A User's Guide to the VRAP Model

- Viability and Risk Assessment Procedure

Norma Jean Sands

NWFSC

June 30, 2012

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Introduction

The Viability and Risk Assessment Procedure (VRAP) model was adapted from the Risk Assessment Procedure (RAP) original developed by Jim Scott[1] (WDFW) and Bob Hayman (Skagit Coop) in the 1990's. The original purpose of the model was to assess the impact of various harvest rates on salmon populations based on the variance in returns and in management precision, including a harvest rate scale based on size of the returns. The model was based on the assumption of density dependence in recruits per spawner and introduced stochasticity in the estimates with variance estimates around the fit of the data to the predicted spawner-recruit curve and in management error. The model has since been expanded to assess the level of productivity and capacity (the two parameters of density dependent spawner recruit functions) needed to sustain a viable population given a level of desired harvest and the estimated variance in returns and management precision.

Population viability is a measure of survival based on abundance, productivity, and/or other conditions that give a population a low risk of extinction over some defined period of time. The population viability criteria used by NOAA in evaluating salmon recovery describe the number, productivity, spatial structure and diversity[2] required for a naturally self-sustaining population to have either a 0.95 or 0.99 probability of persistence over a 100 year time period (is there a NOAA reference for this?).

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[1] Jim Scott was with NOAA Fisheries Western Regional Office when he worked on the RAP model.

[2] The four viability parameters described by McElhany et al. (2000?) for salmonid populations.

The Viability and Risk Assessment Procedure (VRAP) model is a stochastic simulation model written in Visual Basic. VRAP was developed to address the complex life history of Chinook salmon, returning to spawn at multiple ages and being susceptible to fisheries in multiple years. The model may be used to assess various harvest rates given a spawner-recruit function or to determine the parameters of a spawner-recruit function that would satisfy the viability assumption given a desired harvest rate.

The VRAP allows one to choose among the Hockey stick, Ricker, or Beverton-Holt spawner recruit functions to determine the production from spawning escapement. Harvest schemes are then applied to estimate progeny spawners based on cohort analysis. Uncertainty may be introduced at several levels in the analysis. The variance of estimated recruits (based on observed data of escapement and catch) around the spawner recruit curve is used to stochastically determine recruits. In addition, patterns and random variability due to environmental conditions may be introduced by way of two covariates to the analysis. Also, error in achieving a targeted harvest rate may also be introduced.

VRAP uses risk assessment analysis to look at viability status and/or effects of various harvest rates on viability/rebuilding of salmon based on predicted returns from the number of spawners using density dependent spawner-recruit functions and estimated error around the estimates.

VRAP's two modes of operation are:

- Harvest mode to determine RERs: given a spawner recruit function with fit parameters, what is the highest level of harvest that still allows rebuilding of the population, given set risk assumptions, and

- Population mode to determine viability abundance and productivity: given a fixed harvest rate, what spawner recruit parameters (productivity and capacity) are needed to guarantee viability, given set risk levels.

Spawner Recruit Functions

VRAP projects recruits and spawners over a period of years based on a spawner-recruit relationship chosen from Ricker (Ricker 1975), Beverton-Holt (Ricker 1975), and hockey stock (Barrowman and Meyers 2000) functions.

Equations for the three functions are as follows:

$$R = (aSe^{-bS})(M^{c}e^{dF}) \qquad \text{[Ricker]}$$

$$R = (S/[bS + a])(M^{c}e^{dF}) \qquad \text{[Beverton-Holt]}$$

$$R = (\min[aS, b])(M^{c}e^{dF}) \qquad \text{[Hockey stick]}$$

In the above, R is recruits, S is spawners, M is the index of the marine survival correlate and F is the index of the freshwater correlate. There are four function parameters: a is the spawner recruit parameter related to productivity, b is the spawner recruit parameter related to capacity, c is the covariate parameter related to marine survival, and d is the covariate parameter related to freshwater survival. Prior to the influence of the survival covariates the spawner-recruit parameters a and b are as follows:

- For the Ricker function, a is the intrinsic productivity (slope of the curve at the origin) and b is the inverse of the spawner level at maximum recruits.
- For the Beverton-Holt function, a is the inverse of the intrinsic productivity and b is the inverse of the maximum (asymptotic) number of recruits.
- For the Hockey stick function, a is the intrinsic productivity and b is the maximum recruits.

The introduction of the covariates changes the actual productivity and capacity as reflected by the parameters a and b. For a given time period, the adjusted intrinsic productivity would be the base intrinsic productivity time the average survival factor [M^cexp(-dF)] over that time period.

In this application, the Ricker curve is modified in three ways. First, depensation (D) is added to reflect reduced productivity at very low spawner abundance. Second, environmental variation is incorporated in the form of a time-varying index of marine survival (M).

Procedure

VRAP is written in Visual basic and may be run from the Visual Basic software program. It has also been transformed into an executable file (RapViability.exe) and may be run directly from that version; one then needs an ascii input file ready to use. Or VRAP may be run from an prepared Excel file (vrap22*.xls) where the Input is given in a worksheet called Input and macros provided with the Excel file may be used to run the program and to load and delete output sheets. The * in the file name may be filled in as the population name for the runs being made, or as any identification label.

The Excel program will produce ascii input files and the Vrap program will produce ascii output files. The output files can be brought into the Excel file as separate worksheets by using the appropriate macro. The macros are accessed by "buttons" on the Input sheet. One must identify the path to the subdirectory where the RapViability.exe file is found; this is done in cell I2.

Since the ascii files produced and used are comma delimited files, there must be no commas in any of the text input (such as run name). Semicolons may be used instead.

Input

The input, using the Excel file format, is contained in the cells A1 to E51 of the Input sheet. Column E contains the identification name of the input for each row. Columns A to D are for actual input data (numbers or text). An example of the input is given in Table 1.

Table 1. Example of the input used for VRAP with columns and rows indicated. The input title is in cell A1 with B1-D1 being blank.

	A	B	C	D	E
1	Nisqually Chinook Esc:1980-2001; FR: CTC_HRJ_NIS_f_0707; depensation-no;				Title
2	0				Random seed; 0 gives random seed; numbers give fixed seed
3	3000				Number of runs
4	25				Number of years
5	2	5			Minimum and maximum age (for now this is fixed; do not change)
6	0.001				Convergence criterion (% error) for target ER
7	NO				Debug file flag
8	Hoc4				Spawner Recruit function (Ric2;Ric3;Ric4; Bev2;Bev3;Bev4; Hoc2;Hoc3;Hoc4)
9	83.0646	6665	0.1958	-0.000349	S/R a; b parameters; c (Marine); d (Freshwater)
10	1.3026	1.1766			Mean and CV for marine survival index (M^c)
11	Autoc				Trend; Cycle; or Autoc(orrelation) ?
12	0.29	0.62	0.00		Trend/Cycle parameters: rate for trend-amplitude- period & starting pt for cycle; correl for autocorrelation
13	1529	0.4			Mean and CV for flow (or other fw) index (exp(dF))
14	Autoc				Trend; Cycle; or Autoc(orrelation) ?
15	0.37	1499	0.00		Trend/Cycle parameters: rate for trend-amplitude- period & starting pt for cycle; correl for autocorrelation
16	NO				Depensation? ("YES" or "NO")
17	80	63	1		1) Esc. level for depensation to start 2) QET 3)% predicted return at QET (or for r/s=1 third parameter = 1)
18	YES				Determine recruits from adult spawners (not total)?
19	YES				Stock-recruit variation ("YES" or "NO")
20	0	2.779	-0.119		A and B parameters S/R error and error autocorrelation
21	NO				Smolt to adult survival w/variation ("YES" or "NO")
22					Beta distribution a and b parameters and autocorrelation
23	0				Number of breakpoints
24	1				Level to use as base regime
25	0.68				base exploitation rate

26	YES				Include error ("YES" or "NO") in ER management
27	65.395	0.016			Gamma parameters for management error
28	85				Lower escapement threshold
29	719	5			Upper escapement threshold (MSY); # yrs to ave.
30	ER				Step ER (ER) or Pop Capacity (Pop)?
31	0.01				Buffer step size as percent of base ER or Pop capacity
32	0.00	1.45			Min & max buffer (x base for start & end)
33	16704				Initial population size at Age 1 of start year (prior to nat mort)
34	8352				Initial population size at Age 2
35	4744				Initial population size at Age 3
36	2433				Initial population size at Age 4
37	223				Initial population size at Age 5
38	0.5				Age 1 natural mortality
39	0.4				Age 2 natural mortality
40	0.3				Age 3 natural mortality
41	0.2				Age 4 natural mortality
42	0.1				Age 5 natural mortality
43	0.0081				Age 2 average maturation rate
44	0.2709				Age 3 average maturation rate
45	0.7657				Age 4 average maturation rate
46	1.0000				Age 5 average maturation rate
47	0.0848	0.3124			Age 2 average mixed-maturity and mature fishery fishing rates
48	0.2127	0.5941			Age 3 average mixed-maturity and mature fishery fishing rates
49	0.3630	0.5525			Age 4 average mixed-maturity and mature fishery fishing rates
50	0.3952	0.3625			Age 5 average mixed-maturity and mature fishery fishing rates
51	endofinput				end of input indicator

An explanation of input by row (see Table 1) follows.

1) Title for the runs; this can provide information about the population and input data used.

2) Random seed used to start the randomization used at various places within the program to produce random error; if 0 is given as input, the seed is random; if a number is used a fixed seed is used, which is useful when wanting to keep the error constant in comparing runs (used primarily in testing code).

3) Number of runs is the number of simulations done; often 1000 is used. Results are averaged over all simulations.

4) Number of years is the number of years used in producing cohorts; 100 is often used for viability runs and 25 is often used for estimating rebuilding exploitation rates.

5) Minimum and maximum age; for now this is fixed and must be 2 in cell A5 and 5 in cell B5. The next version of VRAP will be able to accept different ranges of years.

6) Convergence criterion for target ER, 0.001 is a convenient level to use. When targeting a specific exploitation rate (ER) the program must supply estimates of harvest rate each age class within each fishery; the program does repeated calculations until the resulting ER matches the targeted ER based on this convergence criterion.

7) Debug file flag. For normal runs this is set to NO; it is used in code development.

8) Spawner Recruit function; this may be Ric2, Ric3, Ric4, Bev2, Bev3, Bev4, Hoc2, Hoc3, or Hoc4 referring to the Ricker (Ric), Beverton-Holt (Bev), or Hockey-stick (Hoc) model and 2, 3, and 4 referring to the number of parameters. Two parameters include only the two spawner recruit parameters (a and b); three parameters includes the ???; and four parameters includes both the

marine and freshwater covariate parameters (c and d).

9) Estimate of model parameters (including mean and coefficient of variation) and error terms for model fit

10) Quasi-extinction threshold (QET) = 250 fish/generation

11) Depensation, set with the following rules:

    a. If lowest observed escapement is greater than the QET, depensation is set to 10 plus the annual QET (63 for Chinook salmon, 83 for coho salmon)

    b. If the lowest observed escapement is greater than the QET, then depensation is equal to the rounded spawner abundance with the highest spawner/recruit return that is near the origin of a graph of spawners vs. recruits

12) Natural mortality, assigned as follows

    a. Chinook salmon: age 1=50%, age 2=40%, age 3=30%, age 4=20%, age 5=10%, age 6=0%.

    b. Coho salmon: age 1=50%, age 2=40%, age 3=30%

13) Harvest rate = average harvest rate over the last 5 years

14) Initial population size at each age = three-year average of abundance at each age prior to natural mortality

15) Average maturation rate at each age, estimated by the model from age structure data

16) Management error = deviation of actual exploitation rates to target exploitation rates

Harvest rate numbers are used to distribute the target exploitation rates among ages and fisheries. For coho salmon, we assumed that all individuals matured at age 3 and all harvest was taken by a terminal fishery. We assumed that all harvest on Interior Columbia ESU Chinook salmon is also taken by a terminal fishery. Data on harvest rates in each fishery for Puget Sound and Lower Columbia ESU Chinook salmon were taken from prior analyses of these populations conducted by N. J. Sands for harvest management purposes. We could not run the VRAP model for the two Lower Columbia Spring Chinook salmon populations included in this analysis because of a lack of age-specific fishery data.

Uncertainty is introduced into the model using process error (derived from deviations of observed data to recruits predicted from the spawner-recruit function), management error (deviation of actual exploitation rates to target exploitation rates), and variation in the covariates expressed as autocorrelation, trend, or cyclic variation. As we did not have management error information for all ESUs, we used management error data from Puget Sound for all populations (gamma parameters = 65.395, 0.016).

The simulation process of VRAP starts with the initial age-specific population size given as input, first applies the age-specific natural mortality, and then determines ocean fishing mortality, the terminal run size (based on maturation rates), the terminal fishing mortality, and the resulting escapement by age. Fish that do not mature remain in the ocean for another year, are aged one year, and constitute the ocean standing stock in the next year. Annual escapement is used to determine the adult equivalent recruits from the spawner recruit function. Adult equivalent recruits are then divided by an age-1 factor to get the age 1 cohort size. The recruit factor (rf) is derived from natural survival (S= 1- natural mortality) and maturation rates (MR) by age as:

$$rf = \sum_{a=2}^{5} [\prod_{i=1}^{a} S_i] [\prod_{i=1}^{a-1} (1 - MR_i)] MR_a$$

Year data are saved, and the new year's cohort is run through the fisheries and escapement determinations. Each simulation was run for 100 years with 3,000 iterations. Extinction risk for a population was calculated as the proportion of trajectories that fall below the QET over the 100 year simulations.

Output

Examples of Uses

Estimating the Rebuilding Exploitation Rate using VRAP Klamath Falls: VRAP estimates the highest ER that one should use to obtain the target escapement (MSY escapement in this case) at least 80% of the time. No covariates were used such that the variability in recruits was maximum (not explained by any environmental covariate). However, it is also assumed that survival is stable (no trend). For the spawner-recruit model based on minimizing the error in predicting recruitment, the RER was 0.60 to obtain an escapement level of 32000 at least 80% of the time (ref?).

Estimating the Risk of Extinction Klamath Falls: VRAP was used in the Pop mode to determine how quickly the population was predicted to go to extinction under various exploitation rates given that the survival trend can be explained by a decreasing cycle. Depensation was used starting at escapements of 1100 and less as no escapements have been observed less than 1100 and we do not know how the population behaves at these low levels. Extinction was set at 850; at this level of spawners there is no return (ref?).

Discussion

Density dependent spawner recruit functions are more robust to maintaining a population due to the increased productivity at low spawning levels. They also introduce a upper limit or capacity to the return abundance, such that the population cannot increase infinitum. Since PVA projects the population into the future based on assumed harvest rates and/or environmental conditions, the number of spawners will easily go outside the range of observed spawners. How we model the return from these "extreme" abundances will make a significant difference in our assessment of viability.

At the low end, we do place limits on productivity of spawners less than the quasi-extinction threshold (QET). It is assumed that production from spawners less than QET are compromised genetically and will lead to extinction of the species. QET is determined based on genetic implications, the quantity of special distribution, and the average age of returns. (see Chum paper)

At spawning levels greater than the maximum abundance in the observed data, the return can be asymptotically leveled out as in the Beverton-Holt and Hockey Stick curves, or it can decrease as in the Ricker curve.

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