

## 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 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.1-2. 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.

Table F.1-1. Summary of Differences between Related Models

Characteristic	M&D	Polansky et al.	MDR
Time frame	1972-2006	1995-2015 (1994 adults also included)	1995-2015
Stages	3 (larvae, juveniles, adults)	4 (post larvae, juveniles, sub-adults, adults)	4 (post larvae, juveniles, sub-adults, adults)
Stock-recruitment survival process variation (Adult to larvae survival)	Lognormal	Lognormal	Lognormal
Other survival process variation	Lognormal	Logit-normal	Lognormal
Density dependence	Beverton-Holt, Ricker, or Deriso-Schnute	None	Beverton-Holt (Ricker and Deriso-Schnute are also possible)
Indices of abundance	3 (20mm, summer tow net, fall midwater trawl)	4 (20mm, summer tow net, fall midwater trawl, spring Kodiak trawl, and spring midwater trawl)	4 (20mm, summer tow net, fall midwater trawl, spring Kodiak trawl, and spring midwater trawl)
Catchability (survey bias)	Catchability fixed at 1 (assumes can't estimate absolute abundance)	Catchability fixed at one for 20mm and for spring Kodiak trawl (2001 and later), estimated for other surveys and years, but spring midwater trawl is assumed equal to the fall midwater trawl.	Catchability fixed at one for 20mm and for spring Kodiak trawl (2001 and later), estimated for other surveys and years, but fall and spring MWT are assumed equal. However, this had confounded parameters, so just estimated the catchability for

Characteristic	M&D	Polansky et al.	MDR
			Adult spring midwater tow
Observation error	Normal with known standard deviation that varies by year	Lognormal with known CV that varies by year (also investigated estimating CV scaler)	Lognormal with known CV that varies by year
Inference framework	Frequentist state-space	Bayesian state-space	Frequentist state-space
Model selection	Two at a time selection based on model averaging of AICC weights (density dependence model selection was based on full factorial without covariates)	Include all covariates and evaluate Bayesian interval coverage of zero	Stochastic exploration of covariate combinations followed by stepwise, AICC-based model selection.

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.  $r > \sim 0.6-0.7$ ).

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.1-2) 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.1-2. 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

Covariate	Impacted Transition	Covariate aggregate months
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
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 covariates 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.1-2). 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. Because of this, combined with a broad skepticism of density dependent dynamics given the depleted state of delta smelt, only the density independent model was used for this application.

Table F.1-3. Summary of “best” models as identified through a hybrid stochastic and stepwise model selection procedure. Signs indicate whether the selected covariate had a positive or negative impact on survival/recruitment, and underlining indicates that variables that were modified between scenarios for this application.

	With Density-Dependence	No Density-Dependence
Density Dependent Transition	Sub-adult Survival	N/A
Post-Larval Survival	Temperature_mean_Jun0Aug0 - Outflow_Jun0Aug0 <u>±</u>	Temperature_mean_Jun0Aug0 - <u>Outflow Jun0Aug0 +</u>
Juvenile Survival	Secchi_mean_Sep0Nov0 - Temperature_mean_Sep0Nov0 <u>±</u>	Secchi_mean_Sep0Nov0 - Temperature_mean_Sep0Nov0 <u>±</u>
Sub-Adult Survival	SouthSecchi_mean_Dec0Feb1 <u>±</u>	<u>OMR_Dec0Feb1+</u> SouthSecchi_mean_Dec0Feb1 <u>±</u>
Recruitment	Fall_X2_Lag -	N/A
Minimum AICc	215	217

\*Summer food density or X2 can be substituted for summer outflow 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  $\lambda$  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.

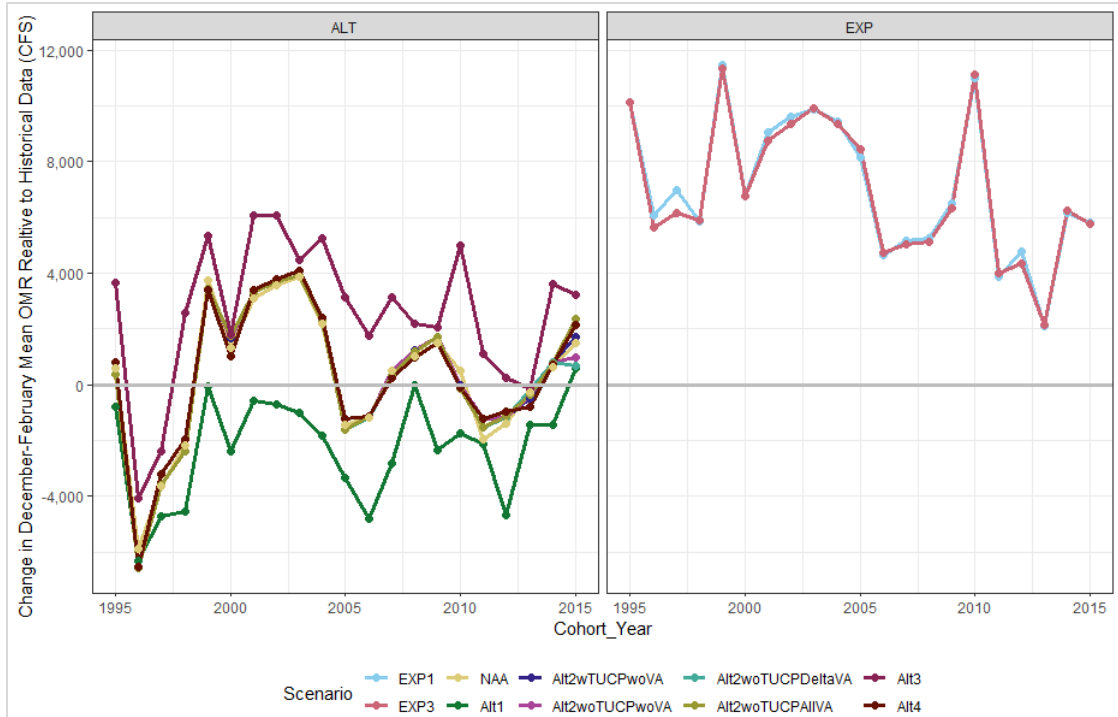


Figure F.1-1. Difference in December-February mean OMR relative to observed data used for model fitting.

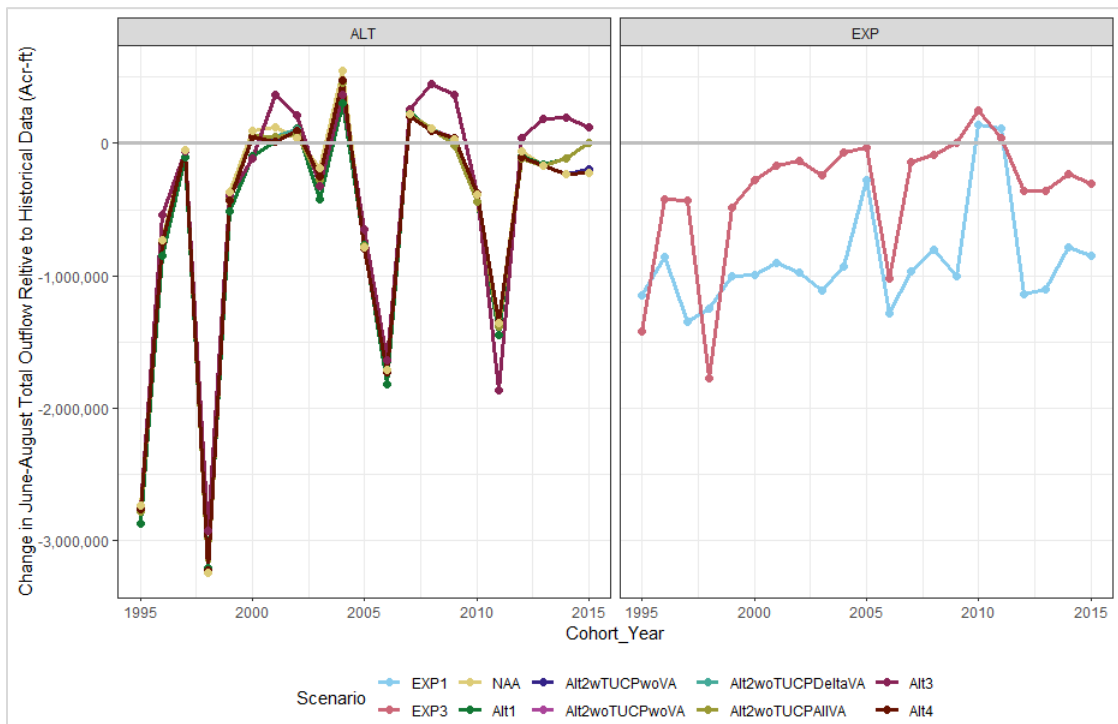


Figure F.1-2. Difference in June-August Total Outflow relative to observed data used for model fitting.



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 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,  $\lambda$ , did not exceed 1 (i.e. positive population growth) for any alternative, but did for both EXP scenarios (Table F.1-41). Projection with unmodified historical covariate values (i.e. the Base scenario) resulted in a geometric mean  $\lambda$  of 0.817 across the 20 modeled years and each of alternatives except for Alt3 ( $\lambda = 0.966$ ) resulted in lower geometric mean values ranging from 0.578 for Alt 1 to 0.75 for the Alt2 phases, Alt4 and NAA. In contrast, EXP1 and EXP3

projections resulted in, on average, positive population growth with geometric mean  $\lambda$  values of 1.380 and 1.524, respectively. Annual population growth rates were relatively low between 2000 and 2007, with brief periods in the late 1990s and around 2010 where positive population growth was projected for all scenarios (Figure F.1-3).

Predictably, delta smelt population performance was impacted by annual hydrologic conditions, with the geometric mean of  $\lambda$  higher during wet and above normal water years and lower during below normal and drier water years ( $\lambda = 0.633$  vs.  $\lambda = 0.905$  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 (Figure F.1-4, Table F.1-4). 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 (Figure F.1-5, Table F.1-5), with Alt3 producing a geometric mean  $\lambda > 1$  during this period. Similarly, only the EXP scenarios resulted in median annual population growth above 1 (i.e. a year-over-year increase in abundance was more common than a decline) while Alt3 resulted in about equal frequency of increasing and decreasing annual growth and all other scenarios resulted in declines in well over 50% of years (Figure F.1-6).

## F.1.6 Discussion

In interpreting the results of the MDR model projections it is important to note that all differences in population performance are being driven by only two variables: winter OMR and summer outflow. The EXP1, EXP3 and Alt3 scenarios likely produced higher  $\lambda$  due primarily to positive winter OMR flows during most years. The effect of summer outflow was likely minor relative to OMR, but relatively high June-August Delta Outflow during dry years (Figure F.1-1, Figure F.1-2) may have also contributed to better performance under Alt3. Conversely, the Alt1 scenario likely produced lower  $\lambda$  relative to most scenarios due to the more negative OMR flows during most months.

The original M&D model was designed as a tool for identifying important covariates of survival and recruitment at multiple life stages. An author of the original model has cautioned that application of the model to comparison of alternative management scenarios is beyond this original scope, and that the results should therefore be interpreted with caution. Important caveats include: 1) the assumption that temperature and turbidity would be insensitive to substantial differences in flow is likely to be violated, and it is unknown whether correlated changes in these other covariates would amplify or dampen the observed effect of outflow and OMR changes, 2) although inclusion of the covariates is statistically supported, their influence is simply correlational, and they may not fully reflect the mechanistic relationships between delta smelt population dynamics and the environment, and most critically, 3) there is substantial residual variation in all of the survival and recruitment transitions after accounting for covariate effects, and so the projections are inherently uncertain. As such, the relative performance of the alternatives and not the actual population growth rates should be given limited weight when interpreting projection results, and instead the relative performance of the alternatives should be emphasized.

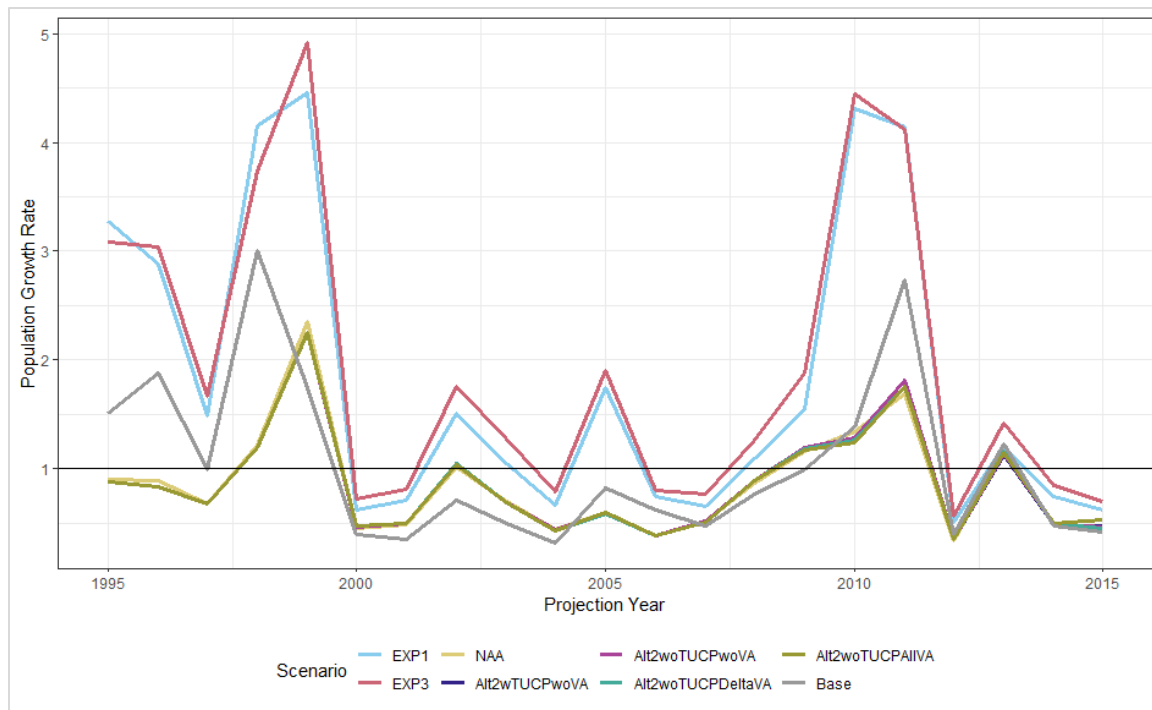


Figure F.1-3. Plot of projected annual population growth rates in EXP1, EXP3, NAA, and Alt2 Phases.



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

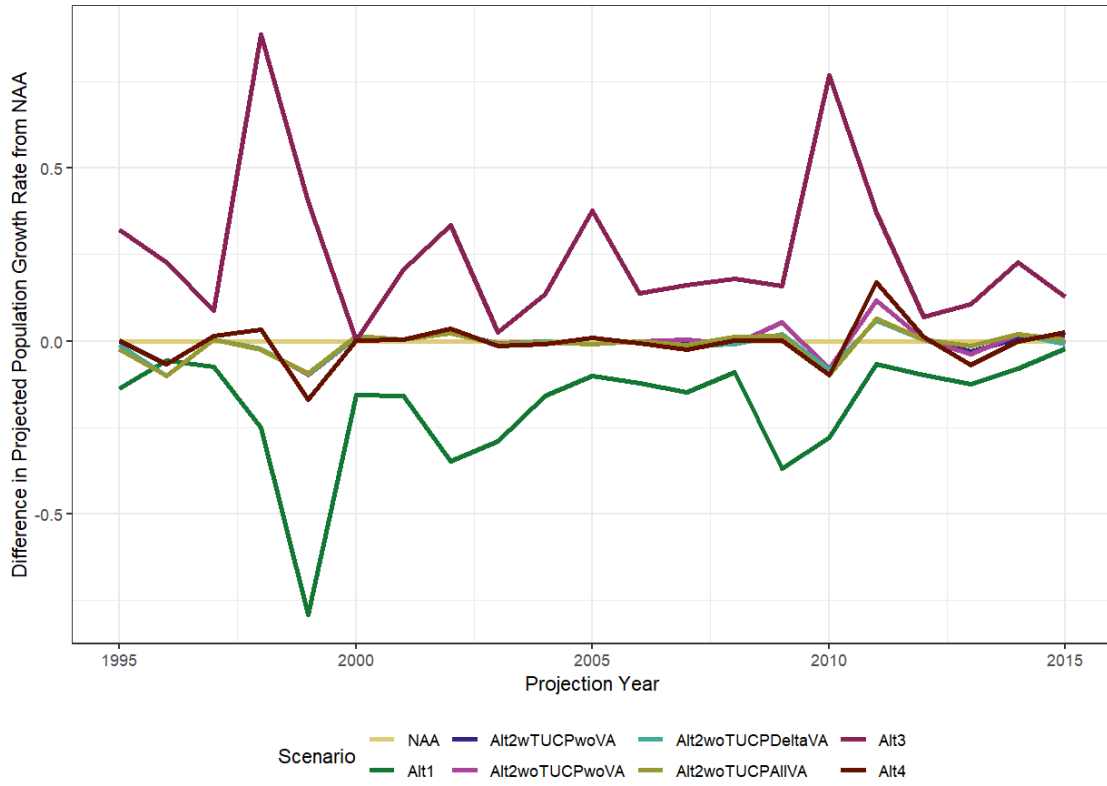


Figure F.1-5. Plot of difference in projected annual population growth rate from NAA.

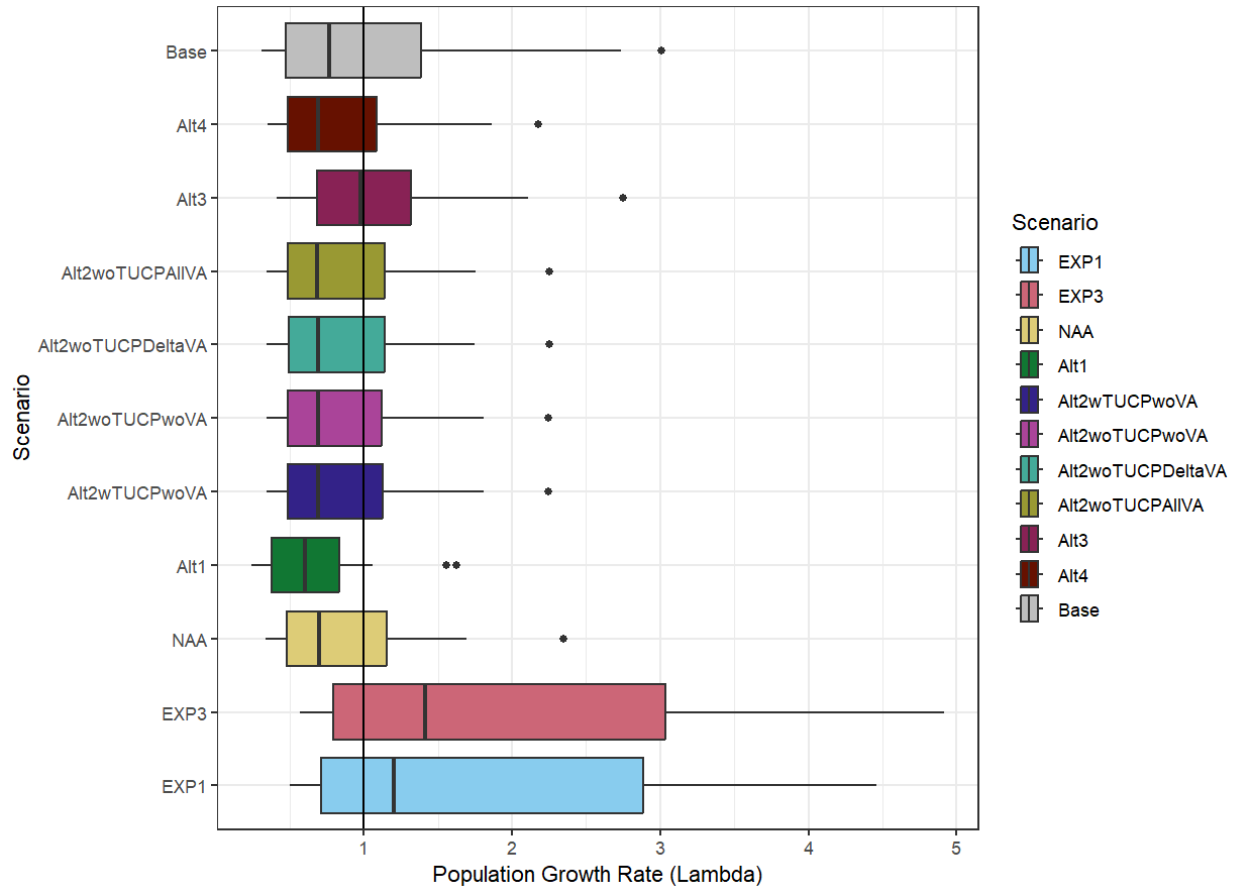


Figure F.1-6. Boxplots showing the complete distributions of annual population growth rates for all scenarios. Black lines show median values, boxes capture the interquartile range, whiskers capture the complete range apart from outliers (black points which are >1.5 times the interquartile range larger than the 75<sup>th</sup>%).

Table F.1-41. Estimates of annual population growth rates (lambda). Parenthetical values show percent change from the baseline projection.

Year	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2wTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllIVA
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)

Year	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2wTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
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)
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.1-52. Estimates of annual population growth rates (lambda). 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)	0.89 (-1)	0.87 (-3)	1.22 (36)	0.9 (0)	0.9 (0)
1996	0.84 (-6)	0.79 (-11)	0.79 (-11)	0.79 (-11)	0.79 (-11)	1.12 (25)	0.83 (-7)	0.89 (0)
1997	0.6 (-11)	0.68 (1)	0.68 (1)	0.68 (1)	0.68 (1)	0.76 (13)	0.69 (2)	0.68 (0)
1998	0.97 (-20)	1.2 (-2)	1.2 (-2)	1.2 (-2)	1.19 (-2)	2.1 (73)	1.25 (3)	1.22 (0)
1999	1.56 (-34)	2.25 (-4)	2.25 (-4)	2.25 (-4)	2.26 (-4)	2.75 (17)	2.18 (-7)	2.35 (0)
2000	0.3 (-34)	0.47 (2)	0.46 (2)	0.46 (2)	0.47 (3)	0.46 (1)	0.46 (0)	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)	0.68 (-2)	0.7 (0)
2004	0.28 (-36)	0.44 (0)	0.44 (0)	0.44 (0)	0.43 (-1)	0.57 (31)	0.43 (-2)	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)	0.37 (-2)	0.38 (0)
2007	0.38 (-28)	0.53 (1)	0.53 (1)	0.51 (-2)	0.51 (-2)	0.68 (31)	0.5 (-5)	0.52 (0)

Year	Alt1	Alt2 woTUCP woVA	Alt2 wTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4	NAA
2008	0.78 (-10)	0.86 (-1)	0.86 (-1)	0.86 (-1)	0.88 (1)	1.05 (21)	0.87 (0)	0.87 (0)
2009	0.79 (-32)	1.21 (5)	1.21 (5)	1.18 (2)	1.17 (1)	1.32 (14)	1.16 (0)	1.16 (0)
2010	1.06 (-21)	1.26 (-6)	1.26 (-6)	1.26 (-6)	1.24 (-7)	2.11 (57)	1.24 (-7)	1.34 (0)
2011	1.63 (-4)	1.81 (7)	1.81 (7)	1.75 (3)	1.76 (4)	2.06 (22)	1.86 (10)	1.69 (0)
2012	0.24 (-29)	0.35 (1)	0.35 (1)	0.35 (1)	0.35 (1)	0.41 (21)	0.35 (4)	0.34 (0)
2013	1.03 (-11)	1.13 (-2)	1.12 (-3)	1.14 (-1)	1.14 (-1)	1.26 (9)	1.09 (-6)	1.16 (0)
2014	0.4 (-17)	0.49 (2)	0.5 (4)	0.5 (4)	0.5 (4)	0.71 (47)	0.48 (0)	0.48 (0)
2015	0.44 (-5)	0.47 (2)	0.46 (-1)	0.45 (-2)	0.47 (1)	0.59 (27)	0.49 (5)	0.46 (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 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.1-7. 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 (-1)	0.75 (-1)	0.75 (-1)	0.97 (28)	0.75 (0)
1995-2004	0.8 (0)	0.58 (-27)	0.79 (-2)	0.79 (-2)	0.79 (-1)	0.79 (-2)	1.01 (26)	0.79 (-1)
2005-2015	0.71 (0)	0.58 (-19)	0.72 (1)	0.71 (0)	0.71 (0)	0.71 (0)	0.93 (31)	0.71 (0)



Grouping	NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
BN/Dry/Critical	0.71 (0)	0.58 (-18)	0.71 (1)	0.71 (1)	0.71 (0)	0.72 (1)	0.89 (26)	0.71 (0)
Above Normal/Wet	0.77 (0)	0.58 (-25)	0.76 (-1)	0.76 (-1)	0.76 (-1)	0.76 (-2)	1 (29)	0.77 (-1)
Critical	0.47 (0)	0.42 (-11)	0.48 (2)	0.48 (2)	0.48 (1)	0.48 (2)	0.65 (37)	0.48 (3)
Dry	0.87 (0)	0.68 (-22)	0.87 (0)	0.87 (0)	0.87 (0)	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 (-1)
Above Normal	0.52 (0)	0.32 (-37)	0.52 (0)	0.52 (0)	0.52 (0)	0.52 (0)	0.57 (11)	0.51 (-1)
Wet	1 (0)	0.82 (-18)	0.98 (-2)	0.98 (-2)	0.98 (-2)	0.98 (-2)	1.31 (31)	1 (0)

## F.1.7 References

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