigating soil moisture-climate interactions in a changing climate: A review. *Earth-Science Reviews*, 99, 3-4, 125-161, doi:10.1016/ j.earscirev.2010.02.004.

Singh, R., Arrighi, J., Jjemba, E., Strachan, K., Spires, M., Kadihasanoglu, A. (2019) 'Heatwave Guide for Cities'. Red Cross Red Crescent Climate Centre.

Stone et al. (2019) Experiment design of the International CLIVAR C20C+ Detection and Attribution Project. *Weather and Climate Extremes*, 24, 100206. https://doi.org/10.1016/j.wace.2019.100206.

Stringfellow & Wagle (2018, May 18). The Economics of Homelessness in Seattle and King County. McKinsey & Company. Retrieved from: https://www.mckinsey.com/featured-insights/future-of-cities/the-economics-of-homelessness-in-seattle-and-king-county. (Accessed on: July 4, 2021).

Tang Q., X. Zhang, and J.A. Francis (2014). Extreme summer weather in northern mid-latitudes linked to a vanishing cryosphere. Nat Clim Change, 4:45–50.

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society, 93(4), 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1.

U.S. Census Bureau (2019). American Housing Survey (AHS). Retrieved from: https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html.

Van Oldenborgh, G.J., van der Wiel, K., Kew, S. et al. (2021). Pathways and pitfalls in extreme event attribution. *Climatic Change*, 166**,** 13, https://doi.org/10.1007/s10584-021-03071-7.

Vautard, R., M. van Aalst, O. Boucher, A. Drouin, K. Haustein, F. Kreienkamp, G.-J. van Oldenborgh, F. E. L. Otto, A. Ribes, Y. Robin, M. Schneider, J.-M. Soubeyroux, P. Stott, S. I. Seneviratne, M. Vogel, M. Vavrus, S.J. (2018). The Influence of Arctic amplification on mid-latitude weather and climate. Curr. Clim. Change Rep. 4, 238–249.

Vecchi, G. A., Delworth, T., Gudgel, R., Kapnick, S., Rosati, A., Wittenberg, A. T., & Zhang, S. (2014). On the seasonal forecasting of regional tropical cyclone activity. Journal of Climate, 27(21), 7994–8016. https://doi.org/10.1175/jcli-d-14-00158.1.

Washington State Department of Social and Health Services (2019). Selected Population and Aging Service Utilization Forecast, King County Aging & Disability Services. Retrieved from: https://www.dshs.wa.gov/altsa/stakeholders/aging-demographic-information. (Accessed on: July 3, 2021).

Wehner (2019). Human contribution to the record-breaking June and July 2019 heat waves in Western Europe, *Environ. Res. Lett.*, https://iopscience.iop.org/article/10.1088/1748-9326/aba3d4/pdf.

Weinberger KR, Harris D, Spangler KR, Zanobetti A, Wellenius GA. (2020). Estimating the number of excess deaths attributable to heat in 297 United States counties. Environ Epidemiol. 2020 Apr 23;4(3):e096. doi: 10.1097/EE9.0000000000000096. PMID: 32613153; PMCID: PMC7289128.

Wehrli, K., Guillod, B. P., Hauser, M., Leclair, M., Seneviratne, S. I. (2019). Identifying key driving processes of major recent heat waves. Journal of Geophysical Research: Atmospheres, 124. https://doi.org/10.1029/2019JD030635.

Yang W, TL Hsieh, GA Vecchi (2021): Why is the Hurricane Season So Sharp? EarthArXiv 2021. doi: 10.31223/X5Q31B.

Comments to the Pacific Fishery Management Council regarding final recommendations by the Southern Resident Killer Whales (SRKW) working Group for fishery management and conservation measures to address risks to the SRKW DPS posed by Council Chinook salmon fisheries.

Kurt Beardslee and Nick Gayeski, Wild Fish Conservancy

Misty MacDuffee, Raincoast Conservation Foundation

Deborah Giles, PhD, Science and Research Director, Wild Orca

October 27 2020

We appreciate the opportunity to provide comments to the Council on the SRKW Working Group (WG) recommendations for fishery management measures to address the risk posed to endangered SRKW by Council Chinook salmon fisheries. We recognize and appreciate the considerable amount of time and effort devoted by the WG to developing the May 2020 Risk Assessment ("RA") and the recommendations in its Draft Range of Alternatives and Recommendations of August 2020("Draft Recommendations"). We hope that these brief comments will assist the Council in choosing an appropriate set of fisheries management alternatives for Council Chinook fisheries that will afford the critically endangered SRKW DPS significant protection from the adverse impacts of fisheries and that will also provide an appropriate range of alternatives for the Environmental Impact Statement (EIS) that we expect the National Marine Fisheries Service (NMFS) to develop as part of the process of producing a new Biological Opinion by May 2021.

For the record we also submit, as part of these Comments, the Note we previously submitted to Council on the Draft RA of September 11, 2019 and comments submitted to NMFS in December 2019. We also submit the Declaration by Dr. Robert Lacy submitted on behalf of Wild Fish Conservancy's Motion for a Preliminary Injunction of Alaska's 2020 Summer Troll season fishery, which includes a Vortex model Population Viability Analysis, updating the PVA published in Lacy et al. 2017.

In brief, we have concerns that the range of alternatives presented in the Draft Recommendations are inadequately precautionary with respect to the dire demographic condition of the SRKW DPS in that they still presume that the burden of proof rests with the SRKW DPS and not the Council fisheries. The Draft Recommendations reveal where they believe the burden lies in subsection 3.1.2.e (List of potential responses if a year's preseason projection fall below a threshold) which states that the "goal of management response(s) would be to benefit SRKWs while still providing some fishing opportunity in years when Chinook abundance is deemed low by surpassing a defined threshold", page 11. The priority is clearly to keep fishers fishing.

First recommended type of alternative:

Consistent with the Precautionary Principle, we offer an alternative approach that appropriately places a greater burden of proof on Council Chinook fisheries and assumes a stronger presumption that the SRKW DPS is likely to be jeopardized (per the ESA) by Council fisheries as currently conducted. We also provide an additional alternative that would require a fundamental re-design of Council Chinook fisheries; one that would further the recovery of ESA-listed wild Chinook populations subject to Council fisheries and better guarantee SRKW access to preferred Chinook prey populations.

The Working Group and NMFS have recognized that no single or multiple Chinook abundance metrics currently appear to be better correlated to SRKW demographic rates than an index of coastwide annual abundance (RA, chapter 5, pp. 73 – 95; NMFS 2019 (section 2.5.4, page 242). In addition, despite the weak relationships between various Chinook abundance indices and SRKW demographic rates, the WG acknowledges that "…in the majority of cases… the point estimates for the fitted relationships were of the expected sign" (i.e., better rates when a Chinook abundance index was "high" and poorer rate when indices were "low", Draft Recommendations page 87).

The RA draws attention to concern that was noted in the Hilborn et al. 2012 Independent Panel Report regarding the statistical or biological significance of correlations between Chinook abundance indices and SRKW demographic rates; specifically the interpretation of such correlations "as confirming a linear causal relationship between Chinook salmon abundance and SRKW vital rates" (RA, page 90). This caution has routinely been raised by skeptics of the significance of Chinook abundance to the current status of the SRKW DPS and by opponents of further restrictions on harvest as conservation actions that are likely to benefit the DPS. Yet, it is never articulated how or why this general point supports claims that further reductions in Chinook harvest will not benefit SRKW.

Regardless of the body of evidence that supports a causal nature, this demographic relationship with Chinook will always be a correlation. There is no (ethical) study that can be conducted to test this relationship in an empirical manner. The skepticism and desire by managers (and others) for *proof* that this relationship is *causal* before taking action is a distraction that leads to irresponsible decision making for an endangered DPS.

There is a strong body of literature that supports acting on the evidence that Chinook abundance is the primary factor driving Southern Resident survival and fecundity, some of which are identified in the RA. Additionally, Velez-Espino et al. (2013) building on findings of Ford et al. (2010) and Ward et al. (2009) demonstrated that fisheries reductions and closures would improve vital rates and recovery trajectories of Southern Resident killer whales. While the role of vessels and contaminants may compound the effects of prey limitation, they do not diminish the primary importance of adequate food.

As noted above, even the RA acknowledges that the correlations between various Chinook abundance indices and SRKW demographic rates are all in the right direction, supporting the conclusion that greater indices of Chinook abundance are likely to result in better SRKW demographic rates.

Further, the skepticism regarding the statistical relationship between Chinook abundance indices and SRKW demographic rates increases the risk that harmful outcomes will eventuate to vulnerable resources. The perspective of Kriebel et al. (2001) is relevant in this context. Regarding uncertainty Kriebel et al. observe "…there is also a strong desire on the part of scientists to be precise. This may result from a confusion of uncertainty with quality of information; but the two concepts are distinct. It is possible to produce high-quality information about greatly uncertain phenomena." The information available to date regarding the relationship of Chinook abundance indices and SRKW demographic rates is of high quality and strongly supportive of risk-averse, precautionary management actions in regard to Council (and other) Chinook fisheries.

The precautionary approach requires that when evidence is inconclusive regarding either the causes of population decline or the effectiveness of potential remedies, strong risk-averse regulatory actions – such as significant change to harvest management – be taken *first* and research presumed to better resolve key uncertainties in status and mechanisms undertaken *subsequently*. The Draft Recommendations imply that strong precautionary reductions in current harvest should await the results of one or several items on a laundry list of potential research topics. We believe, and have argued in previous submissions to the Council and NMFS, that the status of the SRKW DPS is too precarious to justify this "wait-and-see" approach, that flawed logic is being used to avoid risk-averse actions, and this stonewalling contravenes the precautionary approach as it is intended to be applied to an endangered DPS.

We also emphasize a point we have made in past comments, viz; that the state of the SRKW DPS necessitates an immediate need to try to stabilize population numbers and secure the conditions that may permit a slow rebuilding. In the near term, management should aim to halt further decline and secondly achieve a small positive growth rate in the neighborhood of 0.5 to 1%. (For further relevant details, see Lacy 2020, attached). Dismissing potential remedial actions, such as significant coastwide reductions in Chinook harvest, on the grounds that it appears unlikely that such action would achieve the 2.3% annual population growth rate required for de-listing by NMFS' 2008 Recovery Plan, is unjustified and dismissive of the obvious dire condition of the DPS.

We therefore, recommend replacing one or two of the "Alternatives for North of Falcon (NOF) Chinook salmon abundance TS1 Thresholds" listed in Table 3.1.a, page 11 of the Draft Recommendations with the following:

Establish an abundance threshold **below which no fishery can occur**.

We recommend that this threshold be set at a preseason abundance estimate equal to or greater than the error-adjusted TS1 abundance level of 1 to 1.1 million or greater (i.e. between 3.1.2 c and 3.1.2.d). The kinds of "potential responses" in the list in subsection 3.1.2.e of the RA would need to be modified to provide a sliding scale of permissible Chinook harvest levels determined by how far the the TS1 preseason abundance estimate exceeds the threshold.

Adopting this approach will provide greater consideration of the SRKW DPS than the approach embodied in the Draft Report, and it will benefit research and monitoring directed at obtaining more robust time and area knowledge of specific Chinook stocks/populations important to foraging SRKWs. It is more probable that such stocks/populations will be identified when no fishing occurs or when only a deminimus level of fishing occurs when total TS1 Chinook abundance is above the threshold. This also places the burden of justifying and financing the conduct of such research and monitoring on those who wish to expand fishing opportunities.

Adding one or two more alternatives (for different TS1 threshold abundance levels) to Table 3.1.a (in addition to the mandatory no-action 3.1 alternative) would provide a robust set of alternatives for the NMFS (and subsequently the public) to evaluate in the EIS.

Second (new) alternative:

An analysis of age overfishing should be conducted by the Workgroup. Both the Draft Recommendations and the RA acknowledge the fact that most Council Chinook fisheries encounter immature Chinook (as both landed catch and drop off mortality) which contributes to the reduction in age-at-maturity, resulting in a younger average age of spawning populations (which contributes to lower population productivity and reduced capacity for rebuilding) and a younger average age of the catch (with attendant smaller size and lower per-fish landed value).

Southern Resident killer whales are highly selective on large, older Chinook. More than 80% of their Chinook consumption is on salmon greater than 700mm, generally corresponding to fish age 4 and above (Ford and Ellis 2006, Ward et al. 2010). These ages classes typically make up less than 15% of the recent FRAM abundance of 2-5-year-old Chinook in Salish Sea waters. Because of this importance biologically and ecologically, the PFMC needs to expand beyond abundance metrics as the indicator of healthy salmon stocks and recognize the importance of population structure in recovery goals for Chinook and killer whales.

As part of a robust review of this topic, PFMC should examine the benefits to population structure from phasing out, and eventually terminating (within a specified maximum amount of time), fishing in the EEZ north of Falcon (if not from central California to the Canadian border) and moving the PFMC fisheries to terminal areas at and near the mouths of rivers.

Such a transition should significantly reduce, if not eliminate, the risk that immature Chinook are encountered by the fishery. Age overfishing of Chinook in coastal marine mixed stock salmon fisheries is a significant conservation concern because it reinforces the tendency for Chinook to return at younger ages and smaller sizes-at-age, contributing to declines in both fecundity and productivity. Eliminating age overfishing will both increase the proportion of older, larger Chinook in the spawning return (which will benefit population rebuilding) and increase the average size (weight) of individuals in the catch.

Increasing the average weight of Chinook caught will permit the same total catch biomass to be attained with fewer numbers of Chinook, further benefitting spawner abundance and population rebuilding.

Transitioning to terminal or near terminal fisheries should also benefit SRKWs by increasing the probability that SRKW "get to the fish first" before the salmon encounter fisheries.

In conjunction with an analysis of age overfishing and population structure, an analysis should be conducted on the economic benefits to terminally located fishing communities from moving fisheries close to or in the coastal rivers of origin. This should include the use of selective fishing gears that can target hatchery-origin Chinook stocks and specific size classes of wild Chinook stocks, which will further the rebuilding of wild population spawning escapement and general wild stock rebuilding. The analysis should also include the potential economic benefits to local fishing communities of obtaining higher prices for landed Chinook catches from receiving certification for attaining a high conservation standard in the conduct of the fisheries.

These two alternatives, plus one or two of the alternatives presented in the draft report should be the focus of a thorough Environmental Impact Analysis pursuant to NEPA. This should be an integral component of achieving the new Biological Opinion for the PFMC Salmon FMP.

Citations.

Ford J. K. and G.M. Ellis. 2006. Selective foraging by fish-eating killer whales *Orcinus orca* in British Columbia. Marine Ecology Progress Series Vol. 316: 185–199.

Ford, J. K., G. M. Ellis, P. F. Olesiuk and K. C. Balcomb. 2010. Linking killer whale survival and prey abundance: food limitation in the oceans' apex predator? *Biology Letters* 6(1): 139-142.

Hilborn, R., S.P. Cox, F. M.D. Gulland, D.G. Hankin, N.T. Hobbs, D.E. Schindler, and A.W. Trites. 2012. The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel. November 30, 2012. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for NMFS, Seattle, Washington and Fisheries and Oceans Canada (Vancouver. BC). 87p.

Kriebel, D., J. Tickner, P. Epstein, J. Lemons, R. Levins, E.L. Lochler, M. Quinn, R. Rudel, T. Schetter and M. Stoto. 2001. The precautionary principle in environmental science. *Environmental Health Perspectives* 109(9): 871 – 876.

Lacy 2020. Declaration of Dr. Robert Lacy, Ph.D. submitted to the United States District Court of Washington at Seattle in support of plaintiffs Wild Fish Conservancy in Case No. 2:20-cv-00417-MLP, April 15, 2020.

NMFS 2019. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response:
Consultation on the Delegation of Management Authority for Specified Salmon Fisheries to the State of Alaska; NMFS Consultation Number: WCR-2018-10660. April 5, 2019.

Vélez-Espino, A., JK.B. Ford, Charles K. Parken, Graeme Ellis, Eric Ward, Larrie LaVoy, Ken Balcomb, M. Bradley Hanson, Dawn P. Noren, Tom Cooney and Rishi Sharma. 2013. Sensitivity of Resident killer whale population dynamics to Chinook salmon abundance. Prepared for the Pacific Salmon Commission Southern Boundary Fund Vancouver, BC

Ward, E. J., E.E. Holmes and K.C. Balcomb. 2009. Quantifying the effects of prey abundance on killer whale reproduction. *Journal of Applied Ecology* **46**(3): 632-640

Ward, E., Brad Hanson, Laurie Weitkamp and Michael Ford. 2010. Modeling killer whale prey size selection based upon available data. Unpublished Report by the Northwest Fisheries Centre.

List of documents attached as part of these Comments.

Attachment 1: Note on PFMC SRKW Workgroup Draft Risk Assessment of Sept 11 2019: Nick Gayeski, Wild Fish Conservancy and Misty MacDuffee, Raincoast Conservation Foundation, September 26, 2019

Attachment 2: Submission from Wild Fish Conservancy, Raincoast Conservation Foundation, Georgia Strait Alliance, and Natural Resources Defense Council to NOAA on Protective Regulations for Southern Resident killer whales
December 2019

Attachment 3: Declaration of Dr. Robert Lacy, Ph.D. submitted to the United States District Court of Washington at Seattle in support of plaintiffs Wild Fish Conservancy in Case No. 2:20-cv-00417-MLP, April 15, 2020.

ATTACHMENT 1

Note on PFMC SRKW Workgroup Draft Risk Assessment of Sept 11 2019

Nick Gayeski, Wild Fish Conservancy

Misty MacDuffee, Raincoast Conservation Foundation

September 26, 2019

The SRKW workgroup has initiated an important review of PFMC Chinook fisheries and their implications for SRKW. However, the composition of the workgroup indicates that it is not an independent scientific group. It is composed principally of tribal and state fish and wildlife staff whose prime responsibilities are fisheries management. Only a few of the team members, principally NMFS science staff, have the strong technical capabilities in salmon and ecosystem modeling to produce a quantitative assessment of the risk PFMC (Council) Chinook salmon fisheries pose to the survival of the Southern Resident Killer Whale (SRKW) DPS. As such, there are constraints to receiving the products of the workgroup as appropriate to accomplishing this critical task.

The Draft Report (DR) provides a reasonable summary of the status of the SRKW population, its component pods (J, K, and L), and acknowledges the dependence of the population on Chinook salmon. Importantly, the DR acknowledges the evidence accumulated over the past decade that demonstrate significant correlations between various indices of annual Chinook salmon abundance and demographic vital rates of SRKW. Unfortunately, the authors of the DR prevaricate about the significance of this dependence due to inability of the analyses to establish a clear causal relationship between Chinook abundance and SRKW demography.

The DR needs a clear, strong statement regarding the critically endangered status of the SRKW DPS (see DFO's 2019 SAR and PVA model outputs that indicate ongoing population decline with a 26% probability of quasi-extinction (one sex) within 75-97 years https://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2019/2019_030-eng.html.) and the associated need for immediate management measures to arrest further decline.

The DR should be clear at the outset that this constitutes a conservation emergency. The benefit of the doubt regarding candidate management measures under the control of the Council must favor the DPS in accordance with the priority that society places on ESA-listed endangered populations.

The DR's description of the management structure of the Council Chinook fisheries under the current Pacific Salmon Plan (PSP) reveals the shortcomings of the data. This applies to annual Chinook salmon abundance and distribution, and fishery impacts on Chinook stocks known or potentially important to foraging SRKW within their existing and proposed critical habitat.

Similarly, the DR provides evidence concerning the uncertainty of the relationship of various indices of Chinook salmon abundance to SRKW demographics. This uncertainty is due to two primary factors: uncertainties regarding the accuracy and appropriateness of the individual indices of Chinook abundance and distribution, and uncertainties concerning the strength of association between Chinook abundance or distribution indices and specific SRKW demographic parameters. Among the former uncertainties, are uncertainties regarding the age-distribution of Chinook, maturation rates, and the abundance and proportion of immature Chinook in the several stocks subject to Council fisheries. The latter uncertainties are due primarily to small sample sizes which themselves are due to the low population size of the SRKW population and its component pods. These uncertainties are further compounded by the interaction of lack of Chinook prey and other factors known to pose threats to the viability of the SRKW population, in particular vessel noise and toxics contamination. Inevitably, therefore, there is considerable noise in much of the demographic data pertaining to the relationships between SRKW demographics and indices of Chinook prey.

The decision to rely primarily on the results of the Shelton model (Shelton et al. 2018) to characterize coast-wide Chinook distribution seems reasonable, although it too, like FRAM, is compromised by having to rely nearly entirely on hatchery CWT data. However, Shetlon et al.'s results show that there is considerable uncertainty in the estimates of the annual abundance and spatial distribution of particular stocks or combinations of stocks that cannot be resolved without additional research and data acquisition. Even with such research, it is unclear that additional precision in estimates of stock-specific abundance and spatio-temporal distribution will resolve the issues surrounding fine-scale adjustments of Chinook harvest to the benefit of SRKW. This highlights the importance of developing a value-of-information analysis as a component of the risk assessment, which is absent in the DR.

This reinforces the importance of emergency reductions in Council Chinook salmon fisheries that should not be delayed until additional research resolves these uncertainties. Such reductions would also be consistent with according SRKW the benefit of the doubt and appropriately placing the burden of proof on Chinook fisheries. Research and monitoring can be undertaken simultaneously with harvest reductions.

These uncertainties also provide evidence that there is a limit to the ability of stock assessment to provide the level of detailed information necessary to conservatively manage individual Chinook populations and stock aggregates in coastal mixed-stock fisheries. The current plight of the SRKW DPS provides clear evidence that this has, and will probably continue to be, the case.

In addition, there is lack of data and associated uncertainty regarding the age-structure and maturation rates of Chinook stocks in both the FRAM and the Shelton et al. model. The DR does acknowledge that SRKW prefer larger, older age 4+ Chinook salmon and notes that ocean mixed-stock Chinook fisheries encounter and harvest immature, particularly age 2 and 3 Chinook. But there is no effort made to consider addressing ocean fisheries as a means to rebuild an older, more historical age structure of Chinook populations within SRKW proposed or existing critical habitat. Given, the uncertainties noted, there seems good reason to doubt that restoring the historical age/size structure of Chinook can be undertaken while continuing with coastal mixed-stock Council (and more generally PST) Chinook fisheries. Thus, the DR should consider that the mixed-stock nature of these fisheries themselves pose a risk to the survival of the SRKW DPS.

All of this argues for a fully Bayesian risk assessment framework capable of providing probability distributions of the risks posed to SRKW by Council Chinook fisheries. Unfortunately, the risk assessment approach outlined in the DR does not adopt such an approach. The most probable outcome of this failure as the workgroup continues, is to significantly under-estimate the risk Council Chinook fisheries pose to SRKW.

The current model runs reported in section 5, page 47, should be reconfigured using a Bayesian framework so that the results of the regressions can be stated as posterior probability distributions, and not uninformative and problematic frequentist p-values and associated confidence intervals (CIs). Such revised analyses would clearly and properly display the uncertainties of the analyses (and associated model assumptions) which is necessary to display the risk posed to SRKW by failing to appropriately revise Chinook harvest rules. This would also make transparent the burden of proof that is being placed on the SRKW.

In commenting on the statistical significance of the fitted regressions (based on a traditional frequentist statistical approach) the DR acknowledges that "especially when the data are noisy or confounding variables are not accounted for, it is possible for a real effect to be present despite the data having a pattern no more extreme than one that could be explained by chance alone (large p-value). Given the lack of statistical significance, the results should be interpreted with caution. Nevertheless, in almost all cases the fitted relationships were of the expected sign (i.e. survival and fecundity increased with increasing Chinook abundance while occurrence of peanut-head decreased with increasing Chinook abundance)" (p. 47).

Bayesian regression analyses would produce probability distributions of the fitted relationships (instead of dubious p-values and CIs) and require that threshold probabilities be identified for concluding that no action on Chinook harvest is warranted. More appropriate still, is to embed such regression analyses in a broader Bayesian population viability analysis (PVA) that would provide a probability distribution of time to extinction or quasi-extinction. This would reflect the manner in which the Chinook indices-SRKW demographic indices regression contribute to the overall extinction risk, and hence how managers are weighting the risk that Chinook abundances and distributions pose to SRKW persistence. In view of the fact that three PVAs on SRKW have been published (Velez-Espino et al. 2014, Lacy et al. 2017, Clarke-Murray et al. 2019) it is surprising and disappointing that neither the workgroup or NMFS have incorporated their findings or undertaken an 'official' PVA themselves. Such considerations could provide guidance on the critical decision facing the workgroup.

The ESA accords the greatest benefit of the doubt to populations listed as endangered. In particular, in any jeopardy evaluation, the burden is to show that the proposed action will not jeopardize the continued existence of the listed population(s). It is clear from the recent history of the SRKW DPS and the management of Chinook salmon harvest under the PST and PSP (which govern Council Chinook fisheries) that the current fishing regimes remove prey from a food-stressed SRKW DPS. The only uncertainties concern which fisheries adversely affect which Chinook salmon stocks and by how much, when and where, with respect to the prey requirements of foraging SRKW. The burden of these uncertainties must fall on the fisheries, not on endangered whales. This is especially so in the current context, where the immediate management emergency is to take actions that have the greatest probability of bounding the SRKW DPS away from its decline toward extinction. This requires stabilizing the population growth rate, which is currently negative (lambda ~ 0.99, equal to an annual decline in DPS abundance of 1% per year (Velez-Espino et al. 2014, Lacey et al. 2017, Clarke-Murray et al. 2019).

Further, in light of the renewal of the PST, the burden of Chinook harvest reductions that may be undertaken to attempt to halt the decline of the SRKW DPS must fall on the Council fisheries. The April 9 2019 NMFS Biological Opinion concerning the Consultation on the Delegation of Management Authority for Specified Salmon Fisheries to the State of Alaska makes it clear that NMFS considers Treaty Chinook fisheries as configured pursuant to the 2019 Pacific Salmon Treaty to jeopardize ESA-listed Puget Sound Chinook and SRKW[1]. NMFS's finding that there is a need to further mitigate the effects of Chinook harvest beyond what is provided for in the Treaty is tacit admission that, absent the proposed mitigation measures, NMFS would have had to conclude jeopardy. Regardless of the proposed mitigation measures (which are conjectural and dependent on uncertain future funding), the BiOp makes it clear that Chinook harvest poses jeopardy to SRKW, and since Treaty harvest measures have therein been given ESA take coverage, the burden for further necessary modifications in US coastal Chinook fisheries falls on the Council fisheries.

[1] The 2019 BiOP admittedly does not explicitly use the term 'jeopardy'. The exact language is "… the status of Puget Sound Chinook salmon and SRKWs have declined in recent years. A key objective of the U.S. Section during the negotiating process for a new Agreement was therefore to achieve harvest reductions to help address ongoing conservation concerns for Puget Sound Chinook and coincidentally provide benefits for SRKWs", and continues "Further reductions [in Chinook harvest in PST fisheries] are proposed in conjunction with the 2019 Agreement, but there was a practical limit to what could be achieved through the bilateral negotiation process. As a consequence, and in addition to the southeast Alaska, Canadian, and SUS fishery measures identified in the 2019 PST Agreement, the U.S. Section generally recognized that more would be required to mitigate the effects of harvest and other limiting factors that contributed to the reduced status of Puget Sound Chinook salmon and SRKWs" (pp. 9-10).

Accordingly, the risk assessment to be undertaken (or completed) by the working group must identify changes to Council fisheries that, in conjunction with PST Chinook fisheries beyond the control of the Council, alleviate jeopardy to the SRKW. This requires, as already noted, that the risk assessment be framed as a population viability analysis (PVA) that produces SRKW population trajectories and associated extinction probabilities under the current conditions and under candidate management changes to Council Chinook fisheries, starting with a default complete closure of Council Chinook fisheries for a minimum period of time based on SRKW demography. This will likely be at least 5 and more reasonably 10 years, if not more.

Further, the criterion for the target response by SRKW needed to avoid jeopardy should not be a population growth rate of 2.3% /yr. for 28 years required under the SRKW Recovery Plan. This growth rate is inappropriate to a declining small population on the verge of an extinction vortex. Rather, the issue is to arrest the decline and preserve the reproductive potential of SRKW. This suggests that the target short-term annual population growth rate should be on the order of 1% over the next 10 to 20 years. An annual growth rate of one-half of one percent (0.005) would succeed in stabilizing the SRKW at slightly above the current number (73), provided the variance in that growth rate can be made sufficiently small. A steady average annual population growth rate of 0.005 would result in an average SRKW population of 81 individuals at the end of 20 years (compared to the current population of 73). A growth rate of 0.01 would achieve this population size in 10 years and a population size of 89 in 20 years. Modest as this would be, it is a significant step in the right direction compared to the recent negative population trend. An annual population growth rate in the range of one-half to one percent (0.005 to 0.01) appears to have a high probability of being achieved by the termination of all council directed Chinook fisheries. This also indicates that analyses (e.g., Hilborn et al. 2012, and Velez-Espino et al. 2014) that have concluded that further reduction or even closures of coastal Chinook fisheries are unlikely to achieve (in the near term at least) the NMFS SRKW Recovery Plan target annual population growth rate of 2.3% are misleading, if not misguided. The emergency conservation issue is not how to achieve an immediate annual growth rate of 2.3%, but rather the more urgent and appropriate goal to arrest the recent decline, stabilize the population and facilitate its slow rebuilding.

References

Hilborn, R., S. P. Cox, F. M. D. Gulland, D. G. Hankin, N. T. Hobbs, D. E. Schindler, and A. W. Trites. 2012. The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel. November 30, 2012. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for NMFS, Seattle, Washington and Fisheries and Oceans Canada (Vancouver. BC). 87p.

Lacy, R.C., R. Williams, E. Ashe, K.C. Balcomb, L.J. N. Brent, C.W. Clark, D.P. Croft, D.A. Giles, M. MacDuffee and P.C. Paquet. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. *Scientific Reports* 7, Article no: 14119doi:10.1038/s41598-017-14471-0

Murray, C.C., Hannah, L.C., Doniol-Valcroze, T., Wright, B., Stredulinsky, E., Locke, A., and R. Lacy. 2019. Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/056. x. + 88 p.

NMFS 2019. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response Consultation on the Delegation of Management Authority for Specified Salmon Fisheries to the State of Alaska NMFS Consultation Number: WCR-2018-10660.

Shelton, A. O., Satterthwaite, W. H., Ward, E. J., Feist, B. E., and Burke, B. 2019. Using hierarchical models to estimate stock-specific and seasonal variation in ocean distribution, survivorship, and aggregate abundance of fall run Chinook salmon. Canadian Journal of Fisheries and Aquatic Science 76:95-108.

Vélez-Espino, L.A., J.K.B. Ford, H.A. Araujo, G. Ellis, C.K. Parken and R. Sharma. 2014b. Relative importance of Chinook salmon abundance on resident killer whale population growth and viability. *Aquatic Conservation: Marine and Freshwater Ecosystems*.

ATTACHMENT 2

Submission to NOAA on Protective Regulations for
Southern Resident killer whales
December 2019

Summary points

- The marine waters of the North East Pacific that provide critical habitat to SRKWs are undergoing rapid changes to their structure (ex. stratification, trophic composition), function (ex. role of carbonate ions) and processes (ex. pH buffering, nutrient cycling, primary production), which the whales have not evolved with, but must recover within.
- These changes include shifts in the population demographics and structure of Chinook salmon, including run timing, genetic diversity, abundance, maturation rates, size at age, age at return, and fecundity.
- These changes are largely driven by fisheries that select for larger salmon and catch immature Chinook, but also include climate change, excessive hatchery production and potential size selective predation by other resident killer whales.
- Southern Resident killer whales selectively forage on large, older Chinook salmon estimated to represent less than 15% of the Chinook abundance within the Salish Sea.
- Hatcheries, and corresponding Mark Selective Fisheries, have direct and indirect interactions with wild Chinook that undermine their fitness, population structure, abundance and conservation. They are produced to subsidize commercial and sport fisheries from Alaska to California and have failed to recover wild Chinook populations.
- Closing marine mixed stock Chinook fisheries and moving fisheries to terminal areas would increase abundance of mature Chinook within SRKW foraging grounds.
- Significant reductions in Chinook hatchery production must be implemented to rebuild Chinook population structure and SRKW food supply.
- Vessel management measures in US SRKW critical habitat should be harmonized with Canada's 2019 measures to reduce vessel disturbance and improve salmon accessibility.
- These steps offer the best, and perhaps only, chance to restore reproductive potential and improve survival for endangered SRKWs.

Recovery plans for endangered Southern Resident killer whales have been in place in the US and Canada since 2008. Despite the listings and recovery plans, these whales have failed to show any signs of population stabilization, a reversal in their declining trend, or recovery. The most recent Population Viability Analysis (PVA) completed by Canada's Department of Fisheries and Oceans (DFO, Clark-Murray et al. 2019) in August 2019 shows ongoing population decline with a 26% probability of quasi-extinction (one sex) within 75-97 years (SAR: https://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2019/2019_030-eng.html; Clarke-Murray et al. 2019).

DFO's PVA examined the known primary threats (abundance of primary prey, Chinook salmon, vessel noise and disturbance, and contaminants) from an individual and cumulative threat perspective. When considered individually, the modeled effects of individual threats did not replicate the observed population trend in SRKWs over the period 2000-2017. When the threats were considered together (Chinook salmon abundance, vessel noise/physical disturbance, vessel strike and PCB contamination), the output of the PVA model closely replicated the observed population trends for Southern (and Northern) Resident killer whale populations. The authors conclude that Chinook salmon abundance and its interactions with vessel noise and PCBs strongly influenced modelled killer whale population dynamics. Importantly, this PVA follows previous DFO (Velez-Espino *et al.* 2014 a, b) and independent (Lacy *et al.* 2017) viability analyses that show declining trajectories with a 25% to 49% risk of functional extinction (less than 30 individuals) by the end of the century depending on the threats considered.

Despite minor efforts to reduce threats and implement precautionary measures for SRKWs, these actions have not improved declining trends nor have they improved estimated extinction probabilities. This failure has placed the region in the position of having to undertake drastic actions to arrest the decline in Southern Resident population numbers and preserve reproductive potential. Past reductions in Chinook salmon fisheries, including those in the recently renewed Pacific Salmon Treaty, have at best simply followed declining stocks down, rather than making significant precautionary reductions and/or implement closures that would get ahead of population declines and facilitate genuine rebuilding. Herein, we propose actions to be taken immediately to halt the decline and preserve the possibility of recovery of these iconic whales.

Despite high profile attention and proclamations for bold recovery actions by governments in the past few years, the SRKW population has only declined. Absolute population numbers are at critically low levels (73 individuals across the three pods with J pod consisting of 22 members, K pod of 17, and L pod of 34; CWR https://www.whaleresearch.com/orca-population). Extensive analysis has been presented to US authorities on the Task Force and to NOAA, describing the population's precarious biological condition. There should be no disputing the demographic information that shows a dramatic reduction in successful births, declining matriarch and breeding females, skewed sex ratios, in-breeding concerns, disrupted age structure, and destabilized population structure that likely has social, as well as biological, implications. The issue at hand is not whether urgent action is warranted, but the adequacy of the measures needed to reverse this dangerous decline and stabilize the population so as to preserve the possibility of recovery (population rebuilding).

A rapidly changing ocean

Underpinning the historical presence, distribution, and resilience of Resident killer whales are evolutionary ecological processes that support ecosystem function and services. As these processes are disrupted or destroyed, the complex ecological webs that underlie the diversity, abundance, and productivity of Chinook salmon and SRKW (among many other components of Pacific Northwest marine and freshwater ecosystems) unravel. Mixed-stock coastal marine salmon fisheries and large-scale salmon hatchery production are contributing causes of this unraveling.

The diet, biological and cultural traits of Southern Residents have evolved over 250 thousand years into an ecotype that is highly specialized on the geographic distribution, run timing, and size and abundance of Chinook salmon, as well as other seasonally abundant species of the larger Pacific salmon. They also evolved with an acoustic environment that supported their use of sound to meet social and biological life requisites.

The quality of the marine environment (warming, acidification, oxygen loss, nutrient cycling and primary production) along with the spatial, temporal and biological structure of Chinook populations that SRKWs rely on, has changed significantly within the last century, especially so in the last 30-40 years.

Today, the rates, scales, kinds, and combinations of regional and global ecosystem change differ from those at any other time in history. For example, heatwaves from El Nino, the blob, and steady warming in the North Pacific Ocean increases salmon metabolism, food consumption and stress. More importantly, warming temperatures change zooplankton composition and distribution (changing food quality), increase vertebrate and invertebrate predators, drive algae blooms, change historic hydrologic patterns, increase ocean stratification, weaken upwelling processes, and change the base of the salmon food web.

Surface waters are not just warmer, they are more acidic. With higher acidity, sound wave absorption is lowered, making ocean noise louder. More CO_2 uptake has consequences for zooplankton at the base of the food web that use carbonate minerals for shells and skeletons. Models predict that large parts of the Arctic will start to cross a carbonate under-saturation threshold in a decade, with forecasts that most Arctic waters will lack adequate aragonite for shell-building organisms by the 2080s (AMAP 2018).

Other ecosystem changes come from disease, invasive species, contaminants, competition, and a multitude of altered freshwater conditions. Sudden leaps in aberrant ecosystem behaviour are also being observed, with changes often occurring faster than we can understand them. Coupled with this is still a fundamental lack of understanding of the functions and processes that underpin natural systems. This understanding is often a prerequisite to link species decline with threat reduction and conservation action. Its absence allows resource managers to stay the course of conventional management and abdicate demonstrating burden of proof of ecosystem harm.

The take home message from this is that both killer whales and Chinook salmon must now recover in an environment that is vastly different from the one in which they evolved. Their ability to recover is unlikely unless significant measures are taken to stop threats and encourage, rather than undermine, their resilience.

Recommendations

1. **NOAA must reform Chinook harvest in AABM and ISBM fisheries**

SRKWs evolved with the spatial and temporal run timing of Chinook salmon that matured between four and eight years of age (and an increasing percentage of females with age). These salmon returned across the months and seasons to select rivers within the range of SRKW. SRKW are highly selective on mature large (70cm+), old (4 yrs +), and increasingly rare Chinook salmon (for example, 4 and 5 yr old Chinook made up less the 15% of the abundance estimate for 2-5 year old Chinook in the 2018 FRAM pre-season abundance model, Chinook older than this are so rare they are not even factored into models). Unless the historic population structure and run timing of Chinook is restored, SRKWs cannot recover.

Chinook salmon abundance trends show synchronous declines throughout BC, the Transboundary rivers, the Yukon, and Southeast Alaska, with declines in Chinook survival reported from Oregon to Alaska (Grant et al. 2019). Declining Chinook abundance is exacerbated by decreases in Chinook size at age, age at return, age at maturity, and reproductive potential, including reductions in egg size and the numbers of eggs per female, especially among age 4 (ocean age 3) and older females, largely due to the reduction in size-at-age (Grant et al. 2019, Ohlberger et al. 2018, 2019). These changes in population structure are perpetuated by Chinook fisheries that target the largest, oldest salmon, and coastal mixed-stock Chinook fisheries that encounter immature Chinook (Riddell et al. 2013). They are also perpetuated by competition when food supply is limited, competition that is exacerbated by releases of large numbers of hatchery Chinook.

As spawning Chinook return younger and smaller, this affects their spawning success. Large female Chinook have the size and strength to bury their fertilized eggs in course gravel and cobble below the typical scour force of the river. In this way, few are crushed or washed away under typical conditions. As female Chinook decline in size, so does their ability to build adequate redds (nests), leading to lower survival in the fewer, smaller eggs that are deposited. In addition, high quality spawning habitats that can only be utilized by larger Chinook go unused, further depressing population productivity, abundance, and diversity and distorting assessment of the effects of habitat preservation and recovery efforts.

Benefits from a coast-wide marine recreational and commercial Chinook closure

Within two generations of Chinook salmon (8-10 years), the elimination of mixed stock fisheries that encounter and kill mature and immature Chinook can be expected to begin rebuilding an older age structure to many Chinook populations that are critical to SRKW, providing more and larger Chinook to these whales. Estimates in Hilborn et al. (2012) show that the probable effects of full marine fishery closures (US and Canada) would increase total abundance (numbers) of mature age 4 and 5 yr old Chinook to the Salish Sea by about 20% for all stocks combined (Puget Sound, Fraser early, Fraser late, and Lower Georgia Strait). Increases in terminal abundance of this magnitude were shown by Lacy et al. (2017) to stop the declining trend of SRKWs. When combined with vessel management actions to reduce noise and disturbance, such increases in abundance could bring about positive growth rates.

Elimination of marine mixed-stock fisheries is not a no fishing scenario. Terminal and in-river fisheries employing selective fishing gears and methods whose harvests are managed for ecosystem benefits (i.e. by setting egg deposition and adult spawner escapement targets that maximize smolt production (Forseth et al. 2013, Gayeski et al. 2018) can provide salmon to First Nation and Tribal needs. Such fisheries are designed to occur after whales have had access and after component stocks that are currently encountered in mixed stock fishery areas have diverged to their rivers of origin. Fisheries targeting and otherwise affecting populations down the Pacific Coast as far as Monterey Bay, will likely need to be reconfigured in similar ways to those conducted on migrations routes between Alaska and the Salish Sea.

Remove the burden of proof placed on the SRKW

Until now, advocates for SRKW recovery have been made to bear the burden of proof when proposing conservation measures at the expense of other stakeholders and interests. This must change. The burden of Chinook harvest reductions that may be undertaken to attempt to halt the decline of the SRKW DPS must fall on fisheries. The April 2019 NMFS Biological Opinion concerning the Consultation on the Delegation of Management Authority for Specified Salmon Fisheries to the State of Alaska makes it clear that NMFS considers Treaty Chinook fisheries as configured pursuant to the 2019 Pacific Salmon Treaty to jeopardize ESA-listed Puget Sound Chinook and SRKW[1]. NMFS's finding that there is a need to further mitigate the effects of

[1] The 2019 BiOP admittedly does not explicitly use the term 'jeopardy'. The exact language is "… the status of Puget Sound Chinook salmon and SRKWs have declined in recent years. A key objective of the U.S. Section during the negotiating process for a new Agreement was therefore to achieve harvest reductions to help address ongoing conservation concerns for Puget Sound Chinook and coincidentally provide benefits for SRKWs", and continues "Further reductions [in Chinook harvest in PST fisheries] are proposed in conjunction with the 2019 Agreement, but there was a practical limit to what could be achieved through the bilateral negotiation process. As a consequence, and in addition to the southeast Alaska, Canadian, and SUS fishery measures identified in the 2019 PST Agreement, the U.S. Section generally recognized that more would be required to mitigate the effects of

Chinook harvest beyond what is provided for in the Treaty is tacit admission that, absent the proposed mitigation measures, NMFS would have had to conclude jeopardy. Regardless of the proposed mitigation measures (which are conjectural and dependent on uncertain future funding), the Biological Opinion makes it clear that Chinook harvest poses jeopardy to SRKW, and since Treaty harvest measures have therein been given ESA take coverage, the burden for further necessary modifications in US coastal Chinook fisheries falls on the Council fisheries.

2. **Significantly reduce, not increase, Chinook hatchery production**

Hatchery Chinook salmon are produced to subsidize commercial and sport fisheries from Alaska to California. The production of Chinook from Washington, Oregon and California hatcheries has failed to recover Chinook salmon, contributed to overfishing of wild, threatened and endangered populations, contributed to the changes in population structure and run timing, and likely exacerbated competition with wild Chinook in a food limited environment of the North Pacific. Further, the public funds spent on these hatchery programs and facilities takes scarce funding away from wild population monitoring and recovery actions. Continuing to pursue a hatchery strategy will not change this situation. It is likely to undermine recovery efforts for wild Chinook and the needed rebuilding of their age structure, their run-timing, their diversity, their productivity and their abundance. Restoring these attributes is not the objective of production hatcheries. There is also concern that increased hatchery production from Puget Sound will come at a cost to natural production in the Fraser River.

Further, hatchery Chinook are largely late-timing ocean-types. Some of the most endangered Chinook populations, and potentially some of the most important runs for SRKW, are early-timed stream-types and the few remaining winter runs.

At current levels of hatchery production, the proportion of hatchery origin Chinook on wild salmon spawning grounds (pHOS: proportion of hatchery origin spawners) in most Washington rivers exceeds “biologically acceptable” levels recommended by the independent Hatchery Scientific Review Group (HSRG 2009, 2015, WDFW Score/Chinook). This is especially true of most Puget Sound Chinook populations.

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harvest and other limiting factors that contributed to the reduced status of Puget Sound Chinook salmon and SRKWs” (pp. 9-10).

The rush to focus on a conjectural quick fix in the form of increased Chinook hatchery production is symptomatic of the failure of current management to address past mismanagement of Chinook populations coast-wide and the hope that an industrial-technological solution will somehow solve a complex ecological problem. Reliance on this failed industrial tool to address the complex ecological issues facing SRKW and wild Chinook is destined to fail both of them. Such an approach simply repeats the current "placeless" management of salmon that fails to recognize that their great diversity and abundance is rooted in their strong attachment to place: i.e. the rivers of their origin (Gayeski *et al.* 2018). SRKW are an integral component of the Salish Sea ecosystem and any solution to the Chinook crisis affecting them should also be place-based.

Fisheries managers responsible for Chinook salmon and SRKW have ignored the significant harvest issues, perpetuated by hatcheries, that are responsible for a large part of the decline and failure for Chinook to rebuild (Gayeski *et al.* 2018).

3. The role of Pinnipeds

Canadian studies examining the consumption of Chinook by seals and sea lions since pinnipeds numbers have recovered to near historical levels in the last 20+ years, shows that Chinook salmon represent a small percentage of pinniped diet (less than 10% with a mean across all pinnipeds of 0 - 4.4%; DFO 2019). Juvenile, immature and mature salmon have many predators beyond pinnipeds including Humboldt squid, great blue herons and other piscivorous birds, harbour porpoise, Pacific white-sided dolphins, Pacific hake, river lamprey, salmon sharks, sturgeon, tuna, northern fur seals, and other Northeast Pacific Resident killer whales. Relationships that assume single lines between the abundance of prey and a specific predator oversimplify complex marine food webs. A proper appreciation of these food web dynamics and the extent of additive versus compensatory mortality that exists between pinnipeds and their salmon prey make it extremely difficult to predict how the system will react to removal of a predator.

There is also a host of other factors that affect the rate at which salmon are preyed upon. A 2019 workshop (Trites and Rosen *ed*.) identified the extent of kelp forests, habitat complexity, water temperature, stream water height and flow, man-made obstructions to fish passage (bridge, dam, etc.), proximity to pinniped haul outs, alternative prey availability, fishing efforts, and hatchery fish as some of many factors that may be affecting predation. As such, beliefs that a pinniped cull would aid Chinook survival are not supported by available science.

4. **Harmonize U.S. vessel management measures with Canadian measures**

In the spring of 2019, Transport Canada issued an Interim Order prohibiting vessels from approaching any killer whale within 400 metres while in Canadian SRKW critical habitat. Transport Canada also entered into an agreement with identified members of the Pacific Whale Watch Association (PWWA) to avoid and not follow SRKWs.[2] The Transport Canada agreement also enabled listed members of the PWWA to approach Transient/Biggs killer whales to 200 m. Preliminary reports of 2019 vessel compliance with the Order for SRKWs in Canadian waters indicate a good level of compliance and low number of commercial and private whale watch vessel interactions with SRKWs.

5. **Restore access to historical Chinook habitat.**

The rebuilding of wild runs in naturally flowing rivers throughout the historic geographical range of Chinook salmon is a necessary long term goal to give wild salmon the best possibility to recover their population structure, run timing, diversity and abundance. As such, the removal of the Snake River and other dams should be considered part of the long term recovery strategy. Benefits to the recruitment of affected Chinook populations and foraging SRKW would begin to accrue one or more Chinook generations (4+ years) after dam removal. These fish would be available for foraging from southwest Vancouver Island to California and within critical habitat in the Salish Sea.

Conclusion

U.S. government authorities have generally denied the risks of hatchery production to the preservation and recovery of wild Chinook salmon and excluded meaningful discussion of fisheries management issues that perpetuate the decline of wild Chinook salmon. This is a failure to openly and fully consider all factors leading to the current dire condition of the Southern Resident Killer Whale population. There is no credible scientific justification for this. Reductions

[2] See Appendix I "Sustainable Whale Watching Agreement to support the Recovery of Southern Resident Killer Whales"

of Chinook harvest are, with high probability, the most likely tangible action that can provide SRKWs with immediate relief from the major stresses that have been threatening the population with extinction for the past decade or more.

Closing mixed-stock marine commercial and recreational fishing, and significantly reducing hatchery production are required now. Closing such fisheries will ensure they are managed to prioritize the returns of mature Chinook to SRKW foraging refuge areas. The longer this kind of action is postponed, the lower the likelihood that the decline of SRKW can be halted, much less reversed, and the more drastic harvest reductions and other remedial actions will have to be in order to have any chance of success. Absent the actions we advocate, we expect the state of SRKW to get worse, not better, and thus continue the declining trend in the coming few decades, if not sooner.

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References

AMAP Assessment 2018: Arctic Ocean Acidification. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. vi+187pp

Clark-Murray, C., Hannah, L.C., Doniol-Valcroze, T., Wright, B., Stredulinsky, E., Locke, A., and R. Lacy. 2019. Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/056. x. + 88 p.

Fisheries and Oceans Canada. 2019. How seals and sea lions may be affecting Chinook salmon. Presentation to the Southern BC Chinook committee. August 2019.

Forseth, T., P. Fiske, B. Barlaup, H. Gjosaeter, K. Hindar, and O. H. Diserud. 2013. Reference point based management of Norwegian Atlantic Salmon populations. Environmental Conservation 40:356–366.

Gayeski, N. J., J. A. Stanford, D. R. Montgomery, J. Lichatowich, R. M. Peterman, and R. N. Williams. 2018. The Failure of Wild Salmon Management: Need for a Place-Based Conceptual Foundation. *Fisheries* v.43, no. 7 pp. 303 – 309.

Grant, S.C.H., MacDonald, B.L., and Winston, M.L. 2019. State of Canadian Pacific Salmon: Responses to Changing Climate and Habitats. Can. Tech. Rep. Fish. Aquat. Sci. 3332. ix + 50

Hilborn, R., S. Cox, F. Gulland, D. Hankin, T. Hobbs, D.E. Schindler, and A. Trites**.** 2012. The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for National Marine Fisheries Service (Seattle WA) and Fisheries and Oceans Canada (Vancouver BC). 51 pp.

Hooper, D.U., E. C. Adair, B, J. Cardinale, J. E. K. Byrnes, B. A. Hungate, K. L. Matulich, A. Gonzalez, J. E. Duffy, L. Gamfeldt and M. I. O'Connor. 2012.A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature doi:10.1038/nature11118.

Lacy, R.C., R. Williams, E. Ashe, K.C. Balcomb, L.J. N. Brent, C.W. Clark, D.P. Croft, D.A. Giles, M. MacDuffee and P.C. Paquet. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. *Scientific Reports* 7, Article no: 14119doi:10.1038/s41598-017-14471-0

Ohlberger, J., E.J. Ward, D.E. Schindler and B. Lewis. 2018. Demographic changes in Chinook salmon across the Northeast Pacific Ocean. *Fish and fisheries*, *19*(3), 533-546

Ohlberger, Jan, D.E. Schindler, E.J. Ward, T.E. Walsworth and T.E. Essington. 2019. Resurgence of an apex marine predator and the decline in prey body size. *Proceedings of the National Academy of Sciences*.

Price, M.H.H., K. K. English, A. G. Rosenberger, M. MacDuffee, and J. D. Reynolds.2017. Canada's Wild Salmon Policy: an assessment of conservation progress in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences. dx.doi.org/10.1139/cjfas-2017-0127.

Riddell, B., M. Bradford, R. Carmichael, D. Hankin, R. Peterman, and A. Wertheimer. 2013. Assessment of Status and Factors for Decline of Southern BC Chinook Salmon: Independent

Panel's Report. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for Fisheries and Oceans Canada (Vancouver. BC) and Fraser River Aboriginal Fisheries Secretariat (Merritt, BC). xxix + 165 pp. + Appendices.

Ruggerone, G. T. and J. R. Irvine. 2018. Numbers and Biomass of Natural- and Hatchery-Origin Pink Salmon, Chum Salmon, and Sockeye Salmon in the North Pacific Ocean, 1925–2015. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 10:152–168.

Trites, A.W. and Rosen, D.A.S. (eds). 2019. Synthesis of Scientific Knowledge and Uncertainty about Population Dynamics and Diet Preferences of Harbour Seals, Steller Sea Lions and California Sea Lions, and their Impacts on Salmon in the Salish Sea. Technical Workshop Proceedings. May 29-30, 2019. Marine Mammal Research Unit, University of British Columbia, Vancouver, B.C., 67 pages.

Vélez-Espino, L.A., J.K.B. Ford, H.A. Araujo, G. Ellis, C.K. Parken and Balcomb, K. C. 2014a. Comparative demography and viability of northeastern Pacific resident killer whale populations at risk. Canadian Technical Report of Fisheries and Aquatic Sciences 3084: v + 58p.

Vélez-Espino, L.A., J.K.B. Ford, H.A. Araujo, G. Ellis, C.K. Parken and R. Sharma. 2014b. Relative importance of Chinook salmon abundance on resident killer whale population growth and viability. *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Appendix I

SUSTAINABLE WHALE WATCHING AGREEMENT TO SUPPORT THE RECOVERY OF THE SOUTHERN RESIDENT KILLER WHALE

Between:

The Minister of Transport, responsible for the Department of Transport (TC)
(Hereinafter referred to as the Minister)

And

The Membership of the Pacific Whale Watch Association, as represented by their Board of Directors
(Hereinafter referred to as PWWA
(Hereinafter referred to as the "Parties")

SUSTAINABLE WHALE WATCHING AGREEMENT TO SUPPORT THE RECOVERY OF THE SOUTHERN RESIDENT KILLER WHALE

Contents

PREAMBLE:

A. **Whereas** the Southern Resident Killer Whale (SRKW) is a species which has been listed as Endangered under part 2, Schedule 1 of the federal *Species at Risk Act, 2002* (SARA);

B. **And whereas** Canada is committed to the long-term conservation, survival and recovery of aquatic species at risk to ensure the long-term viability of species and to enhance their survival in the wild;

C. **And whereas** the Parties recognize that a key threat to the SRKW is acoustic and physical disturbance from vessels;

D. **And whereas** on May 24, 2018 the Minister of Fisheries, Oceans and the Canadian Coast Guard and the Minister of Environment and Climate Change Canada, as the Minister responsible for Parks Canada Agency, as competent ministers for the SRKW announced that they were of the opinion that the SRKW population faced imminent threats to its survival and recovery;

E. **And whereas** TC has jurisdiction over maritime traffic, has a mandate to promote efficient, environmentally responsible and safe transportation, and has a responsibility to address the environmental impacts of maritime transportation including the mitigation of acoustic and physical disturbance on endangered marine mammals;

F. **And whereas** the PWWA is committed to education and conservation while advocating responsible whale watching, and is also committed to direct conservation, using their extraordinary access to these sensitive populations of marine mammals to help protect them for generations to come;

G. **And whereas** the Parties wish to cooperate in the taking of measures to support the survival and recovery of the SRKW as aligned with the recovery goal and objectives in the Recovery Strategy and recovery measures in the Action Plan, as well as in any future recovery documents prepared in accordance with SARA legislative requirements;

H. **And whereas** the critical habitat of SRKW is currently defined to include coastal waters off British Columbia;

I. **And whereas** the Minister has issued an Interim Order prohibiting vessels from approaching within 400 metres of a killer whale within SRKW critical habitat;

J. **And whereas** members of the PWWA have specialized knowledge and experience to determine whale ecotypes through observation of their behaviour, activity, and appearance;

K. **And whereas** the Minister may authorize a vessel, or a person operating or navigating a vessel, to approach to approach between 200m and 400m of a killer whale, other than a SRKW, for commercial whale-watching purposes, while within the critical habitat of the SRKW, if the person or vessel is subject to an agreement with the Minister related to whale watching and intended to reduce the risk of physical and acoustic disturbance to SRKW;

L. **And whereas** the members of the PWWA are welcome to leverage this agreement to help educate and raise awareness among their clients of the plight of the SRKW and the reasons these actions are being taken.

M. **Now therefore**, the Parties commit to the following:

1. DEFINITIONS

1.1. The following terms defined hereunder and used in this Agreement, when capitalized, will have the following meaning:

1.1.1. **"2019 season"** refers to the months during 2019, specifically June 1st – October 31st, when SRKW are expected to return to their critical habitat in increasing numbers.

1.1.2. **"Acoustic disturbance"** means anthropogenic noise that interferes with SRKW life functions including feeding and foraging, reproduction, socializing, and resting, such that the marine environment cannot support effective acoustic social signaling and echolocation and results in loss of habitat availability and/or function

1.1.3. **"Best available information"** includes relevant scientific, technical, navigational safety, operational, commercial and economic data, community and Indigenous traditional knowledge;

1.1.4. **"Effective Date"** means the date of the last signature affixed to this Agreement;

1.1.5. "**Physical disturbance"** means the physical presence and proximity of vessels to individual SRKW that impedes functions such as feeding, foraging, reproduction, socializing or resting, which may affect SRKW at both the individual and population level;

1.1.6. **"PWWA vessels"** means a vessel operated by a Pacific Whale Watch Association member for the purposes of whale watching and ecotourism business.

2. GOAL AND PURPOSE

2.1. The goal of this agreement is to reduce the risk of physical and acoustic disturbance to Southern Resident killer whales from PWWA vessels for the 2019 season.

2.2. The purposes of this agreement are to:

2.2.1. Set out the specific commitments from PWWA that will assist in achieving the stated goal;

2.2.2. Enable membership of the PWWA, including both Canadian and U.S. members, to fulfil the requirement of an agreement in order to receive authorization to approach between 200m and 400m of a killer whale, other than a SRKW, for commercial whale-watching purposes, while within the critical habitat of the SRKW;

2.2.3. Establish a mechanism for reporting and review with respect to PWWA commitments.

3. PRINCIPLES

3.1. The following principles will guide interpretation and implementation of this Agreement:

3.1.1. **Precaution**: The efforts of the PWWA are being taken in recognition of the need to act in a precautionary manner given the status of the SRKW;

3.1.2. **Adaptation/Adaptive Management**: The Parties recognize that monitoring the effectiveness of existing and future threat reduction measures to abate threats from PWWA vessels and adjusting approaches as necessary will be critical to success;

3.1.3. **Co-benefits**: The Parties will seek opportunities to implement threat reduction measures for SRKW that may also offer co-benefits to other species at risk;

3.1.4. **Transparency**: The Parties will make non-confidential information related to the development, implementation and monitoring of the Agreement and threat reduction measures publicly available subject to section 8.2 of this Agreement; and

3.1.5. **Engagement**: The Parties will seek opportunities for bilateral engagement on the implementation of the agreement.

4. INTERPRETATION

4.1. The preamble hereof and any appendices hereto form an integral part of this Agreement.

4.2. This Agreement is not intended to create any legally binding obligations, duties, commitments or liabilities (contractual or otherwise) on any of the parties. Nor does it create any new legal powers on the part of the Parties or affect in any way the powers, duties and functions of the Minister of Transport under the *Canada Shipping Act, 2001*, the *Canada Marine Act*, or any other federal legislation.

5. MEASURES UNDERTAKEN FOR THE PROTECTION OF SRKW BY THE MEMBERSHIP OF THE PACIFIC WHALE WATCH ASSOCIATION

5.1. The Parties acknowledge that:

5.1.1. Recovery of the SRKW population will require an ecosystem approach applied on a long-term basis that takes into consideration all three main threats to SRKW and will require additional measures to those undertaken by the Parties pursuant to this Agreement;

5.1.2. Other limiting factors that may affect SRKW survival and recovery are beyond the influence of the Parties, including but not limited to events occurring in SRKW critical habitat in US waters.

5.2. In support of the goal set out in section 2.1 and subject to section 9.1, the PWWA and its members commit to:

A) Continue to practice current PWWA guidelines, including travelling at no more than 7 knots when within 1 kilometre of a whale (all types), and turning off sonar, depth sounders, fish finders and other underwater transducers when in the vicinity of a whale (all types);

B) Focus whale watching tours on populations of Bigg's killer whales (Transients), Northern Resident killer whales, Humpback, and other Baleen Whales, and will not intentionally offer, plan or promote excursions based on viewing of SRKW. When periodically encountering SRKW in the course of viewing other whales, PWWA vessels will focus on conservation and education of the SRKW, will not approach within 400 metres, will not follow SRKW, will continue following the go-slow-within-1km approach, and will continue transiting as soon as possible;

C) Ensure to respect the Interim Sanctuary Zones, as established under the Interim Order, which shall not be entered;

D) Carry any written authorization(s) received to approach between 200m and 400m of a killer whale, other than a SRKW, for commercial whale-watching purposes, on board and produce it on request;

E) Log (and report) any incidents involving unintentional approaches to within 400 metres of SRKW, either observed or experienced.

6. TERM, MODIFICATION, TERMINATION & RENEWAL

6.1. This Agreement takes effect on the date of the last signature affixed to this Agreement ("Effective Date").

6.2. This Agreement remains in force for the duration of the 2019 season, unless terminated earlier by one of the Parties or the Parties mutually agree to modify or terminate it.

6.3. The Agreement can only be modified by mutual consent of the Parties or their representatives.

6.4. The Parties may renew this Agreement or any part of it, and its duration may be extended with the mutual written consent of the Parties prior to the expiration of this Agreement.

7. GOVERNANCE

7.1. Should a member of the PWWA be found in violation of this agreement or of the mandatory applicable approach distance(s), the PWWA executive is expected to take appropriate action to ensure that the integrity of the agreement is not jeopardized and inform Canada of their approach to addressing violations.

7.2. The Minister retains discretion to suspend or revoke this agreement and revoke any authorization granted under the Interim Order, regardless of the action(s) taken by the PWWA with regard to addressing violations.

7.3. Monthly update calls between PWWA leadership and TC, represented by the Environmental Policy Group, shall be held to share information, discuss any issues that have arisen, and identify any on-going challenges.

8. MONITORING, RECORD KEEPING & REPORTING

8.1. The PWWA commits to providing the Minister with a list all its members along with the corporate address of their place of business, contact information and vessel information. The PWWA will ensure the list provided to the Minister is current.

8.2. The PWWA commits members to monitoring and keeping records of the progress on actions identified within the Agreement, specifically the implementation of those committed to in subsection 5.2.

8.3. By December 31, 2019, the Parties will review the Agreement against the agreed upon monitoring and record keeping and prepare and issue a report describing the implementation of measures undertaken as part of this Agreement.

9. INFORMATION SHARING

9.1. Each Party agrees, subject to any applicable data sharing agreements and legislative provisions that would prevent them from doing so, to provide the other Party access at no charge to available data and information relevant to the implementation of this Agreement.

9.2. Some data and information may require confidentiality or may have been obtained with an understanding of confidentiality. Data and information so identified by a Party, or a collaborator in programs and activities related to this Agreement, will be held confidential by the Parties to the extent permitted by any relevant legislation and related policies, procedures, and agreements.

10. DISPUTE RESOLUTION

10.1. Where a dispute arises under this Agreement, the dispute shall be resolved through consultations between the Minister's representatives and representatives of PWWA.

11. PARLIAMENT NOT FETTERED

11.1. Nothing in this Agreement shall prohibit, restrict or affect the right or power of the Parliament of Canada to enact any laws whatsoever with respect to any area of law for which the Parliament of Canada has legislative jurisdiction, even if the enactment of any such law affects this Agreement, its interpretation or the obligations of either party.

12. MINISTER NOT FETTERED

12.1. Nothing in this Agreement shall derogate or otherwise fetter the ability of the Minister to regulate, administer, manage, or otherwise deal with the protection of the marine environment from adverse vessel effects and all attendant matters thereto.

13. SIGNATURES

In witness whereof, the Parties have executed this Agreement.

ATTACHMENT 3

HONORABLE MICHELLE L. PETERSON

UNITED STATES DISTRICT COURT
WESTERN DISTRICT OF WASHINGTON
AT SEATTLE

WILD FISH CONSERVANCY NORTHWEST, a Washington non-profit corporation, Plaintiff, v. BARRY THOM, in his official capacity as Regional Administrator of the National Marine Fisheries Service, *et al*, Defendants.	Case No. 2:20-cv-00417-MLP **DECLARATION OF DR. ROBERT LACY, Ph.D.**

I, Robert Lacy, state and declare as follows;

1. I am over eighteen years of age. I have personal knowledge of the facts contained in this declaration and am otherwise competent to testify to the matters in this declaration.

2. I received my B.A. and M.A. in Biology from Wesleyan University in 1977, where I graduated summa cum laude. I received my Ph.D. in Evolutionary Biology with minors in Genetics and Ecology from Cornell University in 1982. I serve on the faculty of the Committee on Evolutionary Biology at University of Chicago. I was a Conservation Scientist for the Chicago Zoological Society from 1985, until my recent retirement and appointment as a Conservation Scientist Emeritus. Although "retired" I still work actively with the Species

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Conservation Toolkit Initiative, a team that develops, distributes, and supports software for species risk assessments and wildlife population management.

3. My qualifications, including publications, is contained in my Curriculum Vitae, which is attached as Exhibit B to this declaration.

4. I have been retained by Wild Fish Conservancy, through its counsel, to provide expert opinions in this matter on issues related to the Southern Resident Killer Whale population and the implications of the National Marine Fisheries Service's ("NMFS") conclusions in the Biological Opinion issued with regard to the 2019 Pacific Salmon Treaty. This declaration describes my opinions and the bases therefor.

5. In addition to drawing upon my knowledge and expertise, I have reviewed the materials cited throughout this declaration and those identified in the list of cited materials attached to this declaration as Exhibit A in developing my opinions expressed herein.

6. In summary, the opinions I express herein are as follows:

a. Analyses conducted in 2015 projected that the Southern Resident Killer Whale population would decline slowly at a rate of about 0.2% per year if environmental conditions and the demographic responses to threats remained as they had been over the previous few decades. Updated analyses on the current population now project about a 1% annual decline, leading to eventual extinction of the population as demographic and genetic problems become worse with the ongoing decline in the breeding population. The numbers of Southern Resident Killer Whales increased from 1976 to a peak in 1993-1996, and has subsequently declined. The 2015 prediction of approximately zero population growth accurately reflected the lack of growth in numbers over the entire time period

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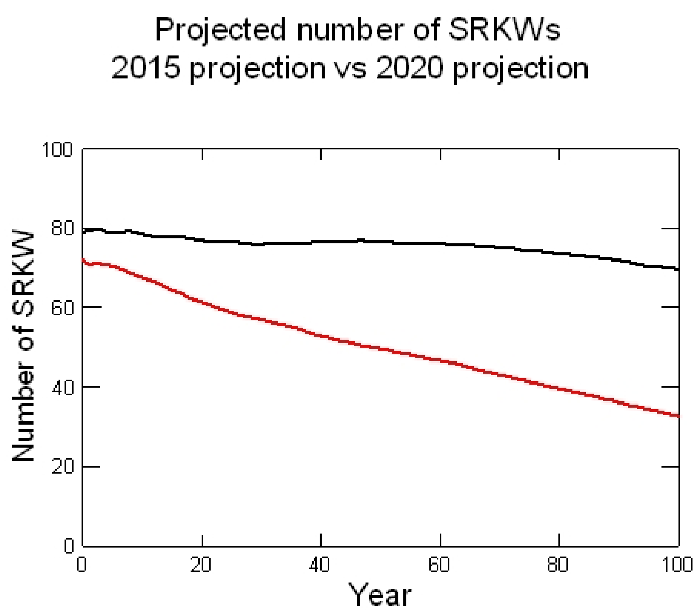
from 1976 to 2020, while the more pessimistic current prediction accurately mirrors the 1% average annual decline that has occurred since 1993. Since 2014, the Southern Resident Killer Whale population has declined at an even faster rate of about 2% per year. Although the difference between a 0.2% annual decline and a 1% annual decline might not seem large, the cumulative effect of the faster rate of decline compounds to become considerable damage across the years. The following graph shows the mean projected number of Southern Resident Killer Whales, using the data from 2015 (upper, black line) and the mean projected number using the current (2020) data (lower, red line). In 2015, we estimated a 9% probability that the population would become functionally extinct with fewer than 30 animals within the next 100 years. With updates to reflect the current situation, I now estimate a 59% probability that the population will drop below 30 animals sometime in the next 100 years, becoming functionally extinct.



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b. The abundance of Chinook prey influences the reproductive rate and the survival rates of the Southern Resident Killer Whale. Analyses indicate that prey abundance is the factor that has the largest impact on Southern Resident Killer Whale population growth or decline. Using published estimates of the effect of prey abundance on demographic rates, we calculate that Chinook total abundance available as prey to the Southern Resident Killer Whale needs to increase by about 10% over the mean levels of the last few decades for the decline of the Southern Resident Killer Whale to be halted. Recovery of the Southern Resident Killer Whale population at the rate (2.3% growth) specified for delisting in the species' Recovery Plan will require an increase in the Chinook prey abundance of about 35%.

c. The NMFS 2019 Biological Opinion ("2019 SEAK BiOp") proposes several actions aimed at increasing the number of Chinook salmon available to the Southern Resident Killer Whales. The reduction in the Southeast Alaska salmon fishery of up to 7.5% in the 2019 Pacific Salmon Treaty relative to the preceding agreement, which is described in the 2019 SEAK BiOp, results in very little change in the Chinook available to the Southern Resident Killer Whales, and therefore would not have a measurable benefit for the endangered Southern Resident Killer Whale.

d. A proposed hatchery expansion aims to increase Chinook available to the Southern Resident Killer Whales by 4-5%. That increase in prey can be estimated to reduce the annual rate of decline of the Southern Resident Killer Whale population from about 1% to about 0.5%, but this would not be sufficient to stop

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the slide toward extinction.

e. The benefits to the Southern Resident Killer Whales of other possible mitigation measures are not quantified in the 2019 SEAK BiOp, and those actions would need to amount to a further increase (above that achieved from the two above mentioned measures) of at least another 5% in the Chinook abundance available as prey to Southern Resident Killer Whales in order for me to predict that the decline of Southern Resident Killer Whales would stop.

f. More aggressive management actions would be required to start the Southern Resident Killer Whale population on a reasonably secure path toward recovery or to meet NMFS' annual population growth rate goal of 2.3%.

7. My career has focused on building the capacity of the world to be much more effective in ensuring the long-term sustainability of species. I have done this via advancing the basic science that must underlie successful programs for sustaining species; providing the accessible tools to enable others to apply the science to species assessments, conservation planning, and population management; training students and colleagues in the use of the tools; and – when necessary – doing the analyses that inform and guide conservation for individual species.

8. Over my career I have developed, freely distributed, and supported software tools for guiding species conservation and population management. My approach has always been to provide tools for powerful and flexible analyses, within user interfaces that are accessible to wildlife managers, students, and others who might not have expertise with computer languages and systems. Consequently, the tools are now used globally to guide population management in nature reserves and zoos, viability analyses and recovery planning by wildlife agencies, and

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integrated assessment of threats to species. The software is used also to teach students about population biology and conservation in many universities.

Population Viability Analysis

9. Population viability analysis (PVA) is a class of scientific techniques that uses demographic modeling to assess risks to wildlife populations and evaluate the likely efficacy of protection, recovery, or restoration options (Shaffer 1990; Boyce 1992; Burgman et al. 1993; Sjögren-Gulve and Ebenhard 2000; Beissinger and McCullough 2002; Morris and Doak 2002). (All references cited in this Declaration are listed in Exhibit A.) PVA usually starts with standard demographic analysis ("life table analysis") to make deterministic projections of the expected population growth rate from the mean birth and death rates (Ricklefs 1990; Caswell 2001). PVA then extends the standard demographic projections in two important ways: (1) the impacts of forces external to the population (e.g., changing habitat quality, extent, and configuration; interactions with other species in the community; impacts of disease or contaminants; harvest, incidental killing, or other direct human impacts) on the demographic rates are explicitly considered and evaluated, and (2) uncertainty in the population trajectory caused by intrinsic (e.g., demographic stochasticity, limitations in local mate availability or other density dependent feedbacks, inbreeding impacts) and extrinsic (e.g., environmental variation, occasional catastrophes) factors can be explicitly modeled, usually through the use of simulation modeling. The outputs of PVA include any desired measure of population performance, but commonly assessed metrics include projected mean population size (N) over time, population growth rates (r), expected annual fluctuations in both N and r, probability of population extinction, and probabilities of quasi-extinction (the likelihood of N falling below any specified number within a specific number of years). These outputs are used to assess risk (e.g., for listing under the

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Endangered Species Act or other protective regulations), assess vulnerability to possible threats, determine sustainable harvest in the context of uncertainty, and determine the suites of actions that would be needed to achieve stated resource protection or restoration goals.

10. A requirement for any PVA model to provide sufficiently accurate and robust projections to allow estimation of population performance is the availability of detailed demographic data. Model input is required from the focal population or comparable reference populations for mortality rates, aspects of reproduction (e.g., age of breeding, age of reproductive senescence, inter-birth intervals, and infant survival), population size, and habitat carrying capacity – as well as the natural fluctuations in these rates. The difficulty in obtaining sufficient demographic data on endangered or protected species is a common challenge to the usefulness of PVA models, and many practitioners consequently recommend that PVA models be used only to provide assessments of relative risk and relative value of management options, rather than absolute measures of population trajectories. In the case of the Southern Resident Killer Whale population, however, demographic data are available from studies by the Center for Whale Research and others that are unprecedented in duration and detail of data collection. This exceptional data set provides a complete census of the total abundance as well as the age and sex composition of the Southern Resident Killer Whale population from 1976 to 2020. This allows for much more accurate projections of population performance and the ability to compare predicted trajectories to the precisely documented fate of the population.

11. PVA models were developed initially for quantifying future risk to populations that are vulnerable to collapse due to a combination of threatening processes (Shaffer 1990). They were soon recognized to be more reliable for assessing relative risk than absolute probabilities of decline or extinction (Beissinger and McCullough 2002; but see Brook et al.

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2000 for evidence that even absolute predictions of population trends can be accurate), and have become most useful in the identification of conservation actions that are most likely to achieve conservation goals (Sjögren-Gulve and Ebenhard 2000). The same methods can be used to quantify injury caused by an externally imposed stress, by comparing measures of population performance in the presence vs. absence of the stress, and to determine what actions would be needed to reverse the impact, restore the population to pre-injury health, and compensate for interim losses. The PVA forecasts can then be used to set the targets for expected performance under proposed restoration plans.

12. The Vortex PVA model that I developed (Lacy and Pollak 2020) is what is known as an individual-based model that projects the fate of each individual in a population. It simulates the effects of both deterministic forces and demographic, environmental and genetic stochastic (or random) events on wildlife populations. Vortex models population dynamics as sequential events that are determined for each individual in a population with probabilities determined from user-specified distributions. Vortex simulates a population by stepping through a series of events that describe an annual cycle of a sexually reproducing organism: mate selection, reproduction, mortality, dispersal, incrementing of age by one year, any managed removals from, or supplementation to, the populations, and limitation of the total population size (habitat "carrying capacity"). The simulations are iterated to generate the distribution of fates that the population might experience. Vortex tracks the sex, age, and parentage of each individual in the population as demographic events (birth, sex determination, mating, dispersal, and death) are simulated. A detailed description of the program structure is provided in Lacy (1993; 2000) and details about the use of Vortex are provided in the manual (Lacy et al. 2020).

13. The Vortex PVA modeling software is well-suited for the analyses of threats to

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the Southern Resident Killer Whale population, as Vortex is the most widely used, tested, and validated individual-based PVA model, and it is publicly accessible so that anyone can re-examine and repeat published analyses. It is highly flexible in allowing all input demographic parameters to be specified optionally as functions of external forces or as rates that change over time. Vortex has been used for modeling population dynamics of various marine mammal species (including bottlenose dolphins, Indo-Pacific bottlenose dolphins, baiji, manatees, dugongs, Hawaiian monk seals, and Mediterranean monk seals), as well as thousands of other species. Vortex has been shown to produce projections that accurately forecast dynamics of well-studied populations (Brook et al. 2000). Both NMFS in its 2019 SEAK BiOp (e.g., pp. 86, 90, 311) and Fisheries and Oceans Canada (Murray et al. 2019, e.g., pp. 3-5, 30, 33, 44, 62) have relied on analyses completed with Vortex for assessing the status of the Southern Resident Killer Whales.

Southern Resident Killer Whales

14. In 2015, at the request of Canada's National Energy Board ("NEB"), I led a team of six scientists conducting a PVA of the risk associated with aspects of the proposed Trans Mountain Expansion Project (Project) on the endangered Southern Resident Killer Whales. In that analysis, the PVA model was used to estimate the increased risk to the Southern Resident Killer Whales from three threats associated with the marine shipping component of the Project: an oil spill, increased acoustic and physical disturbance from ships, and ship strikes. The report also examined the possible effects of decreased Chinook salmon prey base that might result from climate change or human activities, and evaluated those impacts in comparison to the more immediate threats of the proposed Project and as the environmental context within which the impacts of the Project are likely to occur. The report to NEB (Lacy et al. 2015), including

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detailed descriptions of the methods and the data used in the PVA, is publicly available at http://docs.neb-one.gc.ca/fetch.asp?language=E&ID=A4L9G2. The analyses were extended and published in a peer-reviewed scientific paper (Lacy et al. 2017). Further updating of analyses using demographic data on the population through 2018 (Lacy et al. 2018) was submitted to NEB and is available at https://apps.cer-rec.gc.ca/REGDOCS/Search?txthl=A96429-3%20A%20-%20Expert%20Report%20of%20Lacy%20et%20al%20-%202018%20-%20Final%20-%20A6L5R2.

15. As of 2015 and 2017, based on status quo conditions, we projected the Southern Resident Killer Whale population would remain about at its current size or continue a very slow decline (estimated at a mean annual decline of 0.2%). We projected a 9% chance of quasi-extinction within the next 100 years, where the population falls below 30 whales and is no longer viable.

16. I have now updated the PVA model again, using fecundity and survival rates calculated from the detailed records from 1976 through 2018 and applying those rates to the current population of 72 Southern Resident Killer Whales. The following graph shows the mean projected population size (heavier, middle line) and the uncertainty in the trajectory (upper and lower lines showing ± 1 standard deviation among independent repeated simulations of the population).

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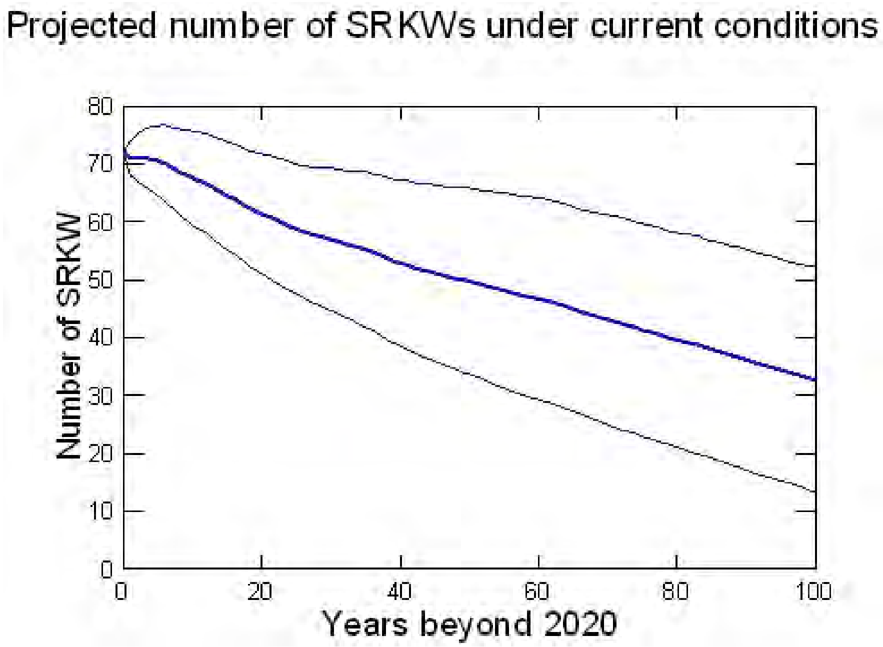

17. With current data, and if the Chinook availability remains at the mean level of the past few decades, the model projects a mean annual decline in the population of Southern Resident Killer Whales of about 1.0%. This is close to what has been occurring recently, and it compares to our 2018 projection of a smaller decline of 0.6% per year (Lacy et al. 2018). About half of difference between the 2018 and 2020 projections is due to the fact that the population is aging (with the mean age of living whales now just over 22 years, whereas it was just over 21 years in 2018), and more animals are now post-reproductive or nearing post-reproductive age. The other half of the difference is due to the fact that we now have parentage data for more of the animals, and that allows us to have more complete estimates of kinships among animals, and that in turn leads to slightly higher estimates of current and future inbreeding.

18. For our model, we obtained estimates of the impact of Chinook prey abundance on the reproductive rates and survival rates of the Southern Resident Killer Whales from published scientific reports (Ward et al. 2009; Velez-Espino et al. 2015; Ford et al. 2010). We

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scaled the numerical relationships so that the mean demographic rates observed in the Southern Resident Killer Whales from 1976 through 2015 were correctly predicted. (The details of the methodology are documented in Lacy et al. 2015 and Lacy et al. 2017 publications.) We then use these relationships to project the Southern Resident Killer Whale population trajectory in several scenarios that tested the impact of prey availability, expressed as a percent change in the annual abundance of Chinook salmon available as prey to the Southern Resident Killer Whales from the mean level over the last three decades.

19. The abundance of Chinook varies over time, and that variation in prey can be entered into the PVA model. However, as documented in the 2019 SEAK BiOp, the extent of that variation is very dependent on which stocks of Chinook are assessed, and it is not known precisely what proportion of the Southern Resident Killer Whale diet is composed of salmon from each stock. I examined the model projections with the Chinook abundance varying randomly across years around the long-term mean values being tested. I found that such an elaboration of the model had very little effect on the long-term projections for the Southern Resident Killer Whale population. This occurs because killer whales are very long-lived and slow breeders, so year to year fluctuations in demography will average out over their lifespans. Therefore, as was done in our prior PVA reports, the results from analyses presented in this declaration assume that the abundance of Chinook is at a fixed level each year and does not vary randomly around that value.

20. Also included in the model are the current estimates of both PCBs and noise disturbance, based on published estimates of the current magnitudes and effects of these threats (Hall et al. 2011; Hall and Williams 2015; Lusseau et al. 2009). These threats are part of the current environment for the Southern Resident Killer Whale, and they interact with the effect of

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prey limitation. (The documented impact of noise disturbance is via a reduction in time that the Southern Resident Killer Whales spend feeding. The primary impact of PCBs is on survival of calves, compounding the reduction in survival that occurs with low prey availability.) Only with these effects of PCB and noise disturbance in the model do we accurately predict the recent observed rate of decline of the population. However, even if these other threats were completely eliminated—which is not possible in the near term and unlikely in the long term—our modeling shows that there would not be adequate prey available to achieve the population growth goal established in the Recovery Plan for the Southern Resident Killer Whale (Lacy et al. 2017).

21. By applying the published relationships of Southern Resident Killer Whale reproductive and survival rates to Chinook abundance, and then testing the benefits to Southern Resident Killer Whales of incremental improvements in the abundance of Chinook prey, the model shows that to achieve a mean zero population growth (i.e., to stop the decline), there would need to be a sustained 10% increase (relative to the 1976-2015 average) in the mean abundance of the Chinook stocks available as prey to the Southern Resident Killer Whales.

22. The analyses conducted in 2015, 2017, and 2018 estimated that a 30% increase in Chinook could achieve the 2.3% growth called for in the Southern Resident Killer Whale Recovery Plan. With the further decline that has occurred in the population in the last few years, our analysis of the 2020 population now projects that a 30% increase in Chinook would result in about 2% growth per year, and a 35% increase in prey would be necessary to meet the recovery goal. The graph below shows the expected Southern Resident Killer Whale population growth across a range of levels of Chinook abundance. The two horizontal lines indicate zero population growth and the 2.3% growth goal of the Recovery Plan.

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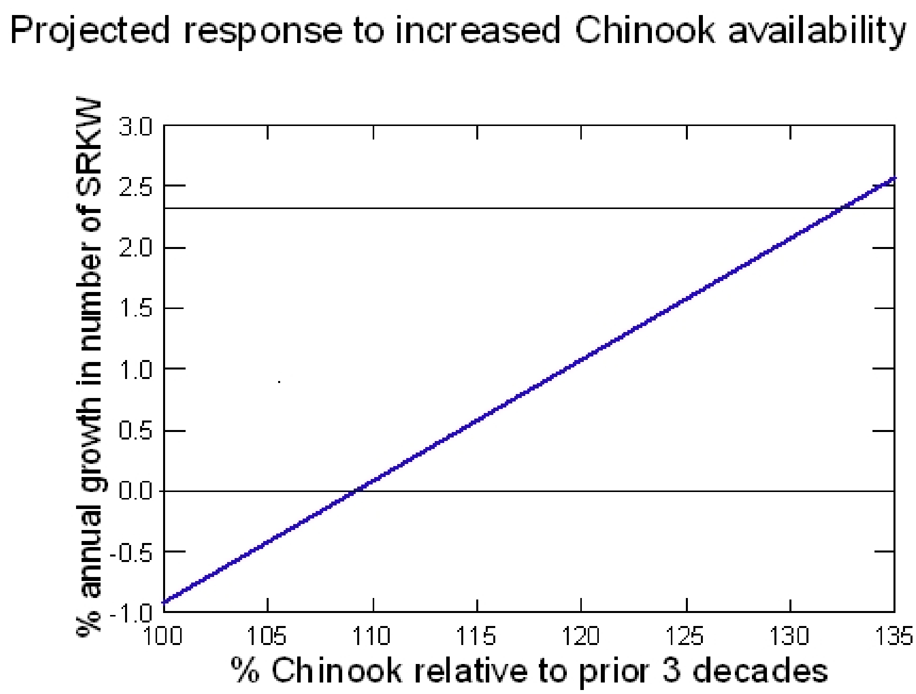

NMFS' Biological Opinion and Impact on Southern Resident Killer Whale Population

23. I was provided with NMFS' 2019 SEAK BiOp for Southeast Alaska salmon fisheries at issue in this matter. I reviewed it closely. In the 2019 SEAK BiOp, NMFS acknowledges that the Southern Resident Killer Whale population is declining, and that is at least partly and maybe mostly due to inadequate prey availability. The 2019 SEAK BiOp cites my previous work (p. 311) as evidence that the biggest threat is that lack of prey, although other factors such as noise, PCBs, oil spills, and other environmental factors all make things worse.

24. In several places, and in various ways, the 2019 SEAK BiOp estimates the reduction in prey available for Southern Resident Killer Whales caused by the Southeast Alaska fisheries (e.g., Tables 41, 42, and 97) as between 2-15% in coastal fisheries and 1-2% in inland fisheries. However, there is significant uncertainty depending on which salmon stocks and for which years the calculations are based. Importantly, the BiOp does not explain how the various percentage reductions mentioned translate to corresponding changes in the total mean abundance of Chinook that provide potential prey for Southern Resident Killer Whales, which is what is

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required for accurate projections of the benefits expected from reductions in the fisheries. The 2019 SEAK BiOp directly states (p. 94) “the impact of reduced Chinook salmon harvest on future availability of Chinook salmon to the Southern Residents is not clear.”

25. The 2019 SEAK BiOp also discusses possible mitigation measures, which could increase the prey availability for Southern Resident Killer Whales. The 2019 SEAK BiOp estimates the newly negotiated 2019 Pacific Salmon Treaty will reduce the Southeast Alaska fishery annual harvest of Chinook by up to 7.5% relative to the harvest under the 2009 Treaty. A proposed increase in hatchery production mitigation seeks to provide 4 to 5% increase in prey available to the Southern Resident Killer Whales. The increase in hatchery production is not yet funded, so I would expect a delay of at least 5 to 10 years to account for allocation of funds, construction of any new facilities, increased programs of production, and then return of hatchery raised Chinook as mature adults.

26. I applied these estimates from the 2019 SEAK BiOp to the Vortex PVA model, in order to project the consequences of the possible scenarios described in the 2019 SEAK BiOp. The estimated 7.5% (maximum) reduction in the Southeast Alaska fishery, applied to a typical 6% reduction in prey available to the Southern Resident Killer Whales caused by the Southeast Alaska fishery as a whole (the 6% being an approximate middle value from the many estimates made in the BiOp), results in a less than 0.5% increase in the Southern Resident Killer Whale prey. This is only 1/20th of the 10% increase that is needed to achieve even a cessation of the decline in Southern Resident Killer Whale population.

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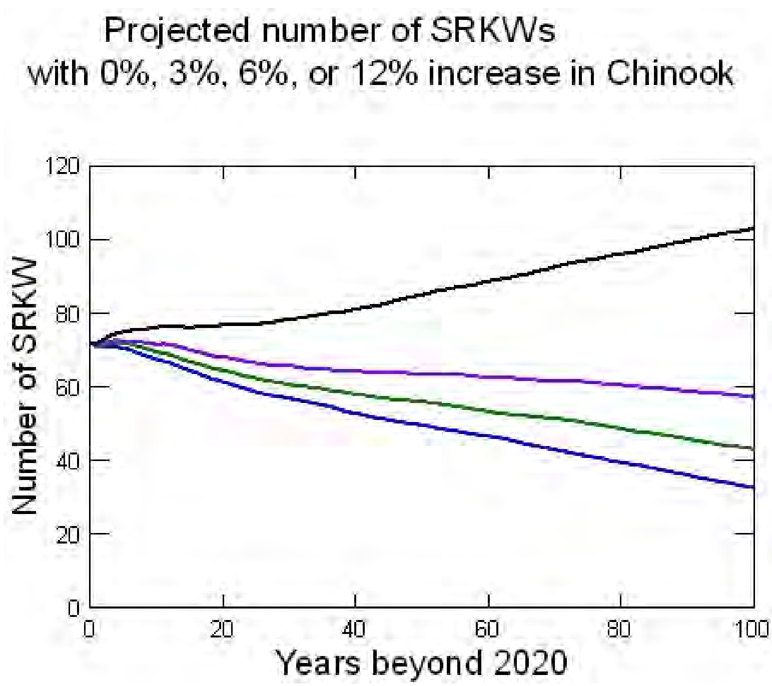
27. To estimate the possible reductions in threats to the Southern Resident Killer Whale that might be achieved with greater reductions in the Chinook fisheries, I projected a Southern Resident Killer Whale population growth with an immediate 6% increase in Chinook prey, and a 3% and a 12% increase in prey (half and double the middle estimate, covering most of the range of values reported in the 2019 SEAK BiOp for specific stocks and years). As shown in the following graph, with the existing baseline in blue (bottom line), the PVA projections for these scenarios show that the 3% increase in Chinook results in a mean 0.7% decline in Southern Resident Killer Whale population per year (green line), the 6% increase in Chinook results in a mean 0.4% decline of the Southern Resident Killer Whale population (purple line), and the 12% increase results in 0.3% positive growth annually (top, black line).



28. The impacts on Southern Resident Killer Whales of other estimates of prey increases that could be achieved by reductions in the fisheries can be extrapolated from the projections of Southern Resident Killer Whale population growth across a range of levels of Chinook abundance, as shown in the graph in paragraph 22, above.

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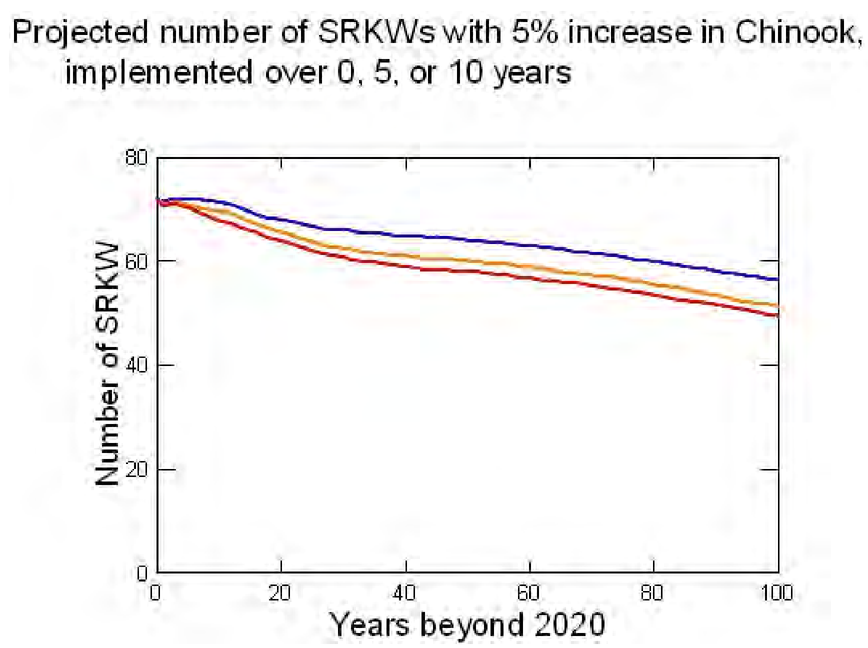
29. I projected the benefits to the Southern Residents of possible (but not yet funded) hatchery projects assuming a 5% increase in Chinook, beginning either 5 years or 10 years in the future. With either time scale for implementation and return of the hatchery-produced Chinook, the mean long-term consequence is a slowing of the decline in Southern Resident Killer Whales from 1.0% to 0.5% per year; therefore, not enough improvement to completely halt the decline. The difference between a 5-year delay and a 10-year delay in enhancement is that by year 10, the slower implementation will result in the Southern Resident Killer Whale population having declined by about 2 more whales before the improvement can begin to take effect. The following graph shows the projections if the mitigation measures achieve a 5% increase in Chinook (as estimated from the proposed hatchery expansion) instantly (top, blue line), after 5 years (middle, orange line), or after 10 years (bottom, red line). As this graph plainly demonstrates, delays in implementation of these theoretical mitigation measures have a very real and lasting impact on the Southern Resident population. Notably, it also shows that the proposed measure – even if implemented immediately – is not enough to stop the decline of Southern Residents.



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30. Combining the actions of reducing the Southeast Alaska Chinook fishery and increasing abundance to the Southern Resident Killer Whale of hatchery-raised Chinook, and possibly other mitigating actions as well (such as additional reductions in additional fisheries managed under the Pacific Salmon Treaty), could achieve the 10% increase in prey necessary for stabilization of the Southern Resident Killer Whale population or even greater increases in prey that would allow for recovery of the Southern Resident Killer Whales. Importantly, however, none of the scenarios proposed in the 2019 SEAK BiOp are projected to achieve this 10% increase in prey abundance. The analyses described above in paragraph 22 document the long-term growth in the Southern Resident Killer Whale population that could be achieved if Chinook abundance is increased by 35% above the mean levels of the last three decades.

31. Implementing mitigation measures, however, will likely require time. To examine responses of the Southern Resident Killer Whale population to delayed implementation, I tested models with increases in the prey abundance starting either 5 years or 10 years from now. The following graph shows the mean projected Southern Resident Killer Whale population size when a 10% increase in Chinook is implemented immediately (top, blue line), after 5 years (middle, orange line), or after 10 years (bottom, red line). The long-term population growth rates after implementation again show that a 10% increase in prey is needed to stop the decline of Southern Resident Killer Whales. However, before that positive result is achieved, the population will have lost 4 whales if implementation takes 5 years, or 8 whales if implementation takes 10 years, relative to the expected population size if the increase in prey were achieved immediately. With positive growth of Southern Resident Killer Whale numbers after implementation of sufficient mitigation measures, a delay in implementation results in a loss of the potential initial years of recovery, and that lack of growth for those initial years leaves the population at a deficit in

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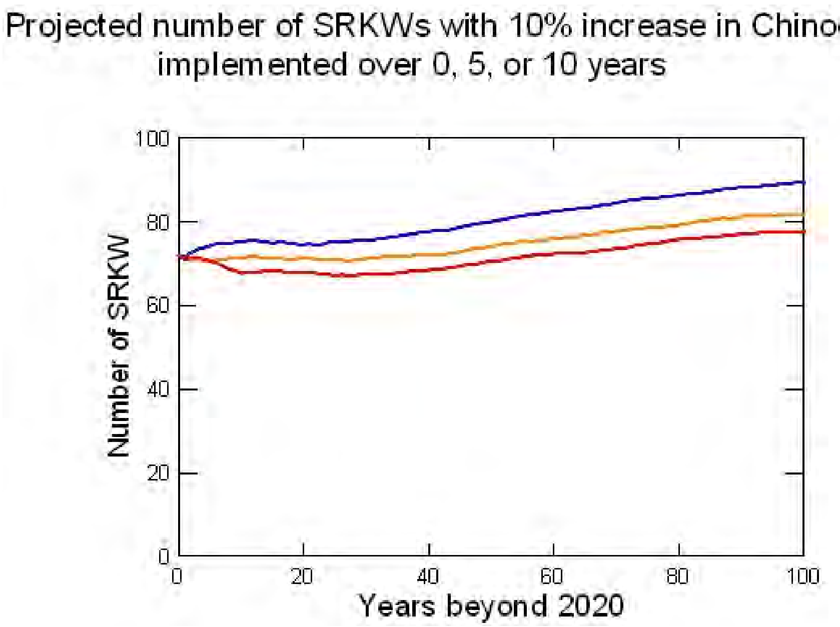
numbers throughout the subsequent recovery compared to what could have been. A 20% increase in Chinook allows for a long-term population growth of about 1% annually, but a delay of 5 or 10 years results in a loss of 8 or 16 whales before the growth begins, respectively, relative to the expected population size if growth had started in 2020.



32. In summary, although the 2019 SEAK BiOp does not provide management targets for slowing, stopping, or reversing the decline of the Southern Resident Killer Whale population, and it does not give specific estimates of the benefits to the Southern Resident Killer Whales of the proposed mitigation measures, for the above analyses I extracted from the 2019 SEAK BiOp what I could regarding the expected benefits of proposed actions. The 2019 SEAK BiOp provides various estimates of changes to Chinook stocks that might be expected from two of the mitigation measures – a reduction in the Southeast Alaska Chinook fishery as specified in the 2019 Pacific Salmon Treaty, and a proposed hatchery expansion – and it mentions other possible actions, such as habitat improvements, for which there is no quantification of expected results. Only if the additional, as yet unquantified, mitigation measures can boost Chinook abundance by

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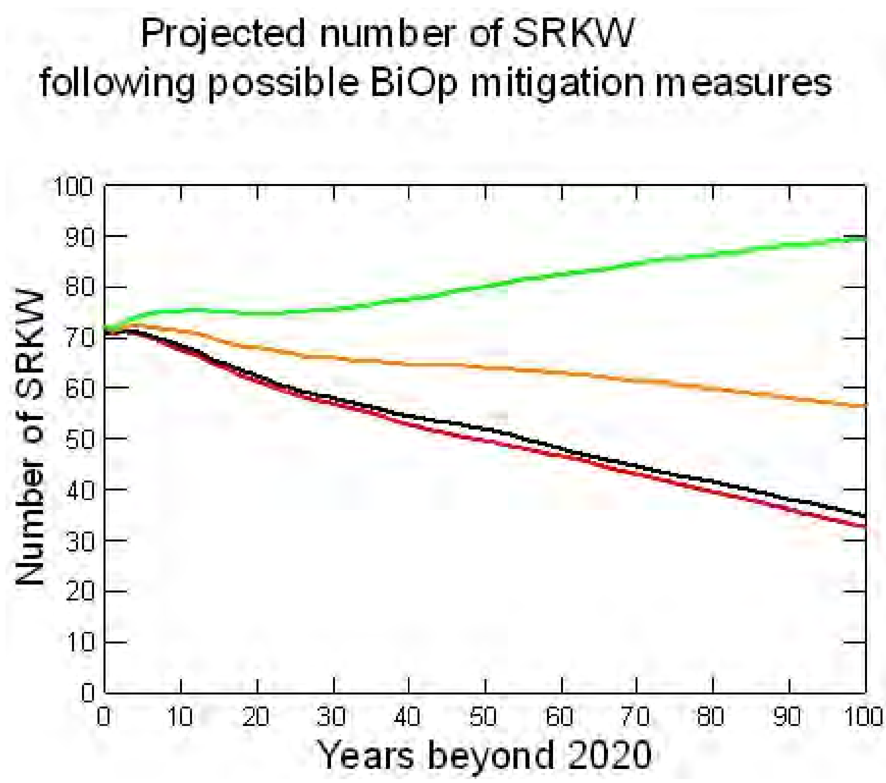
another 5%, would the combined effect of the proposed actions yield the 10% increase in Chinook that is necessary to halt the decline of the Southern Resident Killer Whales. The following graph summarizes the expected trajectory of the Southern Resident Killer Whale population if no changes are made from current conditions (bottom, red line), if a 0.5% increase in overall Chinook available to Southern Resident Killer Whales is produced by the reduced Chinook harvest in the 2019 Pacific Salmon Treaty (black line), if a 5% increase in Chinook is achieved by the hatchery mitigation (orange line), or if sufficient actions can be taken to achieve a 10% increase in Chinook (top, green line).



Conclusions

33. Based on previously published analyses, the results of updated models, my professional experience, and the information contained in the 2019 SEAK BiOp, I make the following conclusions with a reasonable degree of certainty:

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a. The Southern Resident Killer Whale population is in decline, and the projected status has deteriorated in just the past few years. The PVA models, using the latest available data on the current numbers, reproduction, and survival, project accurately the recent population changes.

b. The abundance of Chinook salmon prey available to the Southern Resident Killer Whales is a critical determinant of Southern Resident Killer Whale reproductive success and survival.

c. The mean Chinook abundance over recent years is not enough to allow reproduction by the Southern Resident Killer Whales sufficient to offset mortalities. An increase of about 10% in Chinook abundance would be required to stop the decline of Southern Resident Killer Whales, and an increase of about 35% in Chinook abundance would be required to achieve the healthy population growth rate of 2.3% that is the stated goal in the Southern Resident Killer Whale Recovery Plan.

d. The proposed mitigation measures in the 2019 SEAK BiOp have not been shown to be adequate to protect the future of the Southern Resident Killer Whale population – a short-coming that is admitted even within the 2019 SEAK BiOp. The quantitative estimates made in the 2019 SEAK BiOp would account for, at best and after full implementation, a reduction of half in the rate of decline in numbers of Southern Resident Killer Whales.

e. Full closure of the Southeast Alaska Chinook fishery, especially if combined with other mitigation measures, could result in enough prey to sustain a growing population of Southern Resident Killer Whales. Further enhancement measures

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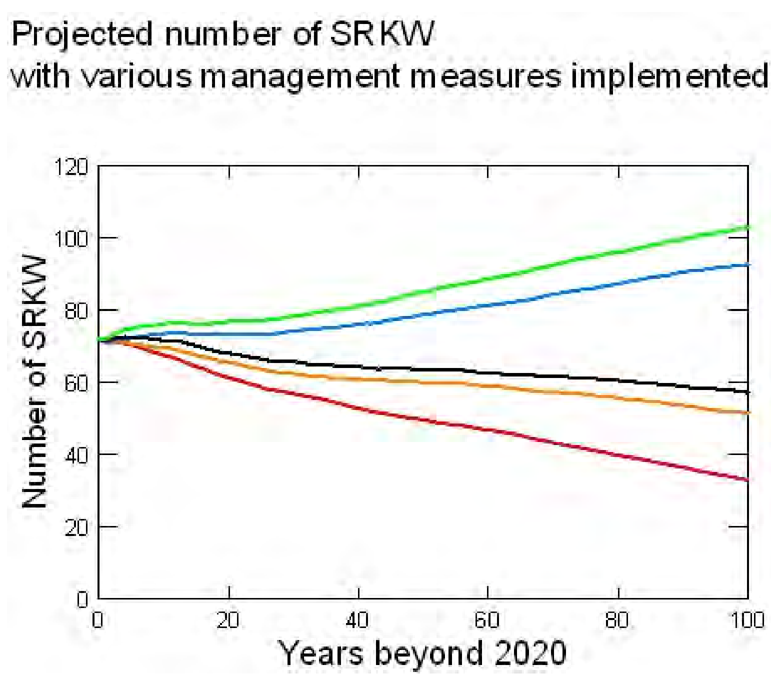
would be required to achieve the recovery goals set in the Recovery Plan for the Southern Resident Killer Whale. The last graph, below, shows projected Southern Resident Killer Whale numbers under current environmental conditions and management (bottom, red line), with the 5% increase in Chinook prey after 5 years, projected to result from the proposed hatchery enhancements (orange line), with a 6% increase in Chinook prey as might be achieved if the Southeast Alaska Chinook fishery is immediately closed (black line), with both the proposed hatchery project plus an additional 6% increase in Chinook abundance (blue line), or if a 12% increase in prey is achieved by the closure of the Southeast Alaska Chinook fishery (top, green line). The amount of increase in Chinook abundance as a result of reductions or closure of fishery harvests and other measures is uncertain, so responses of both the Chinook abundance and then the Southern Resident Killer Whale demography should be monitored closely, with adaptive management adjusting mitigation and enhancement measures as needed.



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I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and accurate.

Executed this 15th day of April, 2020.

Robert Lacy, Ph.D.

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