# Report to Southern Resident Killer Whale Work Group on Abundance indices and forecasts available for Chinook salmon stocks originating south of the Elk River

## Background

The purpose of this document is to review the abundance indices and forecasts available for Chinook salmon stocks originating south of the Elk River (Oregon) and their potential suitability for informing management considerations with respect to Southern Resident Killer Whale (SRKW) prey supply.

Ocean fisheries affecting these stocks are managed through the Pacific Fishery Management Council on an annual cycle that involves review and adoption of abundance forecasts each March and adoption of the fishing season structure each April. The fishing season each year can extend through September or October (and at times into November) and then is closed over the winter. Across all fisheries south of Cape Falcon, fishing seasons can span mid-March through early November, depending on the management zone, however no individual zone is continuously open for that entire period. Mature individuals from fall run stocks in this area return before the end of the calendar year (nominally on September 1) and before the conclusion of fall fisheries. Fall fisheries are sometimes referred to as "credit card" fisheries because removals during the fall are counted against the next year's abundance, which has not yet been forecasted at the time the fall fisheries take place[1]. Ocean fisheries on spring run stocks from this region are not actively managed, but mature individuals from these stocks also return while fisheries are ongoing.

Notably, Chinook salmon stocks originating south of the Elk River appear to have ocean distributions largely restricted south of Cape Falcon, OR (Weitkamp 2010, Shelton et al. 2019). SRKW presence in ocean areas south of Cape Falcon is sporadic and appears largely restricted to the winter and early spring, after the conclusion of fall fisheries and usually before fisheries ramp up the following spring/summer. Fall fisheries may therefore have the most direct link to the availability of these stocks as potential prey for SRKW. Still, fisheries in the spring and summer could also affect prey availability through removals of immature fish which otherwise would have spent another year in the ocean and remained available for SRKW if they did not die of other causes in the meantime, or if SRKW venture south at other times of year[2]. Regardless, it is the abundance of these stocks in winter and early spring after all aforementioned harvest has occurred that likely has the greatest effect on SRKW in the years that they are present in their southern range.

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[1] Because some fish return to spawn after the return date assumed by managers, an unknown portion of these 'credit card' fish would have returned to spawn in the fall of the year they were caught, but this is not accounted for.

[2] Multi-generational effects of spawner numbers and subsequent recruitment (and/or selective pressures on size, growth, and maturation schedules) as affected by fishing are beyond the scope of this workgroup and not considered here.

## Summary recommendations

To the extent that fishery adjustments in relation to potential SRKW prey availability are deemed necessary for stocks originating south of Elk River, we recommend the following stock-specific abundance indices and forecasts be considered:

• **Sacramento River Fall Chinook** (SRFC): Consider the Sacramento Index (SI) when comparing ocean abundance across years and consider the SI forecast available at the March of year *t* Council meeting when planning fisheries for calendar year *t*, including the fall fisheries that are counted against the next management year. Although fall fisheries are prosecuted against an ocean abundance that is better represented by SI(*t*+1) than SI(*t*), forecasts for SI(*t*+1) will not be available until after fall fisheries have concluded. The SI displays significant temporal autocorrelation ($\rho$=0.80 in logged SIs, Rebuilding Plan), so SI(*t*) should be a better predictor of SI(*t*+1) than the longterm mean SI. SI(*t*) discounted by anticipated pre-fall fisheries (i.e., predicted river mouth returns[3]) should also provide the best available index of the ocean abundance of age-4 and older fish at the start of fall. The relative importance of age-4 and older (larger but fewer fish) versus age-3 SRFC as SRKW prey is unclear at this time, however information on the abundance of age-3 fish at the beginning of the fall is more tenuous. Overall it makes sense to consider both SI(t) (as a crude, but best available, forecast of the cohort recruiting to age-3 after fall fisheries) and projected rivermouth returns (i.e. SI(t) scaled down by anticipated ocean harvest, which should be proportional to remaining ocean abundance of age-4 and older fish given constant age structure and maturation rates) as the best available proxies of SRFC potentially available as prey in winter. More weight should be given to projected rivermouth returns if older fish are considered more valuable prey than newly age-3 fish.

When considering the need for additional active management responses to forecasted SRFC abundance, consideration should be given to the existing control rule that ramps down allowable anticipated exploitation rates in response to forecasted abundance (Preseason Report 1, Figure A-1), further bearing in mind that a proportion of the allowable exploitation is allocated to river fisheries, although this fraction is smaller than for most northern stocks. In particular, it should be noted that in many years SRFC is managed toward an escapement floor of 122,000 adult spawners (which equates to anticipated river mouth returns of approximately 143,500 adults), or less in “de minimis” years. Rather than considering year-specific measures, it may be more useful to consider whether this escapement floor is consistent with the desired availability of immature SRFC as prey during the following winter and early spring when SRKW are most likely to be present. Secondarily, it may be useful to evaluate how much impact "de minimis" fisheries could have on prey availability for SRKW, under conditions when abundance is forecast to be low regardless of fishing.

• **Klamath River Fall Chinook** (KRFC): Consider summed age-specific reconstructed ocean abundances when comparing abundance across years, and consider age-specific preseason

[3] Direct observations of adult river mouth returns (presumed to be primarily age-3) in year *t* might better predict the number of older fish remaining in the ocean in fall, but escapement estimates are not available in time to inform management of fall fisheries.

abundance forecasts available at the March of year *t* Council meeting when planning spring/summer fisheries for calendar year *t.* Prey availability relative to SRKW nutritional needs and fall fishery planning against the following year's abundance can be partially informed by projecting preseason abundance estimates of age-3 and age-4 abundance to fall abundances of age-4 and age-5 after accounting for typical natural mortality, maturation, and anticipated spring/summer fishing mortality. The abundance of age-3 fish at the start of fall fisheries is not easily predicted. Consistency with the approach advocated for SRFC might entail assuming it would be equal to the previous year's forecast, but there is substantially less autocorrelation in KRFC age-3 abundance estimates than there is in the SI. As with SRFC, the relative importance of age-3 versus older fish to SRKW is unclear, although KRFC display later maturation and an older age structure than SRFC. Compared to SRFC, a greater share of KRFC interactions with the fishery are within the commercial sector, where larger minimum size limits may reduce fishery impacts on relatively small newly age-3 fish. Impacts on age-3 KRFC in the fall of year *t* are taken into account when planning spring/summer fisheries on age-3 KRFC for year *t*+1.

When considering the need for additional active management responses to forecasted KRFC abundance, consideration should be given to the California Coastal Chinook consultation standard which limits the anticipated age-4 ocean harvest rate of KRFC to no more than 16% as well as the existing control rule that ramps down allowable anticipated exploitation rates in response to low forecasted abundance of KRFC (Preseason Report 1, Figure A-2), further bearing in mind that over 50% of the allowable exploitation in the harvest control rule is allocated to river tribal and sport fisheries. The combination of the harvest control rule and river fishery allocations for KRFC restricted the allowable anticipated age-4 KRFC ocean harvest rates below 16% in 10 out of 17 years 2001-2017 (Satterthwaite et al. 2018). Given the constraints imposed by the application of the California Coastal Chinook Consultation standard every year, it may be worthwhile to consider under what conditions age-4 ocean harvest rates on KRFC of 16% would pose an unacceptable risk to SRKW, and whether the existing control rule sufficiently reduces allowable impacts in such cases.

•**Other stocks**: In the near term, there appears to be little prospect of and/or value in developing management measures for other southern stocks with respect to SRKW. Most other stocks lack abundance forecasts, while the forecasts available are likely of limited utility.

An abundance forecast is available for Sacramento Winter Chinook (SRWC), and the relative timing of forecast availability, preseason planning, potential spatial overlap with SRKW, and adult returns from the ocean are all compatible. However, SRWC are at very low abundance, and harvest is already heavily restricted at all times with further restrictions enforced in response to low forecasted abundance (Preseason Report 1, Figure A-3). SRWC also have small body sizes and a very high age-3 maturation rate, making them less suited as SRKW prey on a per capita basis.

A forecast of Rogue River fall Chinook abundance is available, but there are no direct estimates of Rogue River Chinook harvest rates available and harvest on Rogue River fall Chinook is likely constrained by the KRFC harvest control rule and the California Coastal Chinook consultation standard. If it is deemed necessary to explicitly consider SRKW needs in planning harvest on KRFC, it may be useful to develop a contingency plan for how to respond in years when forecasts are for high KRFC abundance but low Rogue River fall abundance. However, due to similar spatial distributions (Weitkamp 2010, Bellinger et al. 2015, Satterthwaite et al. 2015), abundant KRFC may be able to compensate for scarce Rogue River fall Chinook to the extent that either is required as prey. Similarly, abundant Rogue River fall Chinook might compensate for low abundance of KRFC, but the KRFC control rule would limit harvest of KRFC at low forecasted abundance regardless of SRKW considerations.

Stock-specific abundance forecasts are lacking for the remaining stocks south of Elk River. Of the stocks without an abundance forecast, Sacramento River Spring Chinook may be of particular importance to SRKW due to their life history and what is known about SRKW distribution. In the past, escapements of Central Valley fall and spring Chinook have been moderately correlated (r=0.57, Satterthwaite et al. 2018), such that active management of SRFC harvest might reduce harvest of spring run in years of low spring run abundance as well. However, the correlation (in escapement; correlation in ocean abundance is unknown) was modest in the past, and may break down further in the future due to adaptive increases in the trucking or other downstream transport of hatchery-origin fall Chinook in response to drought or poor river conditions, which does not benefit natural-origin spring run fish exposed to the poor river conditions.

## Stock-Specific Details

### Central Valley Fall Chinook Stock Complex

Sacramento River Fall (SRFC, indicator stock for complex)

The Sacramento Index (SI) for year *t* is the sum of "adult" (age-3 and older) SRFC spawner escapement, SRFC ocean harvest south of Cape Falcon from September 1 of year *t*-1 to August 31 of year *t*, impacts of non-retention ocean fisheries over that same period when they occur, and recreational harvest of SRFC in the Sacramento River Basin (O'Farrell et al. 2013). It serves as an index of adult ocean abundance prior to the start of the fishery, but does not account for effects of natural mortality (and thus does not reflect Chinook consumed as prey), for adult fish foregoing spawning to remain in the ocean for another year (although some of the harvested fish it counts may not have matured in their year of harvest), or for spawners straying outside of the Sacramento River Basin. Annual estimates of the SI are reported in Table II-1 of Preseason Report 1. Forecasts of the SI are delivered to the Council each March based on a log-log regression predicting the SI as a function of last year's jack (age-2) escapement along with an autocorrelated error term (see Figure II-1 of Preseason Report 1).

Scaling the SI from an index of abundance to an estimate of abundance would require assumptions about natural mortality, age structure, maturation schedules, and straying rates. To the extent that any of these factors vary annually, they will confound the relationship between the SI and true abundance. Nevertheless, it is the best available index of SRFC abundance unless and until cohort reconstructions are routinely performed for this stock, and it has the advantage of a relatively long time series for comparison across years.

When the Council meets to plan fisheries for calendar year *t* during its meetings in March and April of calendar year *t*, the most recent SI forecast available indexes adult SRFC ocean abundance on September 1 of year *t*-1. Impacts of fall "credit card" fisheries in calendar year *t*-1 will have already occurred (and are factored into calculating the year *t* harvest rate), as will the period of most likely overlap with SRKW during winter and early spring.

Direct effects of calendar year *t* fishing on SRFC as available prey for SRKW are somewhat limited because a fairly high fraction of SRFC mature at age-3 and thus many of the fish constituting the forecasted SI for year *t* escaping year *t* fisheries would leave the ocean before SRKW are likely to be in areas where SRFC are available as prey. However, year *t* fisheries on adults would affect the number of age-4 and age-5 fish available in the winter, and if natural mortality, maturation rates, and age structure are assumed constant, then the availability of age-4 and age-5 SRFC as prey should be proportional to the fraction of the SI that is not harvested. In addition, fishing during calendar year *t* would affect the availability of age-3 fish after September 1 through impacts on fish that are age-2 during the first part of the calendar year, but the SI is not intended to index the abundance of this age class. Fishery impacts on age-2 and age-3 fish likely covary but are lower for age-2 fish.

Values of the SI display significant temporal autocorrelation ($\rho$=0.80 in logged SI values, Rebuilding Plan) and therefore in the absence of better information one might assume that age-2 abundance is proportional to the SI for the same year, and thus the SI (discounted by planned spring-summer fishing) could be used to index the abundance of age-3 fish that would be left after maturing fish leave the ocean in the fall and remaining fish age up. The SI, scaled down by anticipated ocean impacts, should be proportional to the abundance of age-4 fish in the ocean during the fall and winter after spawners have left the ocean if age structure, maturation rates and natural mortality are constant. The rivermouth escapement of age-3 and older fish for the year t SI would be a more directly proportional index (assuming constant maturation rates) of the number of age-4 and older fish left in the ocean immediately after spawners return, however escapement estimates are not available until spring of the following year, after fall fisheries are prosecuted and after the time of maximum potential overlap with SRKW, thus requiring the use of the forecasted river mouth return after anticipated summer fisheries developed during the fishery planning process.

Thus, even though the most direct impacts of SRFC fisheries on prey availability for SRKW likely occur during the fall period not directly represented by the SI forecast available before the fall fisheries have taken place, the current year's SI forecast appears to be the most suitable proxy available for overall SRFC ocean abundance and availability as SRKW prey. The SI forecast for year *t* could inform fishing from April through August of year *t* through its direct relationship (assuming constant natural mortality and maturation schedules) to ocean abundance of age-4 fish in the fall, and through its indirect relationship (assuming autocorrelation in cohort strength as well as the aforementioned assumptions) to ocean abundance of age-3 fish in the fall. The year *t* SI also is likely the best available abundance index for planning the effects of fall fisheries for year *t* on abundance remaining into the winter, after taking into account the anticipated removals of older fish from fisheries planned for April through August. Thus, consideration should be given to the forecasted river mouth return as a measure of age-4 and older abundance (i.e., the year *t* SI forecast having been scaled down by anticipated ocean harvest).

<u>Sacramento River Late Fall</u>

Ocean abundance indices for Sacramento River Late Fall are not reported to the Council. Escapements of composite "adults" and jacks are routinely reported in Table B-3 of the Review of Ocean Fisheries. The escapement could potentially be converted into an index of ocean abundance based on the assumption that ocean harvest rates are the same as for SRFC. However, Sacramento River Late Fall fish appear to differ from SRFC in both their ocean distribution (more concentrated to the south, Satterthwaite et al. 2013) and their age structure/maturation rates (more likely to delay maturation, Satterthwaite et al. 2017). In theory, ocean harvest rates and ocean abundances could be calculated from cohort reconstructions applied to coded wire tagged late-fall hatchery fish and assuming equivalent ocean impact rates on natural fish, but this has not been done and would be a substantial undertaking. Forecasts of Sacramento River Late Fall abundance or abundance indices are not routinely reported to the Council, although they are an undifferentiated component of the Other Central Valley (OCV) forecast used in the Klamath Ocean Harvest Model (KOHM) and Sacramento Harvest Model (SHM). There is no model for predicting the effects of proposed fishing seasons on Sacramento River Late Fall harvest rates.

Because Sacramento River Late Fall are generally much less abundant than Sacramento River Fall (Review Table B-3 versus B-1) and because their ocean distribution seems restricted to the south relative to Sacramento River Fall (Satterthwaite et al. 2013), it seems unlikely that there is much to be gained for SRKW prey availability by developing tools for more actively managing fishery impacts on Sacramento River Late Fall.

<u>San Joaquin River Fall</u>

Ocean abundance indices for San Joaquin River Fall are not reported to the Council. Escapements of composite "adults" and jacks are routinely reported in Table B-2 of the Review of Ocean Fisheries. The escapement could potentially be converted into an index of ocean abundance based on the assumption that ocean harvest rates are the same as for SRFC, although the stocks may differ in their maturation schedules and/or exposure to fisheries. Forecasts of San Joaquin River Fall abundance or abundance indices are not routinely reported to the Council, although they are an undifferentiated component of the OCV forecast used in the KOHM and SHM. There is no model for predicting the effects of proposed fishing seasons on San Joaquin River Fall harvest rates.

Because the SI is an index of abundance rather than an estimate of abundance, to the extent that Sacramento and San Joaquin River Fall Chinook covary in abundance it can be assumed that the SI is proportional to combined Sacramento and San Joaquin River Fall abundance. Given the usual relative abundance of Sacramento and San Joaquin River Fall stocks (Review Table B-1 vs. B-2) there is likely little to be gained for SRKW management by development and explicit consideration of San Joaquin River Fall abundance indices and forecasts.

**Sacramento River Spring**

Escapements for populations of Sacramento River Spring Chinook are routinely reported in Table B-3 of the Review of Ocean Fisheries. These escapement estimates do no not include an unknown number of spring run fish spawning in natural areas on the Feather River, which are not distinguished from fall run. No abundance estimates are routinely calculated, nor are abundance forecasts made, although they are an undifferentiated component of the OCV forecast used in the KOHM and SHM. Scaling escapement to abundance estimates assuming ocean harvest rates equal to SRFC does not seem advisable due to differences in the return timing, maturation schedule, size-at-age, and ocean distribution of SRFC versus Sacramento River Spring. Conceivably, ocean exploitation rates could be calculated from tagged Feather River Hatchery Spring Chinook and applied to age-specific escapement estimates to generate abundance estimates, but this has not been done and there are questions regarding how representative Feather River Hatchery Spring Chinook are of the natural-origin populations in this stock. There is no model for predicting the effects of proposed fishing seasons on Sacramento River Spring harvest rates.

Sacramento River Spring are listed as Threatened and their consultation standard assumes that protections put in place for Endangered Sacramento River Winter (SRWC, see below) along with other constraints imposed by the FMP are sufficiently protective. Regulations specific to SRWC apply only south of Point Arena, CA whereas the distribution of Sacramento River Spring Chinook extends north of this. Ocean fisheries in the part of Sacramento River Spring distribution north of Point Arena are restricted at all times by the California Coastal Chinook consultation standard, and may be further restricted in years of low forecasted abundance for SRFC and/or KRFC (see below). Sacramento River Spring escapement is moderately correlated with the escapement or river returns of these two stocks (r=0.57 with Central Valley Fall Chinook escapement and r=0.45 with river returns of KRFC, Satterthwaite et al. 2018a). The correlation with Central Valley Fall Chinook may be reduced in the future, due to adaptive trucking of hatchery-origin fall run in response to drought or poor river conditions.

**Sacramento River Winter**

Escapement of Sacramento River Winter Chinook (SRWC) is reported in Table B-3 of the Review of Ocean Fisheries and ocean abundance estimates (presented as projected age-3 escapement in the absence of fishing) are routinely generated via cohort reconstructions. Since 2018, preseason abundance forecasts have been delivered to the Council each March.

Maturing Sacramento River Winter Chinook (SRWC) are assumed to leave the ocean on March 1, thus the preseason forecast, scaled down by anticipated harvest, would be a suitable index of expected ocean abundance during the time of greatest potential overlap with SRKW in the winter. However, it is important to note that SRWC are listed as Endangered and managed under a harvest control rule that ramps down allowable age-3 ocean impact rates from a maximum of 20% to even lower levels at low forecasted abundance (Preseason Report 1, Figure A-3). SRWC are at very low abundance (escapements below 10,000 fish every year since 2007) despite limited fishing impacts, have an ocean distribution restricted to the south relative to other runs (Satterthwaite et al. 2013), are smaller than fall run fish of a given age (Satterthwaite et al. 2012), and have a very high age-3 maturation rate (O'Farrell et al. 2012a). Thus they likely make very little contribution to SRKW diets and there seems to be little potential for benefits from altering SRWC management based on SRKW prey considerations.

**California Coastal Chinook**

Escapement estimates for some components of this stock are reported in Table B-7 of the Review of Ocean Fisheries. However, stock-wide escapement estimates are not available, and prospects for abundance indices, forecasts, or harvest models are limited (O'Farrell et al. 2012b, 2015). This stock is listed as Threatened and although no direct estimates of California Coastal Chinook harvest are available, its consultation standard limits the anticipated age-4 ocean harvest rate of Klamath River Fall Chinook to a maximum of 16.0%, which constrains ocean fisheries in northern California and southern Oregon and thus likely constrains harvest of California Coastal Chinook. (Fisheries may be constrained even further in years of low KRFC abundance forecasts, see below.)

**Southern Oregon Northern California Chinook Stock Complex**

<u>Klamath River Fall</u> (KRFC, indicator stock for complex)

Age-specific ocean abundance estimates from cohort reconstructions are reported annually (Preseason Report 1 Table II-3), and forecasts for age-3, age-4, and age-5 pre-fishery ocean abundance based on sibling regressions and prior-year escapement are delivered to the Council every March (Preseason Report 1 Figure II-3).

When the Council meets to plan fisheries for calendar year *t* during its meetings on March and April of calendar year *t*, the most recent KRFC forecasts are for age-specific ocean abundance on September 1 of year *t*-1. Impacts of fall "credit card" fisheries in calendar year *t*-1 will have already occurred (and are factored into calculating the year *t* harvest rate), as will the period of most likely overlap with SRKW during winter and early spring.

Direct effects of calendar year *t* fishing on KRFC during spring and summer on potential SRKW prey are mainly through removals of the subset of age-3 and age-4 fish that would not have matured that year and thus, if they did not die of other causes, would be available to SRKW the following winter and spring as age-4 and age-5 fish. Harvest (including discard mortality) of age-2 fish in the spring and summer could also affect the availability of age-3 fish the following winter, but KRFC that have recently reached age-3 are relatively small and may be less preferred as SRKW prey. Impacts on age-2 KRFC also likely covary with, but are lower than, impacts on age-3 KRFC which themselves tend to covary with, but are lower than, impacts on age-4 KRFC due primarily to minimum size limits for retention. Thus year *t* preseason forecasts of age-specific KRFC ocean abundance are suitable for informing the planning year *t* spring-summer fisheries.

Abundance at the start of fall fisheries for year *t* can be informed by projecting preseason abundance estimates of age-3 and age-4 abundance to fall abundances of age-4 and age-5 after accounting for typical natural mortality, maturation, and anticipated spring/summer fishing mortality. The abundance of age-3 fish at the start of fall fisheries is not easily predicted. Reconstructed age-3 abundance for KRFC shows substantially less autocorrelation than the SI ($\rho$=0.30 for reconstructed age-3 preseason abundance values from 2001-2017, $\rho$=0.37 for logged values), so there is less support for taking an approach analogous to SRFC and reusing the previous year's forecast. The abundance of newly age-3 fish may be less important than age-4 and age-5 abundances at this time of year due to the small size of newly age-3 KRFC (limiting their retention in the fishery), and the apparent preference of SRKW for larger prey. Impacts on age-3 KRFC in the fall of year *t* are taken into account when planning spring/summer fisheries on age-3 KRFC for year *t*+1.

Availability of age-4 and age-5 KRFC as potential SRKW prey in the winter can therefore be projected based on preseason abundance forecasts for age-3 and age-4 KRFC, discounted by planned spring-summer fisheries, natural mortality, maturation, and planned fall fisheries. However suitable predictors for age 3 abundance in fall and winter are unclear, and quantitative tools for planning of fall fisheries would require substantial development effort (O’Farrell 2009).

Klamath River Spring

Escapements of Klamath River Spring are measured but not routinely reported to the Council. No ocean abundance index is routinely calculated. Total adult run size for Klamath fall and spring runs are moderately correlated (r=0.67 for 2001-2017), with fall run considerably outnumbering spring run (mean adult run size of ~118,000 versus ~23,000). There is no model for predicting the effects of proposed fishing seasons on Klamath River Spring harvest rates. Given the correlation in returns, relative abundance, and the existing tools for active management of KRFC, there would likely be little benefit from treating Klamath River Spring separately from KRFC.

Smith River

No escapement or abundance indices are routinely available.

Southern Oregon Coast

Escapement indices for some components of this stock are reported in Tables B-8 through B-10 of the Review of Ocean fisheries. To indicate the relative ocean abundance for this stock, the Rogue Ocean Population Index (ROPI) is reported to the Council each year (Preseason Report 1, Table II-7). The ROPI scales age-specific escapement estimates of Rogue River fall Chinook to ocean abundances by assuming age-specific ocean impact rates equal to those estimated for KRFC. Postseason estimates of total KRFC adult abundance and the total Rogue Ocean Population Index have been moderately correlated (r=0.60 for 2001-2018), but this correlation must be interpreted with caution because the ROPI is in part driven by the assumption that age-specific impact rates estimated for KRFC apply to Rogue fall Chinook as well. ROPI forecasts are made each year based on sibling regressions applied to the prior year's age-specific escapement. Forecasts are not made for the other Southern Oregon Coast stocks.

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