Evaluation of factors impacting longfin smelt – summary analysis

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Introduction

Longfin smelt is of conservation concern because it is exposed to a variety of anthropogenic factors (e.g. habitat modification, sewage outflow, farm runoff, and water diversions) and survey data has shown a decline in abundance. Longfin smelt was listed as threatened under the California Endangered Species Act in 2009. In 2012, the United States Fish and Wildlife Service determined that listing the Bay-Delta population of longfin smelt under the Federal Endangered Species Act was "warranted, but precluded." However, the reason for the decline is not yet understood. A life cycle model was developed for longfin smelt to evaluate the influence of environmental covariates on survival and recruitment to provide information on the possible causes of the decline.

Methods

A life cycle model was developed for longfin smelt which contains dynamics for the spawning adult stage then subsequent juvenile stage followed by a pre-adult stage of late zero to early one year olds and finally an adult late age one to age two year olds. Two versions of the model were evaluated which differed in that the first version assumed only the adult stage were spawners and the second version added to the spawners both the pre-adults and adults. In the first version, 22 environmental covariates were evaluated for possible inclusion in the model; in the second version, an additional 14 covariates were added to the list (Table 1). Several of the covariates provided alternative measures of the same quantity; for example the second version contained 13 flow related factors. An alternative second version of the model was run on a smaller limited number of covariates but those largely measured different aspects of the environment. Factors evaluated in the alternative second version of the model are listed in Table 2.

A step-wise forward selection procedure was applied to the candidate covariates. After a covariate is selected by the step-wise procedure, it is included in the life-cycle model along with all previously chosen covariates and the AICc Akaike score is calculated. If the selected covariate improves the AICc, then that covariate is added to the list of chosen covariates. The process is repeated as long as the AICc is improved. After a tentative final model is identified, standard deviations and approximate 95%

confidence intervals are calculated for the coefficients of all covariates in the model. If the estimated 95% confidence interval for a coefficient overlaps the number 0 then we have tentative evidence that the particular covariate is not statistically significant. In that case another step is made to remove the questionable covariate and recalculate the AICc score. If the recalculated model has an improved AICc score then that model is the new final model.

Results

Of the 11 different model scenarios evaluated all final model configurations contained the factors flow, spring temperature, and prey; 10 of the 11 contained an ammonium factor; 6 of the 11 contained a predator factor; sechi depth occurs in 1 of the 11; and 4 of the 5 runs (second version only) contained presence of the overbite clam. The outflow threshold factors were among the poorest flow variables in terms of the final AICc scores. A complete list of the various model scenarios is given in Appendix 1 for the first model version and Appendix 2 for the second model version.

The various flow variables are highly correlated, and the two best ones in terms of Akaike scores included either Sacramento River runoff or Napa River flow which differed with their initial correlation to process error by less than 0.001. The Sacramento River runoff variable had the slightly higher correlation and therefore was chosen first by our selection criteria. However the final version 2 model AICc score was substantially better for the scenario that included Napa River flow. Further evaluation of the two flow variables with a smaller list of covariates continued to show that Napa River flow has a substantially improved Akaike score as seen in Appendix 3.

Table 1. Covariates evaluated for inclusion in the life cycle model for longfin smelt

Factor	Time	Stage	sign of coefficient
Mysid	July to September	Juveniles to pre-adult	positive
Mysid	May to June	Adult to Juveniles	positive
OMR	January to March	Adult to Juveniles	positive
X2	April to June	Adult to Juveniles	negative
Secchi	April to June	Adult to Juveniles	negative
Secchi	August to September	Juveniles to pre-adult	negative
Outflow	January to March	Adult to Juveniles	positive
Eury	April to May	Adult to Juveniles	positive
Napa R	Jan-Mar	Adult to Juveniles	positive
outflow threshold indicator at 34500 cfs	Mar-May	Adult to Juveniles	positive
outflow threshold indicator at 44500 cfs	Mar-May	Adult to Juveniles	positive
chinook salmon Chipps Island trawl	Apr-May	Adult to Juveniles	negative
predators central +San pablo	Annual	all stages	negative
predators suisun Bay	Jan-Mar	Adult to Juveniles	negative
predators suisun	Mar-Jul	Adult to Juveniles	negative
avg MWT temperature	January to March	Adult to Juveniles	negative
avg MWT temperature	April to June	Adult to Juveniles	negative
avg MWT temperature	July	Adult to Juveniles	negative
area weighted ammonium	April to June	Adult to Juveniles	negative
Central Bay ammonium	April to June	Adult to Juveniles	negative
San Pablo ammonium	April to June	Adult to Juveniles	negative
Suisun Bay ammonium	April to June	Adult to Juveniles	negative
Pseudodiaptomus	April to July	Adult to Juveniles	positive
Water Temperature where smelt occur	spring	Adult to Juveniles	negative
Secchi Depth where smelt occur	spring	Adult to Juveniles	negative
predators where smelt occur total 12 months	year round	all stages	negative
Metric Tons of Ammonium discharged Sacramento	April to June	Adult to Juveniles	negative
Sacramento River Inflow	April to June	Adult to Juveniles	positive
Ammonium/inflow	April to June	Adult to Juveniles	negative
Sacramento River Runoff	prev Oct to March	Adult to Juveniles	positive
Sacramento Runoff	April to June	Adult to Juveniles	positive

Sacramento Runoff	prev Oct to July	Adult to Juveniles	positive
Sacramento + San Joaquin Runoff	prev Oct to March	Adult to Juveniles	positive
Sacramento + San Joaquin Runoff	April to July	Adult to Juveniles	positive
Sacramento + San Joaquin Runoff	year round	all stages	positive
overbite clam presence	year round	all stages	negative

Table 2. Reduced set of covariates for model version 2 alternative

Factor	Time	Stage	sign of coefficient
Mysid	May to June	Adult to Juveniles	positive
Secchi depth	April to June	Adult to Juveniles	negative
Eurytemera	April to May	Adult to Juveniles	positive
Napa River flow	Jan-Mar	Adult to Juveniles	positive
Predators central +San Pablo	Annual	Adult to Juveniles	negative
Average temperature	April to June	Adult to Juveniles	negative
San Pablo ammonium	April to June	Adult to Juveniles	negative
Sacramento River runoff	prev Oct to July	Adult to Juveniles	positive
Overbite clam presence	year round	Adult to Juveniles	negative
Mysid	July to September	Juveniles to pre-adult	positive

Appendix 1. Results with model version 1 in which spawners are the adult stage (November-March) age 1 to age 2.

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		142.36	101	8	300.73	302.44
Outflow threshold 34500	A->J	100.02	102	9	218.03	220.20
San Pablo ammonium	A->J	93.68	103	10	207.35	210.03
Temp April-June	A->J	86.34	104	11	194.67	197.93
Mysid JS	J->PA	78.76	105	12	181.53	185.43
napa	A->J	72.27	106	13	170.54	175.15
predator C+SP	J->PA	70.63	107	14	169.26	174.65
predator C+SP	A->J	69.23	108	15	168.46	174.70
predator C+SP	PA->A	68.46	109	16	168.92	176.08
no Outflow		70.35	107	14	168.70	174.08
no Outflow no pred J		71.45	106	13	168.90	173.51

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		142.36	101	8	300.73	302.44
X2	A->J	101.41	102	9	220.83	223.00
San Pablo ammonium	A->J	92.73	103	10	205.47	208.15
Mysid JS	J->PA	86.38	104	11	194.76	198.02
Temp April-June	A->J	79.64	105	12	183.28	187.18
predator C+SP	A->J	76.76	106	13	179.52	184.13
predator C+SP	J->PA	75.40	107	14	178.81	184.19
predator C+SP	PA->A	74.50	108	15	178.99	185.23

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		142.36	101	8	300.73	302.44
Napa	A->J	106.99	102	9	231.97	234.14
San Pablo ammonium	A->J	93.48	103	10	206.95	209.64
Temp April-June	A->J	84.07	104	11	190.13	193.39
Mysid JS	J->PA	76.72	105	12	177.44	181.34
predator C+SP	A->J	71.45	106	13	168.90	173.51
predator C+SP	J->PA	70.35	107	14	168.70	174.08
predator C+SP	PA->A	69.52	108	15	169.03	175.26

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		142.36	101	8	300.73	302.44
Suisun Bay ammonium	A->J	113.81	102	9	245.63	247.80
Temp April-June	A->J	101.39	103	10	222.79	225.47
Mysid JS	J->PA	98.79	104	11	219.58	222.84
Eury	A->J	91.45	105	12	206.90	210.80
predator C+SP	J->PA	90.50	106	13	207.00	211.61

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		142.36	101	8	300.73	302.44
ave ammonium	A->J	94.92	102	9	207.83	210.00
Temp April-June	A->J	87.97	103	10	195.94	198.62
Mysid JS	J->PA	80.59	104	11	183.19	186.45
napa	A->J	75.97	105	12	175.93	179.83
predator C+SP	J->PA	74.42	106	13	174.85	179.46
predator C+SP	PA->A	73.67	107	14	175.34	180.73

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		142.36	101	8	300.73	302.44
Outflow threshold 44500	A->J	112.37	102	9	242.74	244.91
San Pablo ammonium	A->J	102.36	103	10	224.73	227.41
Temp April-June	A->J	95.89	104	11	213.78	217.03
Mysid JS	J->PA	91.59	105	12	207.19	211.09
predator C+SP	PA->A	90.75	106	13	207.49	212.10

Appendix 2. Results of model version 2 in which both pre-adults (October-March) age 0 to age 1 and adults (November-March) age 1 to age 2 smelt are equally weighted in the model as spawners.

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
Sac Runoff Oct previous year thru June of current year	A->J	108.27	102	9	234.54	236.71
San Pablo ammonium	A->J	97.45	103	10	214.90	217.58
Mysid J-S	J->PA	91.16	104	11	204.33	207.59
Temp A-J	A->J	84.05	105	12	192.11	196.01
pred SP	J->PA	81.84	106	13	189.69	194.29
sac+SJ runoff	PA->A	80.98	107	14	189.96	195.34
with napa		81.34335		13	188.69	193.29

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
X2	A->J	143.23	102	9	304.45	306.62
spr temp	A->J	131.47	103	10	282.94	285.62
SP amm	A->J	119.23	104	11	260.46	263.72
Xsechhi S	A->J	102.00	105	12	227.99	231.89
clam	J->PA	94.90	106	13	215.81	220.42
Mysid	J->PA	91.65	107	14	211.31	216.69
Eury	A->J	83.77	108	15	197.53	203.77
tot Sav+SJ runnoff	PA->A	82.92	109	16	197.84	204.99
			107	14	28.00	33.38
			106	13	26.00	30.61

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
Napa	A->J	115.17	102	9	248.33	250.50
SP amm	A->J	103.07	103	10	226.14	228.82
S temp	A->J	90.23	104	11	202.46	205.72
Mysid	J->PA	82.51	105	12	189.01	192.91
mt Amm	A->J	77.54	106	13	181.07	185.68
clam	J->PA	75.44	107	14	178.89	184.27
Temp JM	A->J	73.40	108	15	176.80	183.03
tot Sav+SJ runnoff	PA->A	72.44	109	16	176.88	184.04
No Temp JM		75.44	107	14	178.89	184.27
no clam		75.43	107	14	178.86	184.24

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
Outflow 34500	A->J	120.69	102	9	259.37	261.54
Clam	A->J	108.04	103	10	236.07	238.75
Temp JM	A->J	101.48	104	11	224.97	228.23
Mysid	J->PA	96.03	105	12	216.05	219.95
CB Amm	A->J	92.42	106	13	210.84	215.44
clam	J->PA	89.99	107	14	207.99	213.37
tot Sav+SJ runnoff	PA->A	88.99	108	15	207.99	214.22

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
Outflow 44500	A->J	127.07	102	9	272.14	274.30
Clam	A->J	113.80	103	10	247.60	250.28
Temp S	A->J	109.46	104	11	240.92	244.18
SP amm	A->J	106.24	105	12	236.49	240.39
runoff S-SJ	PA->A	105.04	106	13	236.08	240.69
Mysid	J->PA	103.24	107	14	234.47	239.86
Apr-Jun Ammon/inflow	A->J	100.55	108	15	231.10	237.33
Temp JM	A->J	98.64604	109	16	229.29	236.45
predator central +San pablo	J->PA	98.24475	110	17	230.49	238.65
without runoff S-SJ	PA->A	99.83023	108	15	229.66	235.89
without Temp JM	A->J	101.6932	107	14	231.39	236.77

Appendix 3. Comparison of results for model version 2 on a reduced set of covariates for the two flow variables Sacramento runoff and Napa River flow.

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
Sac Runoff Oct previous year thru June of current year	A->J	108.27	102	9	234.54	236.71
San Pablo ammonium	A->J	97.45	103	10	214.90	217.58
Mysid J-S	J->PA	91.16	104	11	204.33	207.59
Temp A-J	A->J	84.05	105	12	192.11	196.01
pred SP	J->PA	81.84	106	13	189.69	194.29
pred SP	PA->A	81.07	107	14	190.13	195.52

Additional factor	Stage	nlnL	Pars	Real Pars	AIC	AICc
None		157.67	101	8	331.34	333.06
napa	A->J	115.17	102	9	248.33	250.50
San Pablo ammonium	A->J	103.07	103	10	226.14	228.82
Temp A-J	A->J	91.81	104	11	205.61	208.87
Mysid J-S	J->PA	84.23	105	12	192.45	196.35
pred SP	A->J	79.95	106	13	185.90	190.50
pred SP	J->PA	78.51	107	14	185.02	190.40
Eury	A->J	76.04	108	15	182.08	188.32