# Spawner-Recruit Analysis of Skeena River Sockeye and Icelandic herring

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# Abstract

In this assignment, we fit the both the Beverton-Holt and Ricker spawner-recruit curves to Skeena River sockeye data and the Beverton-Holt curve to Icelandic herring data. For the Beverton-Holt curve, I found that the total negative log likelihood estimate (29.43) was minimized when = 3,671.0, = 1,001.3, and = 0.47 for the Skeena sockeye data and that the total negative log likelihood estimate (37.72) was minimized when = 309.0, = 28.5, and = 0.89 for the Icelandic herring data. Using the Ricker curve, I established that the total negative log likelihood estimate (29.22) was minimized when = 1.2, = 1,922.8, and = 0.46 for the Skeena sockeye data. Using the parameters from the Skeena sockeye Beverton-Holt curve, I determined that the steepness for this fishery is 0.48, indicating that the population is fairly sensitive to fishing pressure. Because the total negative log likelihood for both curves were very similar for the Skeena data, I used the AIC to determine which model fit the data best. The Ricker curve had a slightly lower AIC value and was determined as the best model to fit the data. Likelihood profiles on the parameters a and b for the Ricker curve showed that the model is not overly sensitive to variation in these parameters. Finally, using the relationship that the average sustainable yield of the fishery is equal to the difference between recruits and spawners, I was able to determine that the maximum average sustained yield occurred near a spawning stock size of 800 and produced a sustained yield near 843.

# Introduction

One of the classic fisheries datasets used to describe the relationship between spawners and recruitment is from the Skeena River sockeye data. (note: some of you may have seen this before). Two possible stock-recruit curves exist for this time series: the Beverton-Holt, and Ricker curves. The important difference between these two curves is that at high levels of spawners, the number of recruits in the Beverton-Holt model reaches an asymptote, while in the Ricker model, the number of recruits may start to decline at higher number of spawners.

The purpose of this paper is to evaluate the spawner-recruit relationship for two fisheries data sets. We will fit both curves to the Skeena River data (Skeena.xls), and the Beverton Holt curve to the Icelandic Herring data. For the Skeena River data we will use AIC to compare model fits.

# Materials and Methods

1. The first objective is to fit the Beverton-Holt model to both data sets (45 pts). Find the best Beverton-Holt fit using the equation  to the data in the files SKEENA.XLS and ICESUM.XLS. Assume that the only type of error we are modeling is process error, and that the process error is multiplicative:

We have a deterministic prediction



Because we assume no observation error, the difference between what is observed and what was predicted without process error is the process error



The ‘w’ term in each year is assumed to be i.i.d. (independent and identically distributed) ~ Normal (0, σ). For this assignment, give the estimated values of each of the parameters (MLEs), a, b and σ as well as the estimate of the total negative log likelihood. Plot the spawner recruit curve showing the data (as points) and the best fit line. Note that this form of the Beverton Holt curve is algebraically different from that used in the last homework, but the curve has the same shape. Calculate the steepness at the maximum likelihood fit for parameters a and b for the Skeena data only. To do this you will need to recognize that the unfished recruitment (R0 in last weeks notation) is the value of recruitment when the predicted recruits is equal to the predicted spawners. The unfished stock size is the same, the number of spawners when the number of spawners equals the number of recruits. The ratio between R0 and the recruitment at 20% of the unfished stock size will be the steepness.

2. The second objective is to fit the Ricker curve, R = S \* exp(a\*(1-S/b)), to the Skeena River data only (not to the Icelandic Herring data set) (40 pts). Assume the same error distribution as above.

First, give the MLEs for a, b, σ, as well as the total negative log likelihood. Second, compare the Beverton Holt fit to the Ricker using the AIC, which model is preferred? Third, modify your spreadsheet to incorporate the analytic formula for σ that we’ve been using in previous homeworks and labs. Show a contour plot giving the likelihood (scaled to the maximum of 1.0) against the parameters a and b. Graph the likelihood profiles for the parameters a and b individually. Use the following values for the parameters, providing both a table of the results (well formatted in scaled likelihoods) and plots. This can be done with a TABLE function in EXCEL.

a. For parameter a go from .2 to 2.0 in steps of 0.05.

1. For parameter b go from 1000 to 8000 in steps of 200
2. The spawner recruit relationship is the dominant factor in determining the escapement goals for Pacific salmon. The sustained yield at spawning stock size is the expected recruitment less the spawning stock.

Yield = R – S

Using your results in parts 1 and 2 for the Skeena river sockeye salmon, discuss what spawning stock size would produce the highest average catch (if you want full credit, it would probably be best to give a numerical answer as well).

3. The third part of the assignment is to differentiate between observation and process error in your own research (15 pts) or in some real world problem you are aware of. Very briefly (e.g. 1-2 sentences) describe what type of data are being collected. Then describe 1 type of observation error and 1 type of process error that may be present in the data. Feel free to use separate data sets for each type of error, or if you have no data, describe hypothetical scenarios.

# Results

Using the Beverton-Holt spawner-recruit relationship on the Skeena River sockeye salmon data, it was found that the total negative log likelihood estimate (29.43) was minimized when = 3,671.0, = 1,001.3, and = 0.47 (Table 1). In addition, using the Beverton-Holt relationship on the Icelandic Herring data, it was found that the total negative log likelihood estimate (37.72) was minimized when = 309.0, = 28.5, and = 0.89 (Table 1). The Beverton-Holt spawner-recruit curves and the observed recruit data for the Skeena River sockeye and Icelandic herring are shown in Figures 1 and 2, respectively.

Table 1. Estimated parameter values (a,b, and ) and the total negative log likelihood for the best Beverton-Holt fit using the equation for both the Skeena River sockeye and Icelandic herring data.



Using these parameters and the equation , I set the unfished recruitment RO equal to unfished stock size SO and algebraically solved for S to find the relationship

Using the estimated best fit parameter values from Table 1, I found that

This is the value of recruitment at which the predicted recruits is equal to the predicted spawners. Next, 20% of SO (534) was used to calculate the recruitment using the equation for the Beverton-Holt curve to yield a recruitment at 20% of the virgin spawning stock of 1,277. To calculate steepness, I found the ratio between RO and the recruitment at 20% of the unfished stock size to yield a value of 0.48.

Next, using the Ricker spawner-recruit relationship (R = S \* exp(a\*(1-S/b))) on the Skeena River sockeye salmon data, I found that the total negative log likelihood estimate (29.22) was minimized when = 1.2, = 1,922.8, and = 0.46 (Table 2).



Figure 1. Best fit Beverton-Holt () and Ricker (R = S \* exp(a\*(1-S/b))) spawner-recruit curves with observed recruit values for the Skeena River sockeye salmon data. Parameters for the best fit curves are shown in Table 2.



Figure 2. Best fit Beverton-Holt () spawner-recruit curve with observed recruit values for the Icelandic herring data. Parameters for the best fit curves are shown in Table 1.

Because both the Beverton-Holt and Ricker models had similar values for their total negative log likelihoods (Table 2), the models were compared using the Akaike Information Criterion (AIC) according to the equation

Where is the log likelihood, Y is the data, Mi is the model I, and pi is the number of parameters. Estimated parameter values (a,b, and ), maximum likelihood estimations, total negative log likelihoods, and AIC values for the best Beverton-Holt and Ricker spawner-recruit fits are shown in Table 2.

Table 2. Estimated parameter values (a,b, and ), maximum likelihood estimation, and the total negative log likelihood for the best Beverton-Holt and Ricker spawner-recruit fits for the Skeena River sockeye data.



Using the AIC as a means to compare models, I was able to show that the Ricker spawner-recruitment model does a slightly better job of fitting the data (Table 2). The Ricker model had an AIC value of 64.44, while the Beverton-Holt model had a slightly higher AIC of 54.87.

The contour plot showing relative likelihood profiles for the parameters a and b for the Beverton-Hold stock-recruitment model fit to the Skeen River sockeye salmon data demonstrated that the model is not overly sensitive to variations in the parameters a and b (Figure 3). Further, likelihood profiles for the parameters showed that likelihood estimates were maximized for the parameter *a* in the range of 1.0-1.5 (Figure 4) and for parameter *b* in the range of 1,400-4,000 (Figure 5). Examining the likelihood profiles, it appears that the Ricker model is not overly sensitive to changes in either of these parameters.

Finally, I determined the spawning stock size that would produce the highest average catch using the relationship

Yield = R – S

To determine this, I simply calculated the difference between the predicted recruits and spawners over a large range of spawner values and found where this difference was maximized. I determined that this occurred near a spawning stock size of 800 and produced a sustained yield near 843.

# Discussion

Here, I will discuss only the results from the Skeena River sockeye data. Fitting the Beverton-Holt and Ricker spawner-recruitment models to the data proved to be an informative exercise in estimating the spawning stock size necessary to maintain the highest average fishery yield. After fitting both of the models to the data, one of the first steps I took was to calculate the steepness of the fishery using the parameters from the Beverton-Holt curve. I determined that the steepness of the Skeena sockeye population is 0.48. This implies that this population is fairly sensitive to fishing pressure (i.e. 1 = not sensitive, 0.2 = extremely sensitive).

After fitting both models to the data, both the Beverton-Holt and the Ricker curves had very similar total negative log likelihoods. As a result, I used the AIC to compare the models. The AIC values were also similar, but it turned out that the Ricker curve provided a slightly better fit to the data. Therefore, the Ricker curve was used for all further analyses. The next stage was to test the sensitivity of the Ricker model to variations in the a and b parameters. Examining the contour plot of the parameters a and b, it appears that the model was not overly sensitive to varying values of the parameters. There were no really long ridges along the contour plot and a fairly narrow range of both parameters that provided high relative likelihoods. The individual likelihood profiles for both a and b corroborated this finding. Both profiles had fairly distinct peaks and no extremely broad tails.

Finally, using the relationship that sustained yield is equal to the difference between recruits and spawners, I was able to determine that the long-term sustainable yield of the fishery is near 843 and that this occurs near a spawning stock size of 800. This proved to be a fairly informative exercise with management implications.

Salmon redd counts are commonly used by various agencies throughout the Pacific Northwest as an index of spawner abundance. Personnel simply walk along streams, or in some cases fly above in helicopters, and count the number salmon redds in a stream reach. An example of the observation error is the bias produced from human error. Often, the counters simply miss redds because of glare on the water from the sun and thus produce low counts. Conversely, counters may mistake natural mounds in the gravel as a salmon red and produce counts that are too high. This produces observation error. An example of process error in this situation is the number of spawners making it to the spawning grounds. Variation in the number of spawners producing redds can be due to a large number of environmental variables such as ocean survival.

# Acknowledgements

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# References

Punt, A.E. and R. Hilborn. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Reviews in Fish Biology and Fisheries. 7: 35-63.

# Tables

Table 3. Relative likelihood profiles for the parameters a and b for the Beverton-Holt stock-recruitment model fit to the Skeena River sockeye salmon data. 

# List of Figures

Figure 3. Contour plot of joint likelihood in a and b space.



Figure 4. Likelihood profile for ‘a’.



Figure 5. Likelihood profile for ‘b’.

