# Appendix F, Modeling

# Attachment F.1 Maunder and Deriso in R Model

## F.1.1 Model Overview

The Delta Smelt life cycle model published by Maunder and Deriso (2011) was updated in 2021 following the approach of Polansky et al. (2021) as far as practical, by modifying and generalizing the originally published model. This update to the publication version (henceforth referred to as the Maunder and Deriso model in R, or MDR) models a single cohort life strategy species that dies after it reproduces (i.e. the final transition is from adults to recruits and very few adults survive to the next time period e.g. an annual species). It is modelled in a Frequentist state-space framework allowing for both process variation and observation error. Transition between stages (i.e. survival and the stock-recruitment relationship) can be a function of density and covariates, in addition to unexplained temporal variation (process error). Covariates can also be used to influence the density dependent relationship or the survey catchability (bias). The model can be fitted to any number of surveys representing any of the stages. There is also flexibility in the timing of density dependence, surveys, process error and covariates. The covariates can be can estimated as random variables to represent uncertainty in the measurement of the covariates, dealing with missing covariates, or allowing for uncertainty in projections, but this is not illustrated here.

Relative to the 2011 publication, the MDR includes an additional stage (sub-adults), with stages adjusted appropriately, fit to two additional indices of abundance for adults (spring midwater trawl prior to 2001 and spring Kodiak trawl for 2001 and later). Additionally, catchability (survey bias) is now estimated for the spring midwater trawl, and the likelihood function was changed to a log normal. The time period was also extended and now includes cohorts between 1995 and 2015. Potential covariates of survival and recruitment were borrowed from Smith et al. (2021). The surveys were fitted at the start of the stage before any other processes occurred. Covariates and process variation were added after density dependence when it was included.

## F.1.2 Model Development

In 2021 and 2022, Mark Maunder developed a generalized life cycle model, extending the model described by Deriso and Maunder (2011) [henceforth referred to as the M&D model] and applied the resulting model to Delta smelt, with candidate covariates and several of the model extensions borrowed from Polansky et al. (2021). Important differences between the original M&D model and the application of Polansky et al. nevertheless remain, and include model structure, surveys used, inference method, covariates tested and consideration of density dependence; these differences are summarized in Table F.1-1. The updated model, hereafter referred to as the MDR, is programmed in Template Model Builder (TMB; Kristensen et al. 2016) within R (R Core Team 2017) in a Frequentist, state-space framework allowing for both process variation and observation error. Transition between stages (i.e. survival and the stock-recruitment relationship) can be a function of density and covariates, in addition to unexplained temporal variation (process error). For the purposes of the application described herein – and based on previous analysis showing near equal support for density-dependent and -independent model forms – all transitions were assumed to be density-independent.

The MDR was modified from the original M&D model to include an additional stage (sub-adults; with the other stages adjusted appropriately) and estimate catchability (i.e. survey bias). The MDR is also fit to two additional indices of abundance for adults (spring midwater trawl prior to 2001 and spring Kodiak trawl for 2001 and later), and the likelihood function was changed to a log-normal likelihood. The period (1995-2015) and the covariates used by Polansky et al. (2021) are different than those used in Maunder and Deriso (2011), and so were also updated in the MDR.

### F.1.2.1 Workflow for application of MDR to Scenario Evaluation

Building from Mark Maunder's 2021 work, ICF has extended the MDR for evaluation of alternative management scenarios. The underlying population dynamics model, and the statistical model fitting procedures, as coded in C++ were not altered, but ICF significantly expanded upon the R code used to fit, validate, and project the population dynamics model given alternative sets of environmental covariate values and associated model parameter estimates. Primary extensions include streamlined processing of covariate data to allow for rapid iteration between model formulations, an automated process for generating scenarios with modified covariate values based on hypothetical management actions, a series of functions for producing visualizations that aid in model interpretation and validation, and a function-based approach to model projection under multiple scenarios. The general methods for such scenario evaluation are as follow:

1. Select candidate covariates of each life-stage transition. An initial, extensive set of covariate data taken from the analysis of Smith et al. (2021) was provided by USFWS and served as the candidate set for model selection.

2. Select a base model. The "best" model was defined as the combination of covariates resulting in the lowest Akaike's Information Criterion and was identified through a hybrid approach that used both stochastic and step-wise methods (see below).

3. Fit the model to historic abundance indices and covariate data. The model is fit using maximum likelihood with optimization algorithms provided by TMB.

4. Project the model with baseline and alternative covariate values.

    a. Although theoretically possible, the state-space nature of the MDR poses challenges for backward-looking projection. That is to say, it is difficult to "rewind" the model to the beginning of the time-series used in model fitting and project forward from the historical abundances. As a result, model runs were projected forward from 2015, the last year in the data used for fitting.

b. The predicted effect of various management actions was evaluated by modifying the historical covariates (OMR and Delta Outflow) to reflect alterations in water operations. Modified timeseries of covariates were then used in the model projection phase. A baseline projection was also created by recycling all 1995-2015 covariate data.

5. Calculate annual population growth rates for the projected populations and compare them to baseline projections.

   a. Projected populations trajectories for each scenario were compared with one another and with the baseline (i.e. projection with unmodified historic covariates) to evaluate the relative performance of Delta Smelt under varying levels of entrainment loss during December-April.

   b. Note that the projections should be used only for comparative purposes and should not be interpreted as accurate predictions of future abundances. In developing and evaluating the MDR, Mark Maunder noted that forward projection resulted in highly uncertain abundance estimates because even after the inclusion of covariates and density dependence, a large amount of unexplained temporal variation in survival remains.

#### F.1.2.2 Model Selection

A wide range of environmental and operational covariates have been hypothesized to impact recruitment and/or life-stage specific survival in Delta Smelt. As a statistical model, the MDR is suitable for identifying and evaluating the strength of correlations between each of the modeled vital rates and one or more candidate covariates. In contrast to a mathematical simulation, such as the Delta smelt individual based model (IBMR), the form and strength of any covariate influence cannot be manually specified, and so hypothetical management scenarios can only be compared through projection when a managed covariate is found to significantly influence one or more vital rate. A commonly used approach for selection of an optimal model is to begin with all candidate covariates included and then sequentially remove variables based on some selection criterion. However, this stepwise approach has several important limitations when applied to the MDR model:

1. Inclusion of multiple correlated covariates of a single life-stage transition in the model tends to produce poor fits and obscure the influence of such covariates. Stepwise selection must therefore be initiated from a set a candidate set where covariates of a given transition are not highly correlated (i.e. $r >$ ~0.6-0.7).

2. The importance of a covariate may depend on the inclusion of another covariate in the same, or a separate life-stage transition, and in such cases a stepwise approach to model selection can exclude an important covariate.

3. Retention of a covariate may depend on whether density dependence is included in one or more of the life-stage transitions.

A global model selection approach where all potential combinations of covariates are evaluated would theoretically overcome these limitations, but such an approach is precluded by computational time: given a large pool of potential survival and recruitment covariates, and four separate transitions to which covariates may be applied, the number of potential model parameterizations is extremely large. As an alternative approach, a stochastic model selection procedure was therefore developed that attempts to realize the benefits of global model selection (i.e. identifying potential synergies or dependencies between covariates) within a reasonable amount of computational time. The stochastic approach involved random selection of two covariates per transition from the complete set of candidates (Table F.1-1) and random selection of which, if any, life stages were subject to density dependence (options for density dependence were weighted such that there was equal probability of no density dependence and *any* density dependence). All covariate data sources, and summarization approaches are as reported in Smith et. al (2021).

Table F.1-1. Candidate Covariates included in Model Selection

| **Covariate^** | **Impacted Transition** | **Covariate aggregate months*** |
|---|---|---|
| X2 | Post-larval survival | June-August |
| Delta Outflow | Post-larval survival | June-August |
| Delta mean Temperature | Post-larval survival | June-August |
| Delta mean Secchi depth | Post-larval survival | June-August |
| Food (small) | Post-larval survival | June-August |
| Food (small/large) | Post-larval survival | June-August |
| Inland Silverside Index | Post-larval survival | June-August |
| Threadfin Shad Index | Post-larval survival | June-August |
| Tridentiger Goby Index | Post-larval survival | June-August |
| South Delta Secchi Depth | Post-larval survival | April-June |
| OMR | Post-larval survival | April-June |
| X2 | Juvenile Survival | September-November |
| Delta Outflow | Juvenile Survival | September-November |
| Delta mean Temperature | Juvenile Survival | September-November |
| Delta mean Secchi depth | Juvenile Survival | September-November |
| Food (large) | Juvenile Survival | September-November |
| Food (small/large) | Juvenile Survival | September-November |
| Age 1+ Striped Bass Index | Juvenile Survival | September-November |
| OMR | Sub-adult Survival | December-February |
| Delta Outflow | Sub-adult Survival | December-February |
| South Delta Secchi Depth | Sub-adult Survival | December-February |
| Delta mean Temperature | Sub-adult Survival | December-February |

| Covariate^ | Impacted Transition | Covariate aggregate months* |
|---|---|---|
| Delta mean Secchi depth | Sub-adult Survival | December-February |
| Proportional Entrainment (Low Bookend) | Sub-adult Survival | December-February |
| Proportional Entrainment (High Bookend) | Sub-adult Survival | December-February |
| Salvage | Sub-adult Survival | December-February |
| Age 1+ Striped Bass Index | Sub-adult Survival | December |
| Food (large) | Sub-adult Survival | December-February |
| Delta Outflow | Recruitment | March-May |
| Delta mean Temperature | Recruitment | March-May |
| Delta mean Secchi depth | Recruitment | March-May |
| Food (small) | Recruitment | March-May |
| Food (large) | Recruitment | March-May |
| Inland Silverside Index | Recruitment | March-May |
| Tridentiger Goby Index | Recruitment | March-May |
| X2 | Recruitment | Prior September-November |

For each randomly generated model, Akaike's Information Criterion corrected for small sample sizes (AICc) was calculated as an index of overall model performance. Next, 80% confidence intervals were calculated for each covariate in the model and were evaluated for significance (i.e. overlap of zero). This stochastic model fitting procedure was repeated 400,000 times. After completion of stochastic model building, the results were summarized by calculating, for each candidate covariate, the proportion of times the covariate was significant in a model, given that it was selected (i.e. 80% confidence interval excluding zero), and the average AICc of the models in which a covariate was included. In addition, the model with the lowest overall AICc score was used as a starting point for a final, stepwise model selection approach to evaluate whether a better model could be produced by including more or less than two covairates per transition.

The overall "best" model identified after application of the hybrid stochastic-stepwise model selection process included South Delta Secchi depth and Beverton-Holt density dependence for the sub-adult survival transition. The lowest AICc model excluding density dependence also included OMR as a significant covariate of sub-adult survival (Table F.1-1). Models where $\Delta$AICc <2 are generally considered to be essentially equal in terms of parsimony, and so based on this analysis the role of density dependence remains equivocal.

Table F.1-2. Summary of “best” models as identified through a hybrid stochastic and stepwise model selection procedure.

| | With Density-Dependence | No Density-Dependence |
|---|---|---|
| Density Dependent Transition | Sub-adult Survival | N/A |
| Post-Larval Survival | Temperature_mean_Jun0Aug0<br>NJACM_BPUV_Jun0Aug0* | Temperature_mean_Jun0Aug0<br>NJACM_BPUV_Jun0Aug0* |
| Juvenile Survival | Secchi_mean_Sep0Nov0<br>Temperature_mean_Sep0Nov0 | Secchi_mean_Sep0Nov0<br>Temperature_mean_Sep0Nov0 |
| Sub-Adult Survival | SouthSecchi_mean_Dec0Feb1 | OMR_Dec0Feb1<br>SouthSecchi_mean_Dec0Feb1 |
| Recruitment | Fall_X2_Lag | N/A |
| Minimum AICc | 215 | 217 |

*Summer food density or X2 can be substituted for summer outlfow with negligible impact on AICc

## F.1.3 Model Application

The approach to evaluating alternative management actions with the MDR was similar to that used in support of the Collaborative Science and Adaptive Management Program (CSAMP) Delta Smelt Structured Decision Making (SDM) process. After fitting and optimizing the model as described above, historic covariate data (1995-2015) were modified following CalSim 3 scenarios and the geometric mean λ across all years was calculated for each scenario. Other model inputs including temperature and turbidity were not adjusted as doing so would necessitate substantial additional model development. Monthly flow data were obtained from CalSim 3 outputs for each scenario. For Old and Middle River flow the monthly values were averaged across the December-February period. For summer outflow, the cumulative daily flow from June-August was estimated from monthly CalSim 3 Net Delta Outflow Index values by converting cfs to acre-feet (1 cfs = 1.983 acre-feet per day), multiplying each monthly value by the number of days in the month, and then summing across months. The approach to covariate summarization was intended to match the methods of Smith et al. (2021) as closely as possible, though note that because this model does not separate entrainment and natural mortality or include sub-cohorts, winter OMR is a single covariate in the MDR while it is separated into multiple variables by Smith et al. (2021). Differences in the scenario values from the outflow (Figure F.1-1) and OMR (Figure F.1-2) data used for model fitting show that the alternatives generally reduced June-August outflow in wet years while EXP1 and EXP3 reduce outflow across most years, while OMR was more positive in non-wet years and more negative in wet years with Alt3 consistently higher and Alt1 consistently lower than the NAA and Alt2 options.

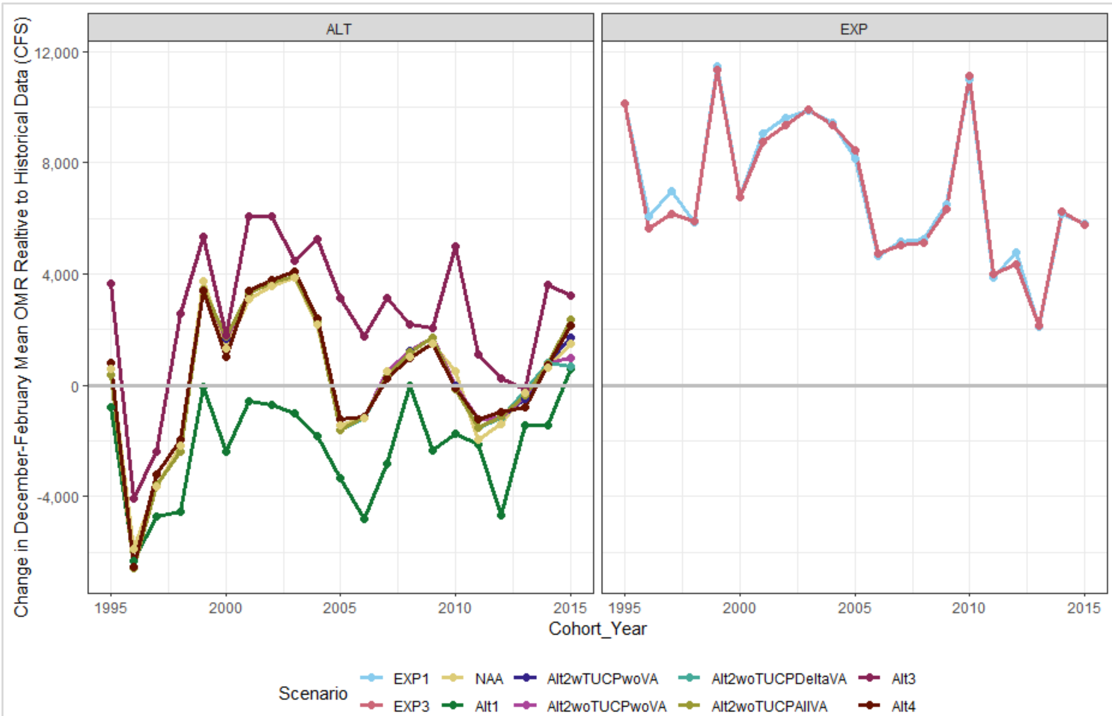


Figure F.1-1. Difference in December-February mean OMR relative to observed data used for model fitting.


Figure F.1-2. Difference in June-August Total Outflow relative to observed data used for model fitting.

To evaluate alternatives, the adjusted flow covariate values and unadjusted temperature and turbidity covariate values described above were used to project Delta Smelt population dynamics forward from the last included adult index observation (2015). The state-space implementation of the model makes it impractical to project forward from the 1995 adult abundance, and so the projected abundances are not expected to match the historic index values. However, in the density-independent implementation used for this application, the proportional change in abundance (i.e. the key performance metric, $\lambda$) is insensitive to the starting abundance. For the sake of simplicity, results are therefore discussed in terms of the observed time-period (1995-2015). In general, the absolute values of projected abundances and population growth should be interpreted cautiously because a high level of residual variability is not explained by the model covariates. Results should therefore be used primarily to compare alternatives.

## F.1.4 Assumptions/Uncertainty

1. Abundance indices are assumed to be normally distributed.
2. Stock-recruitment and survival process error are assumed to be lognormally distributed and density-independent.
3. Delta Smelt are treated as annual species.
4. Covariates are assumed to be independent: the approach to scenario evaluation modifies values of prescribed covariates and assumes that it would be possible to achieve such values without influencing other covariates (e.g. outflow could be increased without impacting Delta water temperature or turbidity).
5. Projections do not incorporate any uncertainty in covariate estimates and cannot be interpreted as actual predictions of future annual abundance. The utility of projections is the ability to compare the relative performance of multiple alternatives; absolute abundances and population growth rates should therefore be discussed with great caution and with proper caveats.

### F.1.4.1 Code and Data Repository

Covariate used data for model fitting were obtained from Smith et al. (2021). All CalSim3 data and code for fitting models, projecting alternatives and summarizing/visualizing results are available from Reclamation upon request.

## F.1.5 Results

Across the complete projection period (1995-2015 covariate values, projected forward from the observed 2015 adult abundance index) the geometric mean of the expected population growth, λ, did not exceed 1 (i.e. positive population growth) for any alternative, but did for both EXP scenarios (Table F.1-3). Projection with unmodified historical covariate values (i.e. the Base scenario) resulted in a geometric mean λ of 0.817 across the 20 modeled years and each of alternatives except for Alt3 (λ = 0.966) resulted in lower geometric mean values ranging from 0.578 for Alt 1 to 0.75 for the Alt2 phases and NAA. In contrast, EXP1 and EXP3 projections resulted in, on average, positive population growth with geometric mean λ values of 1.380 and 1.524, respectively. Predictably, delta smelt population performance was impacted by annual hydrologic conditions, with the geometric mean of λ higher during wet and above normal water years and lower during below normal and drier water years (λ =0.633 vs. λ=0.905 under the baseline projection). Projection under each of the alternatives, except for Alt1, produced increases in population growth rate relative to the baseline in below normal and drier water years. In contrast, for all alternatives during above normal and wet water years (and Alt1 during all water year types), projections resulted in decreased population growth relative to the baseline. The combined effect of these changes was reduced variability in population growth between hydrological groupings, but no overall improvement in delta smelt population growth. Projection of both EXP scenarios resulted in increased population growth relative to the baseline, with larger increases in above normal and wet water years. Because wet and above normal water years were more common in the first half of the time-series (1995-2004), average population growth was projected to be higher during this period for all scenarios, with Alt3 producing a geometric mean λ>1 during this period.

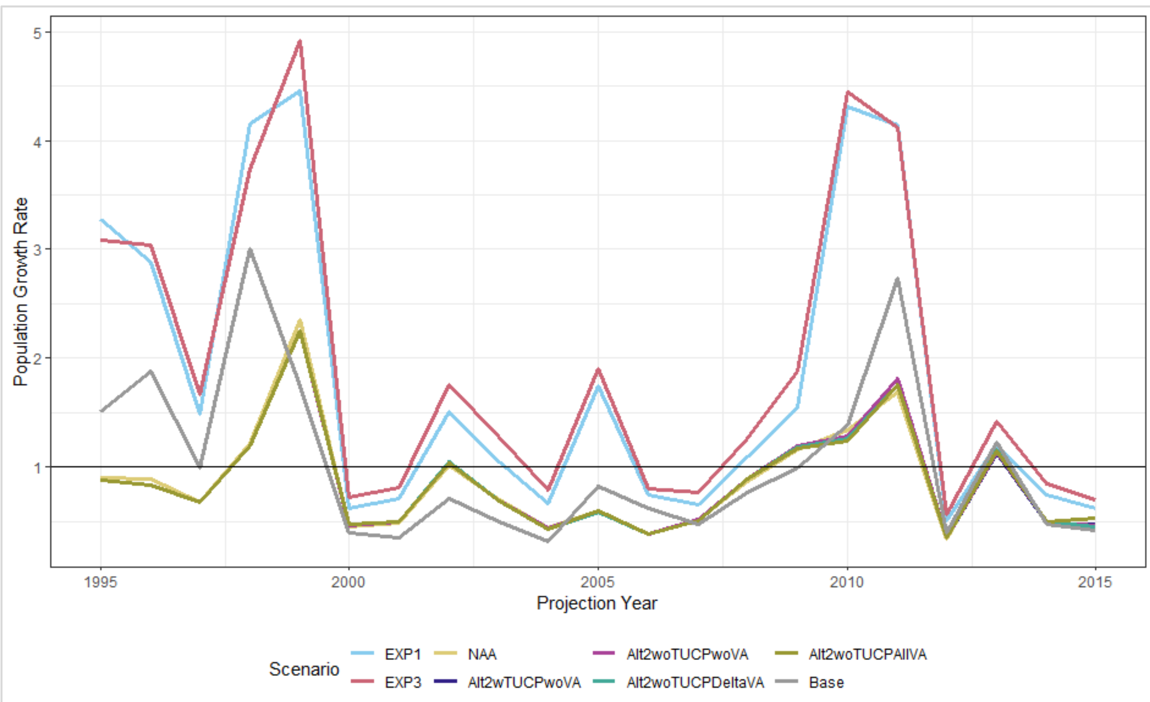


Figure F.1-3. Plot of projected annual population growth rates in EXP1, EXP3, NAA, and Alt2 Phases.

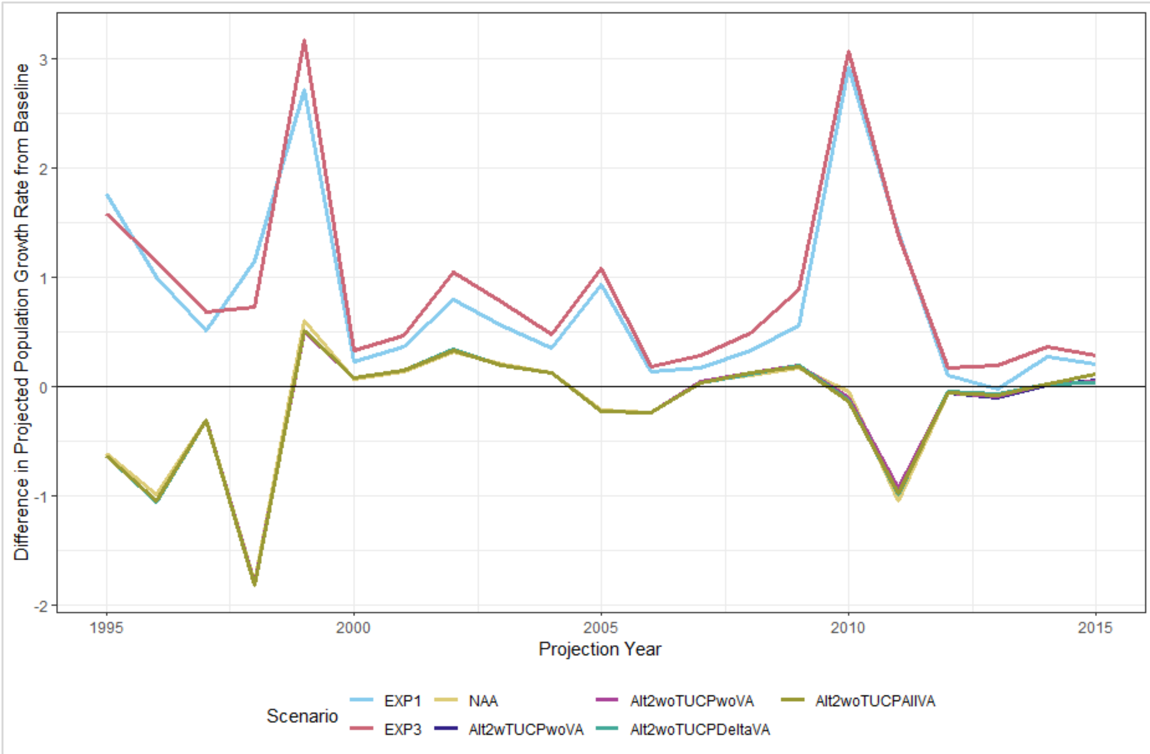


Figure F.1-4. Difference from baseline in projected population growth rates in EXP1, EXP3, NAA, and Alt2 Phases.

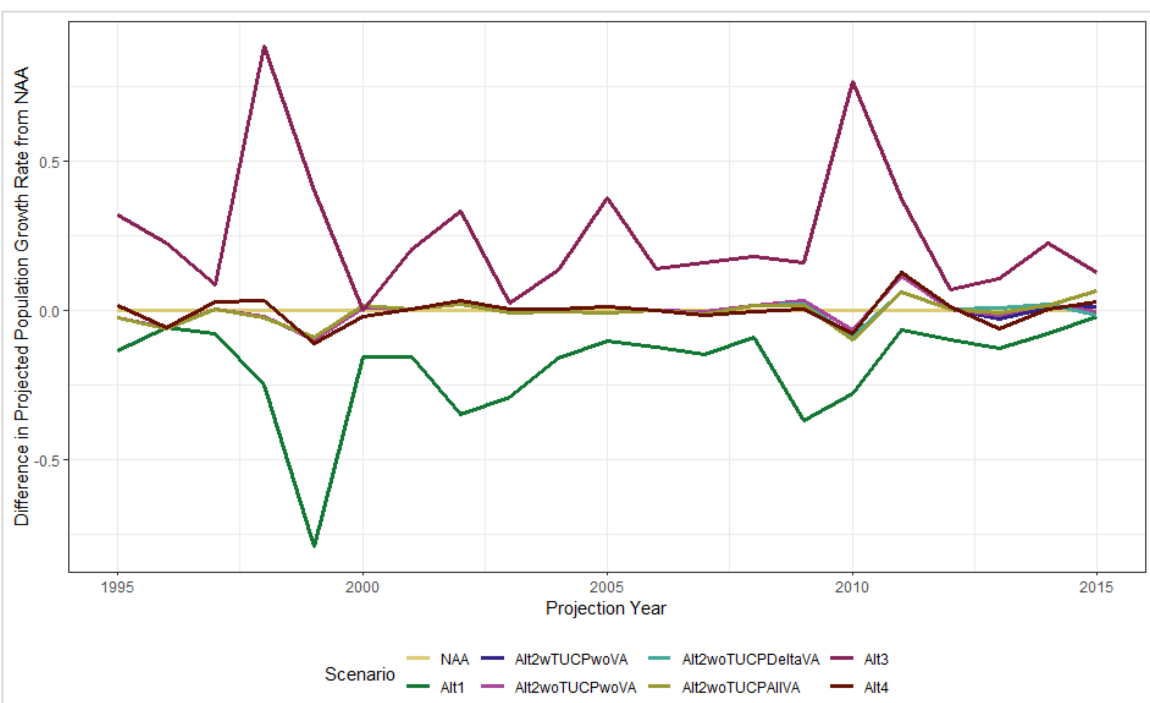


Figure F.1-5. Plot of difference in projected annual population growth rate from NAA.

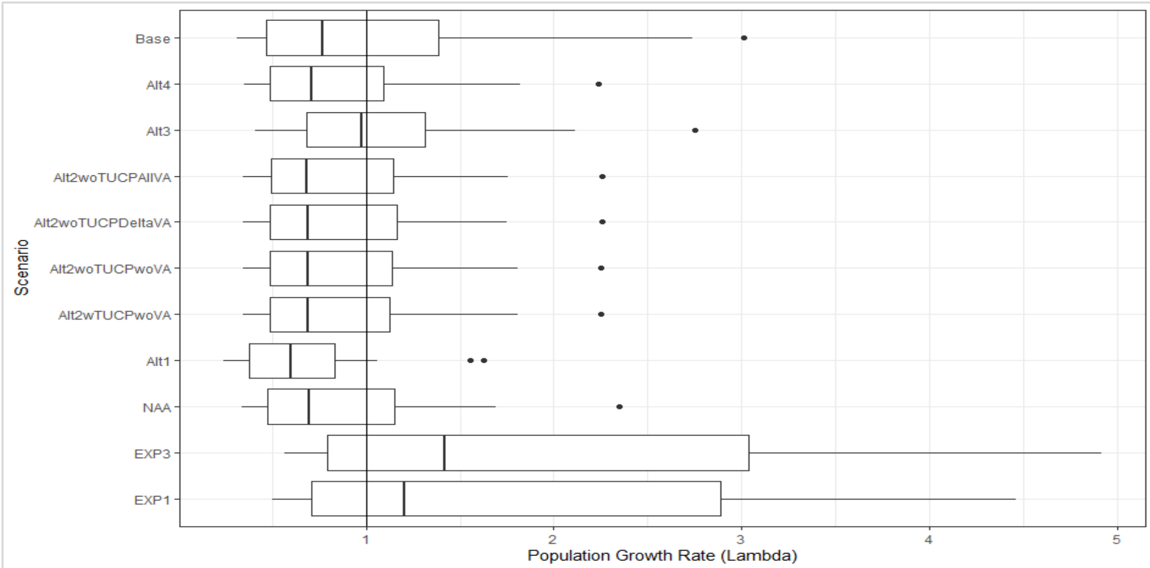


Figure F.1-6. Boxplots showing the complete distributions of population growth rate for all scenarios.

Table F.1-3. Estimates by annual growth rates. Parenthetical values show percent change from the baseline projection.

| Year | EXP1 | EXP3 | NAA | Alt2woTUCP woVA | Alt2wTUCP woVA | Alt2woTUCP DeltaVA | Alt2woTUCP AllVA |
|---|---|---|---|---|---|---|---|
| 1995 | 3.27 (117) | 3.09 (105) | 0.9 (-41) | 0.88 (-42) | 0.88 (-42) | 0.87 (-42) | 0.87 (-42) |
| 1996 | 2.89 (53) | 3.04 (61) | 0.89 (-53) | 0.84 (-56) | 0.84 (-56) | 0.83 (-56) | 0.83 (-56) |
| 1997 | 1.49 (51) | 1.67 (69) | 0.68 (-31) | 0.68 (-31) | 0.68 (-31) | 0.68 (-31) | 0.68 (-31) |
| 1998 | 4.15 (38) | 3.74 (24) | 1.22 (-59) | 1.2 (-60) | 1.2 (-60) | 1.19 (-60) | 1.19 (-60) |
| 1999 | 4.46 (155) | 4.92 (182) | 2.35 (34) | 2.25 (29) | 2.25 (29) | 2.26 (29) | 2.26 (29) |
| 2000 | 0.62 (59) | 0.72 (86) | 0.45 (17) | 0.46 (19) | 0.46 (19) | 0.47 (21) | 0.47 (21) |
| 2001 | 0.71 (105) | 0.81 (132) | 0.49 (40) | 0.49 (41) | 0.49 (41) | 0.49 (41) | 0.49 (41) |
| 2002 | 1.5 (113) | 1.75 (149) | 1.02 (44) | 1.05 (48) | 1.05 (48) | 1.05 (48) | 1.04 (47) |
| 2003 | 1.05 (113) | 1.27 (157) | 0.7 (41) | 0.69 (40) | 0.69 (40) | 0.69 (40) | 0.69 (39) |
| 2004 | 0.66 (112) | 0.79 (152) | 0.44 (40) | 0.43 (39) | 0.43 (39) | 0.43 (38) | 0.43 (38) |
| 2005 | 1.74 (113) | 1.9 (132) | 0.6 (-27) | 0.59 (-28) | 0.59 (-28) | 0.59 (-28) | 0.59 (-28) |
| 2006 | 0.75 (21) | 0.8 (29) | 0.38 (-38) | 0.38 (-38) | 0.38 (-38) | 0.38 (-38) | 0.38 (-38) |
| 2007 | 0.65 (37) | 0.76 (61) | 0.52 (10) | 0.52 (10) | 0.52 (10) | 0.51 (8) | 0.51 (8) |
| 2008 | 1.1 (43) | 1.26 (64) | 0.87 (13) | 0.89 (16) | 0.89 (16) | 0.89 (15) | 0.89 (16) |
| 2009 | 1.55 (56) | 1.88 (89) | 1.16 (17) | 1.19 (20) | 1.19 (20) | 1.18 (19) | 1.17 (18) |
| 2010 | 4.3 (211) | 4.44 (221) | 1.34 (-3) | 1.28 (-8) | 1.28 (-8) | 1.26 (-9) | 1.24 (-10) |

| Year | EXP1 | EXP3 | NAA | Alt2woTUCP woVA | Alt2wTUCP woVA | Alt2woTUCP DeltaVA | Alt2woTUCP AllVA |
|---|---|---|---|---|---|---|---|
| 2011 | 4.14 (51) | 4.12 (51) | 1.69 (-38) | 1.81 (-34) | 1.81 (-34) | 1.75 (-36) | 1.76 (-36) |
| 2012 | 0.5 (27) | 0.57 (43) | 0.34 (-14) | 0.35 (-13) | 0.35 (-13) | 0.35 (-13) | 0.35 (-13) |
| 2013 | 1.2 (-2) | 1.42 (15) | 1.16 (-6) | 1.14 (-7) | 1.13 (-8) | 1.16 (-5) | 1.15 (-7) |
| 2014 | 0.74 (57) | 0.84 (78) | 0.48 (1) | 0.5 (6) | 0.49 (3) | 0.5 (6) | 0.5 (5) |
| 2015 | 0.62 (50) | 0.7 (68) | 0.46 (11) | 0.46 (10) | 0.47 (14) | 0.45 (7) | 0.53 (27) |

Table F.1-4. Estimates by annual growth rates. Parenthetical values show percent change from the NAA projection.

| Year | Alt1 | Alt2 woTUCP woVA | Alt2 wTUCP woVA | Alt2 woTUCP DeltaVA | Alt2 woTUCP AllVA | Alt3 | Alt4 | NAA |
|---|---|---|---|---|---|---|---|---|
| 1995 | 0.76 (-15) | 0.88 (-2) | 0.88 (-2) | 0.87 (-3) | 0.87 (-3) | 1.22 (36) | 0.92 (2) | 0.9 (0) |
| 1996 | 0.84 (-6) | 0.84 (-7) | 0.84 (-7) | 0.83 (-7) | 0.83 (-7) | 1.12 (25) | 0.84 (-6) | 0.89 (0) |
| 1997 | 0.6 (-11) | 0.68 (1) | 0.68 (1) | 0.68 (1) | 0.68 (1) | 0.76 (13) | 0.71 (5) | 0.68 (0) |
| 1998 | 0.97 (-20) | 1.2 (-2) | 1.2 (-2) | 1.19 (-2) | 1.19 (-2) | 2.1 (73) | 1.25 (3) | 1.22 (0) |
| 1999 | 1.56 (-34) | 2.25 (-4) | 2.25 (-4) | 2.26 (-4) | 2.26 (-4) | 2.75 (17) | 2.24 (-5) | 2.35 (0) |
| 2000 | 0.3 (-34) | 0.46 (2) | 0.46 (2) | 0.47 (4) | 0.47 (3) | 0.46 (1) | 0.44 (-4) | 0.45 (0) |
| 2001 | 0.33 (-32) | 0.49 (1) | 0.49 (1) | 0.49 (1) | 0.49 (1) | 0.69 (42) | 0.49 (1) | 0.49 (0) |
| 2002 | 0.67 (-34) | 1.05 (3) | 1.05 (3) | 1.05 (3) | 1.04 (2) | 1.35 (33) | 1.05 (3) | 1.02 (0) |
| 2003 | 0.41 (-41) | 0.69 (-1) | 0.69 (-1) | 0.69 (-1) | 0.69 (-1) | 0.72 (3) | 0.7 (1) | 0.7 (0) |
| 2004 | 0.28 (-36) | 0.43 (-1) | 0.43 (-1) | 0.43 (-1) | 0.43 (-1) | 0.57 (31) | 0.44 (1) | 0.44 (0) |
| 2005 | 0.5 (-17) | 0.59 (-2) | 0.59 (-2) | 0.59 (-2) | 0.59 (-1) | 0.98 (63) | 0.61 (2) | 0.6 (0) |
| 2006 | 0.26 (-32) | 0.38 (0) | 0.38 (0) | 0.38 (0) | 0.38 (0) | 0.52 (36) | 0.38 (0) | 0.38 (0) |
| 2007 | 0.38 (-28) | 0.52 (-1) | 0.52 (-1) | 0.51 (-2) | 0.51 (-2) | 0.68 (31) | 0.51 (-3) | 0.52 (0) |
| 2008 | 0.78 (-10) | 0.89 (2) | 0.89 (2) | 0.89 (2) | 0.89 (2) | 1.05 (21) | 0.86 (-1) | 0.87 (0) |
| 2009 | 0.79 (-32) | 1.19 (3) | 1.19 (3) | 1.18 (2) | 1.17 (1) | 1.32 (14) | 1.16 (0) | 1.16 (0) |
| 2010 | 1.06 (-21) | 1.28 (-5) | 1.28 (-5) | 1.26 (-6) | 1.24 (-7) | 2.11 (57) | 1.27 (-6) | 1.34 (0) |
| 2011 | 1.63 (-4) | 1.81 (7) | 1.81 (7) | 1.75 (4) | 1.76 (4) | 2.06 (22) | 1.82 (8) | 1.69 (0) |
| 2012 | 0.24 (-29) | 0.35 (1) | 0.35 (1) | 0.35 (2) | 0.35 (1) | 0.41 (21) | 0.35 (4) | 0.34 (0) |
| 2013 | 1.03 (-11) | 1.14 (-1) | 1.13 (-2) | 1.16 (1) | 1.15 (-1) | 1.26 (9) | 1.09 (-5) | 1.16 (0) |
| 2014 | 0.4 (-17) | 0.5 (4) | 0.49 (2) | 0.5 (4) | 0.5 (4) | 0.71 (47) | 0.48 (1) | 0.48 (0) |
| 2015 | 0.44 (-5) | 0.46 (-1) | 0.47 (2) | 0.45 (-3) | 0.53 (14) | 0.59 (27) | 0.49 (6) | 0.46 (0) |

Table F.1-5. Maunder and Deriso in R estimated population growth rates by water year type. Parenthetical values show percent change from the baseline projection.

| Grouping | EXP1 | EXP3 | NAA | Alt2 wTUCP woVA | Alt2 woTUCP woVA | Alt2 woTUCP DeltaVA | Alt2 woTUCP AllVA | Baseline |
|---|---|---|---|---|---|---|---|---|
| All | 1.38 (69) | 1.52 (86) | 0.75 (-8) | 0.75 (-8) | 0.75 (-8) | 0.75 (-8) | 0.75 (-8) | 0.82 (0) |
| 1995-2004 | 1.62 (88) | 1.77 (106) | 0.8 (-7) | 0.79 (-8) | 0.79 (-8) | 0.79 (-8) | 0.79 (-8) | 0.86 (0) |
| 2005-2015 | 1.2 (53) | 1.33 (71) | 0.71 (-9) | 0.72 (-8) | 0.72 (-8) | 0.71 (-9) | 0.72 (-8) | 0.78 (0) |
| BN/Dry/Critical | 0.94 (48) | 1.08 (71) | 0.71 (12) | 0.72 (13) | 0.72 (13) | 0.71 (13) | 0.73 (16) | 0.63 (0) |
| Above Normal/Wet | 1.61 (78) | 1.75 (93) | 0.77 (-15) | 0.77 (-15) | 0.77 (-15) | 0.76 (-16) | 0.76 (-16) | 0.91 (0) |
| Critical | 0.68 (53) | 0.77 (73) | 0.47 (6) | 0.48 (8) | 0.48 (8) | 0.47 (6) | 0.51 (15) | 0.44 (0) |
| Dry | 1.1 (45) | 1.28 (70) | 0.87 (15) | 0.87 (16) | 0.88 (16) | 0.88 (16) | 0.87 (16) | 0.76 (0) |
| Below Normal | 1.3 (90) | 1.45 (112) | 0.68 (-1) | 0.68 (-1) | 0.68 (-1) | 0.67 (-2) | 0.67 (-2) | 0.68 (0) |
| Above Normal | 0.76 (93) | 0.9 (129) | 0.52 (32) | 0.52 (32) | 0.52 (32) | 0.52 (33) | 0.52 (32) | 0.39 (0) |
| Wet | 2.6 (64) | 2.66 (68) | 1 (-37) | 0.99 (-38) | 0.99 (-38) | 0.98 (-38) | 0.98 (-38) | 1.58 (0) |

Table F.1-6. Maunder and Deriso in R estimated population growth rates by water year type. Parenthetical values show percent change from the NAA projection.

| Grouping | NAA | Alt1 | Alt2 wTUCP woVA | Alt2 woTUCP woVA | Alt2 woTUCP DeltaVA | Alt2 woTUCP AllVA | Alt3 | Alt4 |
|---|---|---|---|---|---|---|---|---|
| All | 0.75 (0) | 0.58 (-23) | 0.75 (0) | 0.75 (0) | 0.75 (0) | 0.75 (0) | 0.97 (28) | 0.75 (0) |
| 1995-2004 | 0.8 (0) | 0.58 (-27) | 0.79 (-1) | 0.79 (-1) | 0.79 (-1) | 0.79 (-1) | 1.01 (26) | 0.8 (0) |
| 2005-2015 | 0.71 (0) | 0.58 (-19) | 0.72 (1) | 0.72 (1) | 0.71 (0) | 0.72 (1) | 0.93 (31) | 0.72 (0) |
| BN/Dry/Critical | 0.71 (0) | 0.58 (-18) | 0.72 (1) | 0.72 (1) | 0.71 (1) | 0.73 (3) | 0.89 (26) | 0.71 (0) |
| Above Normal/Wet | 0.77 (0) | 0.58 (-25) | 0.77 (-1) | 0.77 (-1) | 0.76 (-1) | 0.76 (-1) | 1 (29) | 0.77 (0) |
| Critical | 0.47 (0) | 0.42 (-11) | 0.48 (2) | 0.48 (2) | 0.47 (0) | 0.51 (9) | 0.65 (37) | 0.49 (3) |
| Dry | 0.87 (0) | 0.68 (-22) | 0.87 (1) | 0.88 (1) | 0.88 (1) | 0.87 (1) | 1.05 (21) | 0.86 (-1) |
| Below Normal | 0.68 (0) | 0.5 (-26) | 0.68 (-1) | 0.68 (-1) | 0.67 (-1) | 0.67 (-2) | 0.95 (40) | 0.68 (0) |
| Above Normal | 0.52 (0) | 0.32 (-37) | 0.52 (0) | 0.52 (0) | 0.52 (1) | 0.52 (0) | 0.57 (11) | 0.51 (-1) |
| Wet | 1 (0) | 0.82 (-18) | 0.99 (-1) | 0.99 (-1) | 0.98 (-2) | 0.98 (-2) | 1.31 (31) | 1.01 (1) |

## F.1.6 Results

- Geometric mean of population growth rate from 1995 to 2015 was lower than historic baseline projections for all scenarios except EXP1, EXP3, and Alt3 scenarios. EXP1, EXP3 and Alt3 performed better than most scenarios/alternatives (i.e., higher $\lambda$) and Alt1 performed worse than most alternatives (i.e., lower $\lambda$). All Alt2 options, and the NAA performed similarly.
- EXP1, EXP3 and Alt3 scenarios likely produced in higher $\lambda$ due to more positive OMR flows and the relatively high June-August Delta Outflow during dry years (Figure F.1-1, Figure F.1-2). Alt1 scenario likely produced lower $\lambda$ relative to most scenarios due to the more negative OMR flows during most months.

## F.1.7 References


Maunder, M. N., and R. B. Deriso. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*). *Can. J. Fish. Aquat. Sci.* 68(7):1285–1306.

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