A Simple Procedure to Evaluate Salmon Escapement Trends that Emphasizes Biological Meaning Over Statistical Significance

Harold J. Geiger and Xinxian Zhang

Reprinted from the Alaska Fishery Research Bulletin
Vol. 9 No. 2, Winter 2002

The Alaska Fisheries Research Bulletin can be found on the World Wide Web at URL:
http://www.ak.gov/adfg/geninfo/pubs/afrb/afrbhome.htm

Alaska Fishery Research Bulletin 9(2):128–134. 2002.

A Simple Procedure to Evaluate Salmon Escapement Trends that Emphasizes Biological Meaning Over Statistical Significance

Harold J. Geiger and Xinxian Zhang

ABSTRACT: Statistical hypothesis testing for a "significant" decline is poorly suited for the analysis of salmon stock trends. Unfortunately, when statistical hypothesis-test machinery is applied to an escapement series, biologically unimportant, small downward fluctuations can be considered "significant," especially in long series. Alternatively, often very steep declines in escapement levels are found to be "not significant," especially in short series. The hypothesis test may tell more about the length of the series than the magnitude of the decline or the stock dynamics. We propose a simple and robust method of estimating the magnitude of stock decline (or increase), and propose a way to reference stock decline in terms of an underlying escapement level at the beginning of the series, so the decline can be judged in some kind of context. We regressed escapement on time using a resistant regression line. We propose using the back-cast estimate of what the escapement was in year zero of the series as a nonparametric escapement benchmark, and we call this benchmark the year-zero reference point. This back-cast estimate is just the estimated y-intercept of the regression line. In several 15-year series that we examined, we concluded that an escapement decline was *biologically meaningful* when the estimated underlying annual decline was more than 5% of the year-zero reference point, as that decline will result in the underlying escapement level dropping by half over a 10-year period.

INTRODUCTION

Statistical significance is easy to assess. An analyst needs to master a few reasonably consistent, inflexible rules, and some probability terminology describing error rates and so forth. Today, many of these rules are conveniently programmed into a computer. The basic raw materials are a data set, a computer, and perhaps an elementary statistical textbook. The end result is that the rules (such as how to do a *t*-test) are applied to the data, and the result is categorized into one of two clearly labeled outcomes: the result was *statistically significant*, or the result was *not statistically significant*. Even though the theory involves some highly subjective aspects, such as the selection of a significance probability, these subjective elements have been more or less standardized to add to the air of objectivity of statistical hypothesis testing.

Hypothesis-testing theory is based on a form of a proof by negation that is common in mathematics: a hypothesis that the analyst wants to discredit is provisionally assumed to be true, but it leads to a contradiction or an absurd conclusion, so the original hypothesis is rejected. In statistical hypothesis testing, the hypothesis the analyst wants to discredit is called the *null hypothesis*, and when it is provisionally assumed to be true, the hypothesis is rejected if it is judged to lead to an unlikely outcome (e.g., Snedecor and Cochran 1967; Berger 1980; Casella and Berger 1990). The data are combined into a statistical summary, called the *test statistic*. A measure called the *significance probability* corresponds to each test statistic, and the smaller this value, the more unlikely the null hypothesis is thought to be. (This is not really a probability, in the sense of the relative frequency of some outcome, but a more complex idea, further giving this approach an air of mathematical sophistication.) In any event, the significance probability is used to determine whether the "result," is "significant" or not, depending on whether or not it is bigger or smaller than a reference value, usually denoted as α. For some reason, by convention, α is almost always set to 0.05.

Critical thinkers have tried to describe the problems with this system for years. McCloskey (1995)—in an

Authors: HAROLD J. GEIGER is a research supervisor for the Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 240020, Douglas, AK 99824. E-mail: hal_geiger@fishgame.state.ak.us. XINXIAN ZHANG is a Biometrician for the Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 240020, Douglas, AK 99824. Email: xinxian_zhang@fishgame.state.ak.us
Acknowledgments: We thank Renate Riff and Steve Heinl for critical reviews. Steve pointed us to several interesting data sets, and helped us formulate some of our recommendations.

article titled *The Insignificance of Statistical Significance*—stated the problem quite clearly: "scientists care about whether a result is statistically significant, but they should care more about whether or not it is meaningful—whether it has, to use a technical term, oomph." Some statisticians, especially Bayesian statisticians, have been critical of statistical hypothesis testing for years, but much of their work is so highly mathematical that it is inaccessible to most biologists. To summarize some of this literature, statistical hypothesis testing does not make the distinction between *statistical significance* and what is sometimes called *real significance*.

In many practical applications (at least in the field of fisheries) the null hypothesis is wrong, and usually this is obvious based on well-studied principles. For example, was some stock present—at any level (even one fish!)—in some mixture of stocks? Has the underlying return per spawner changed (even by 0.000001 fish!) over the course of 10 years in some stock? The problem is that "wrong" is often a matter of degrees in an actual, practical discussion. Because the statistical hypothesis testing procedure cannot distinguish between a hypothesis that is completely wrong from one that is substantially right, approximately right, or even much, much closer to right than what people previously believed, hypothesis testing alone will often lead to poor decisions. An acquaintance of one of the authors was dying of a fatal disease a few years ago. He went to considerable trouble to get into a clinical trial of an experimental drug because he read in an abstract from a medical journal that in early trials a new drug "significantly" extended the life of those afflicted with his disease. When he later discovered that this significant average extension was merely a matter of a few days over the course of two years, he correctly concluded that either scientists should pick a word other than "significant," scientists are not very critical thinkers, or both.

At some level, scientists understand this problem, even if they don't know what to do about it. Even honest and highly respected scientists certainly have ways to manipulate the hypothesis-test outcomes to place the results in the "statistically significant" category, or the "not statistically significant" category to suit what they believe. For proof of this, one simply needs to compare the number of "significant" results in the scientific studies of the *Exxon Valdez* oil spill supported by the Exxon Corporation (Wells et al. 1995), with the studies looking at essentially the same populations, but supported by the Trustee Council (Rice et al. 1995). Regardless of who had a better study about the effect of the oil spill, it certainly seems that some scientists provided subtle "help" to ensure statistical significance came out the way they wanted. In their defense, experienced analysts have repeatedly seen what seems to be a divergence between statistics and common sense. But the bigger problem is that collectively we do not have a simple, easy-to-use, trustworthy method to distinguish real and statistical significance.

Excellent examples of this problem are often found in attempts to answer the question of whether or not a salmon stock is in some kind of decline. First, the hypothesis that the escapement only goes up or down around a completely fixed average is wrong. No statistical tests are needed: salmon populations do fluctuate over an inter-decadal scale. The fluctuations are caused by many factors, and ocean climate change is clearly one of them. Atmospheric forcing of ocean processes affect salmon's habitat in many ways, and these effects persist over decades (Quinn and Marshall 1989; Beamish and Bouillon 1993; Hare and Francis 1995; Adkison et al. 1996; Mantua et al. 1997; Beamish et al. 1998; and many others).

During periods of favorable environmental conditions, the escapement tends to increase, and during periods of unfavorable conditions, escapement tends to decrease. This is because management error is linked to total recruitment for most managed salmon stocks. In other words, when total run size increases or decreases, usually both catch and escapement levels tend to move in the same direction. The ability to detect a trend, and label it "significant," will be a function of the length of the data series, past variability, and the size of the underlying trend. Because statistical power is so strongly affected by sample size, a 2% annual decline may be "significant" in one system with a long, stable data series, but a 5% decline may not be "significant" in another system with a shorter history of monitoring. The use of correlation coefficients and most nonparametric statistical tests serve to even further distance the statistical result from something with intuitive biological meaning.

Our intent is to measure the trend in salmon escapement, either up or down, and provide a way to put the change into some kind of biological context.

NONPARAMETRIC ESCAPEMENT REFERENCE POINT

Consider the escapement series in Figure 1. To say that the decline is statistically significant is to provide a level of mathematical overkill that hardly seems necessary. The escapement has clearly declined. The stock assessment challenge is to measure the decline, and provide a context to give that decline some meaning. We will

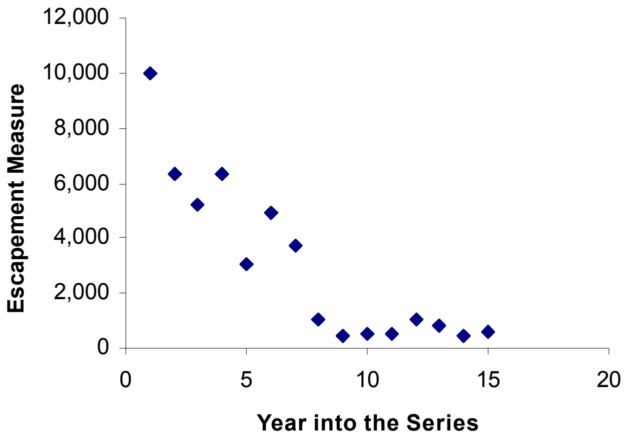

Figure 1. Simulated salmon escapement data collected over a 15-year period. Each observation was generated from 85% of the previous value, multiplied by a lognormal random value. Note that seven of the lowest values in the series are in the most recent half of the data set.

do that by using a very simple form of robust regression (regression that will not be strongly affected by points that lay far off the estimated line), and then estimating an escapement reference point before the beginning of the series, which we will call the *year-zero reference point*. Just as *forecasting* is a prediction of a data outcome in the future based on a model, we call *back-casting* a model prediction of a value from the past. The regression line is used to back-cast to an estimate of escapement at year zero in the series, and we will use this back-cast value of escapement for a benchmark to compare a decline or increase. Tukey (1977) launched a search for simple, easily computed statistics and graphics, with good sampling properties, that de-emphasized significance testing. Velleman and Hoaglin (1981) describe many of these methods, generally based on Tukey's ideas. We will use the *resistant line* of Velleman and Hoaglin (1981, Chapter 5), for its ease of calculation, but more importantly for its excellent sampling properties when estimating a trend in data with large outliers.

We suggest truncating any escapement series to the most recent 15 or 21 years. The first reason is that stocks change, and we want to consider escapements that were gathered in the same production regime. In general, Alaskan salmon stocks in the early 1970s were operating under different recruitment dynamics for reasons that have been linked to environmental change (Beamish and Bouilon 1993; Beamish et al. 1998). Also, 15 and 21 divide evenly by three, and this method is based on an analysis of three periods. Because five years is approximately one generation in most salmon species, 15 years is approximately three generations. If there are less than 15 years of data, we suggest working with just two periods defined by breaking the data series in half. Because pink salmon runs are made up of two (odd-year and even-year runs) populations of short generation length, we suggest using 21-year series for pink salmon to better describe larger trends that are common to both runs, although 15 years will also work for pink salmon. Alternatively, we recommend breaking pink salmon into separate odd- and even-year series of 15 years each.

Consider the 15-year series in Figure 1 as an example. We divided the data into thirds based on time. The values for the data in the first third are {10,000, 6,341, 5,192, 6,345, 3,021} and the values in the last third are {486, 1,017, 798, 468, 572}; medians for each period are underlined. We denote the median value in the first third as m_1 (in this case, 6,341), and denote median in the last third as m_3 (in this case, 572). Because there are five years in the first third, five years in the second third, and five years in the last third, there are 5/2+5+5/2=10 years between the middle year in the first third and the middle year in the last third. (If we used 21 years of data for the whole series, there would be 14 years between the first and last period.) The robust estimate of the underlying decline is found by calculating the slope through these data as *slope* = (m_1–m_3)/(years between periods) = (572–6,341)/(10 years). This works out to a 577 fish decline per year, about 9% of the median value of the escapement during the first period.

The back-cast estimate of escapement the year before the first observation is found by averaging the three possible estimates of the *y*-axis intercept that result from applying the slope to the median points for each of the three periods. Let $years_i$ equal the number of years from the beginning of the series to the midpoint for period *i* (i.e., 3 years for *i*=1, 8 years for *i*=2, and 13 years for *i*=3, for a 15-year series). Solving the equation,

$$slope_i = \frac{y_{0,i} - m_i}{years_i},$$

with $slope_i$ calculated as described above, gives three *y*-axis intercepts:

$$y_{0,i} = slope_i\,(years_i) + m_i\ .$$

Then, averaging the three intercepts (note two of the intercepts should always be the same) yields the desired result: the final estimate of year-zero escapement, our reference point:

$$y_0 = \sum \frac{y_{0,i}}{3}\ .$$

The values in the middle third of the escapement series are {4,916, 3,696, 1,065, 438, 504}, the median value is 1,065, there are 8 years to the middle of the third period, and the slope is 577 fish/year. Then, the second of the three intercepts is given by 577fish/year (8 years)+1,065 fish, or 5,681 fish.

In this case, the three intercept estimates are 8,071, 5,681, and 8,071. Then the robust escapement reference point is the mean of these three values, or 7,274 fish. Using the *y*-axis intercept as our reference point, the estimated decline is 8% per year.

If, over a 15-year period, the median escapement from the recent period is anywhere near 50% or less of the reference point, the stock has undergone a large decline. Similarly, if the robust estimate of annual decline through the whole series is anywhere near 5% of the reference point, from the year-zero period, the underlying escapement level will have dropped by half in 10 years. Therefore, if the robust estimate of decline is 5% or more of the year-zero reference point the decline is considered a *biologically meaningful decline.*

ACTUAL EXAMPLES

Yukon River fall chum salmon

Figure 2 shows 15 years of escapement estimates for fall chum salmon (*Oncorhynchus keta*) in the Yukon River (Eggers 2001). If the data set is divided in thirds based on time, as previously described, then the median escapement in the earliest period is 376 thousand, and the median escapement in the most recent period is 291 thousand fish. The year-zero reference point is 488 thousand fish. The robust estimate of decline is about 8.5 thousand fish per year, just under 2% of the year-zero reference point. Note that the median escapement in the recent period is about 60% of the reference point. These data were used just to illustrate the method and provide a typical example of a declining escapement series; a complete analysis would require a comparison of all escapements to the escapement goal.

Because this is under a 5% decline, we would not conclude the decline is biologically meaningful, even though this is a fairly large decline.

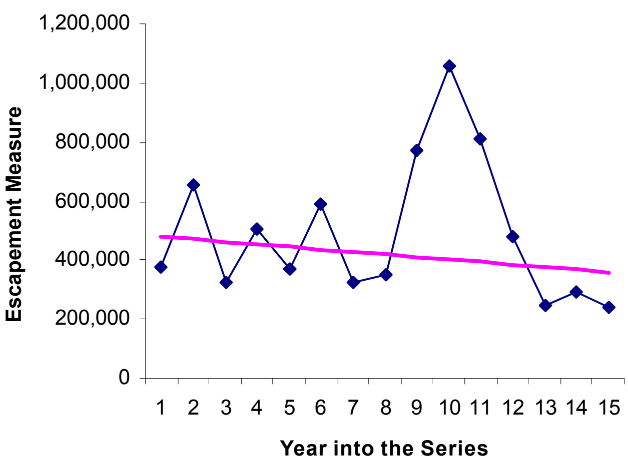

Figure 2. Escapement data for Yukon River fall chum salmon from the 15-year period of 1986 to 2000. Note the downward trend. The thick line is the resistant line, and the value of that line as it crosses the *y*-axis is the year-zero reference point.

Prince William Sound pink salmon in the early 1990s

Pink salmon *O. gorbuscha* escapement counts into the Northwest and Coghill districts of Prince William Sound in the early 1990s show a decline resulting from overharvest (Geiger 1994). This time period was chosen to demonstrate the method on a series during an actual overharvest event. Figure 3 shows the data series of the Northwest District up through 1993. The year-zero

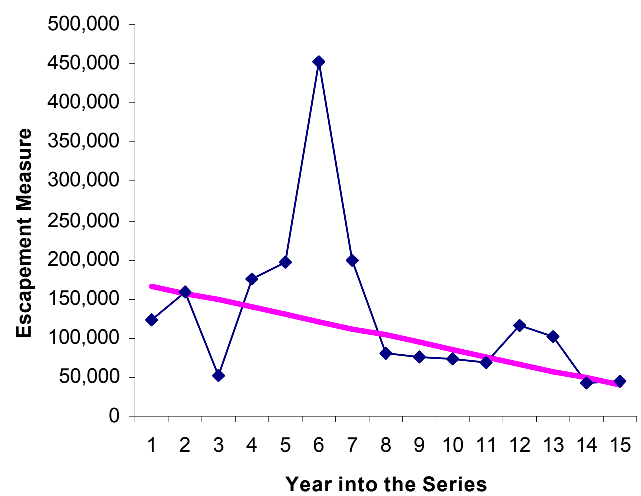

Figure 3. Actual pink salmon escapement data for the Northwest District of Prince William Sound from the 15-year period of 1979 to 1993. The thick line is the resistant line, and the value of that line as it crosses the *y*-axis is the year-zero reference point. Note that six of the seven lowest escapements are in the most recent period. In general, we suggest using 21-year series with pink salmon when both odd- and even-year lines are combined, but in this example, 15 years of data were used.

reference point is 176 thousand, and the robust estimate of decline is just over 9.0 thousand fish per year. This decline is just over 5% of the estimated year-zero reference point, and the recent-year median is just 39% of the year-zero reference point. So, escapements in this data series clearly declined, and this decline is considered biologically meaningful. In those years, the published escapement goal for this series was 136 thousand, a value below but near the year-zero reference point. The last two years in the series were approximately 33% of the published escapement goals for those years. The important feature of these data is that escapement had been declining since about year 6 (1984) in the series when fish from this district began to be caught in intensive hatchery fisheries in the southwestern and northwestern part of Prince William Sound (Geiger 1994).

Hugh Smith Lake sockeye salmon

Hugh Smith Lake in Southeast Alaska has been the focus of enhancement activities since the mid 1980s. At times, more than 2.0 million eggs have been taken to produce juvenile sockeye salmon *O. nerka* planted into the lake. Sockeye salmon from this system are captured in large pink salmon fisheries in southern Southeast Alaska, and managers of these pink salmon fisheries have very little stock-specific information about the sockeye salmon caught incidentally.

It appears that the sockeye salmon escapements to Hugh Smith Lake have been declining throughout the data series, but that the biggest decline in the 15-year data set is fairly recent (Figure 4). The robust estimate of decline is 302 fish per year. The year-zero reference point is just under 9,000, which is outside the escapement goal range. The decline is about 3% of the year-zero reference point. From the point of view of assessing the status of this stock, a more important comparison is the escapement level with the escapement goal. The escapement goal range for this system is 15,000 to 35,000 sockeye salmon spawners. Recent escapements have been about 20% of the lower end of the escapement goal range. Note that the escapement has been within the goal range only twice in the last 15 years, in 1987 and in 1992.

If we increase the number of years under consideration to 21, we get a different picture (Figure 5). With 21 years, the estimated decline is 659 fish per year, which is 5% of the new year-zero reference point of 12,800. Including the larger data set shows the decline has been going on longer than 15 years, and that the steepest decline was in the early part of the series. The statistical significance of this decline could be judged in different ways – from tests based on nonparametric correlation

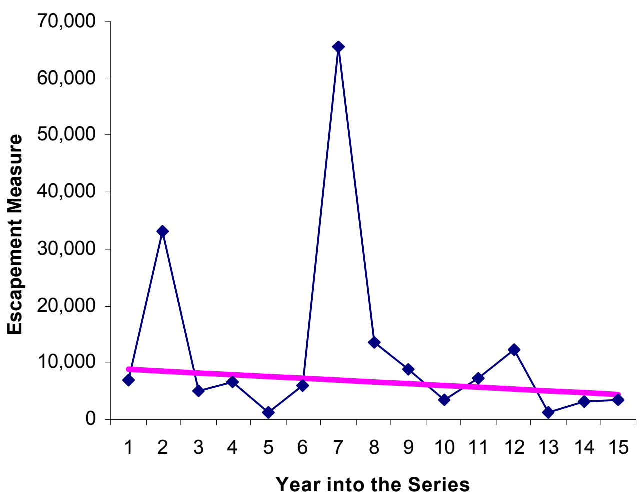

Figure 4. Escapements of sockeye salmon to Hugh Smith Lake in Southeast Alaska from the 15-year period of 1986 to 2000. The thick line is the resistant line, and the value of that line as it crosses the *y*-axis is the year-zero reference point. Note the downward trend (3% of the year-zero reference point).

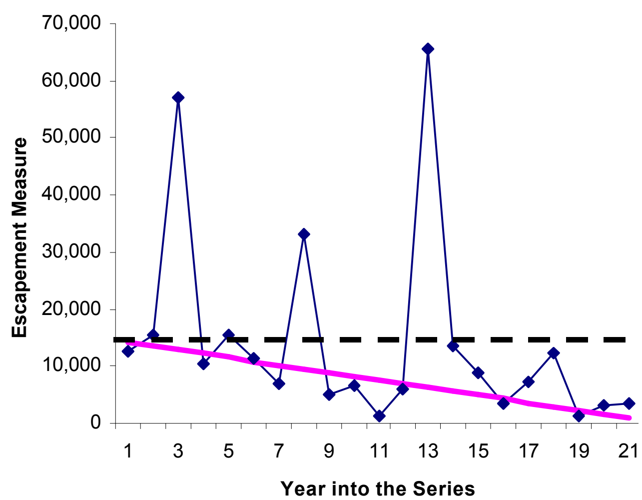

Figure 5. Escapement estimates for Hugh Smith Lake sockeye salmon from the 21-year period of 1980 to 2000. The thick line is the resistant line, and the value of that line as it crosses the *y*-axis is the year-zero reference point. The estimated decline is 5% of the year-zero reference point per year, which is considered biologically meaningful. The dotted line shows the lower end of the escapement goal range.

coefficients to an *F*-test based on regression analysis. Interestingly, the Spearman's Rho test would be considered marginally significant ($P \approx 0.05$), and the *F*-test would usually be considered non-significant ($P=0.17$). Either way, this decline was significant from a population-dynamics point of view.

DISCUSSION

Escapement series are often very noisy, with extreme outliers far outside of the usual range of the data because of fishery strikes, unusual oceanographic phenomena, or for reasons that are just unknowable. Trend measures that are based on means, such as the usual linear regression, are too influenced by unusual outlying observations to be reliable and consistent. For that reason alone, the resistant line is useful in summarizing trend information, or at least the linear component of trend, and to establish a statistically stable estimate of decline. Once the concept of the year-zero reference point is understood to be the "underlying" escapement level at the beginning of the series, this measurement has a simple, intuitive appeal. If a stock is subject to a heightened level of scrutiny because of declining yield and stock size, then the year-zero reference point is a robust estimate of what the escapement was prior to a number of years of decline. No analysis of stock size alone will help explain the reason for the decline and the role of harvest, environmental change, or habitat alteration in the decline. In the end, the year-zero reference point is simply a measure of what level of escapement was achievable in the past, so that the escapement today can be viewed in some kind of context.

We used simple simulations in spreadsheets to demonstrate to ourselves that the year-zero reference point has better sampling properties than summaries based on averages. This is an easy exercise for anyone interested in applying the techniques we described, and we suggest that it be the first step in applying this technique. However, although the year-zero reference point has relatively stable sampling properties, it will not perform well in the case of sharp increases or decreases, especially given one or more changes in trend within the data series. No statistical approach will consistently provide a reasonable *linear* summary of trends in stocks with sharp or multiple changes in escapement level. Even so, using a spreadsheet and some hypothetical data sets, it is easy to see that the resistant line performs at least as well as any other linear smoothing technique with actual escapement data, and that it usually performs much better, especially with noisy data containing outliers. Using simulations, we found many cases of negative values of year-zero reference points with fast stock increases, and these results have been observed in actual fisheries data (in Southeast Alaska's pink salmon, for example). This was especially true of several chum salmon data sets that were brought to our attention. In these cases, the estimate of stock increase or decrease may still be valuable, but because the stock is usually increasing in this situation, the year-zero reference point is not needed to give the increase any context. It is usually good enough to simply report that escapement has been increasing.

The hardest recommendation for us to justify is the suggestion that a decline of 5% per year with a 15-year data set be judged biologically meaningful. First we examined several stocks that we considered to clearly show meaningful declines, and we noted that the measured decline in a 15-year data series was 5% or greater. However, the fact that a decline of 5% of the starting value, over a 10-year period, will lead to a fall in escapement by half is what led us to conclude this decline was biologically meaningful.

In a 21-year data set, the level of decline that triggers the conclusion that the decline is biologically meaningful should be lower than for 15-year data sets. Since a 21-year series contains substantially more data than a 15-year series, the same measured annual decline represents a far larger, more persistent drop, and represents a more stable statistical estimate of the decline. We suggest that a 3% decline be judged biologically meaningful when 21 years of data are used in the analysis.

If a critic still is not happy with our method, we wish to point out again the need for some means of putting a decline in a biological context for the analysis of trends to have any meaning for fisheries management. A critic may argue that the year-zero reference point is an imperfect way to do that – which is, of course, correct. But in the case of stocks without an extensive record of study, the year-zero reference point is a big improvement over the significance-testing approach, which is a test for any decline at all, no matter how small and inconsequential and a test that does not incorporate any biological context.

All stocks are constantly undergoing changes to recruitment patterns, changes to fishing patterns, and changes to management. These changes inevitably create short-term trends, half of which, in an overall stable situation, in the long term, must be downward trends. The ability to detect a statistically significant decline is dependent on the random variable of sample size – maybe more so than the dynamics of the stock. If an analyst thinks he or she can supply an estimated biological reference point, such as the escapement that will provide maximum sustained catch, these kinds of values make much better comparisons than the year-zero reference point. For example, to say “the recent three escapements are less than 80% of the estimated escapement that will produce maximum catch,” is enormously more informative than to say, “the stock significantly declined.” The former is even much more informative than to say “the stock decline is 3% of the year-zero reference point.”

Other analysts may look at declines that we would not classify as biologically meaningful, and conclude that the declines are important and should be given a different classification. We offer no argument with that – in fact we would be pleased to see the shift from the mechanical statistical approach to some dialogue about what level of decline should be permitted. Our recommendations are just intended as starting points, and we suggest that anyone using these techniques carefully consider their own situation, and develop their own criteria for what level of drop he or she would consider biologically meaningful. This analyst may still wish to use our approach; he or she only needs to change the level of decline considered biologically meaningful – which is appropriately a subjective decision that should involve a level of biological judgment.

LITERATURE CITED

Adkison, M. D., R. M. Peterman, M. F. Lapointe, D. M. Gillis, and J. Korman. 1996. Alternate models of climate effects on sockeye salmon, *Oncorhynchus nerka*, productivity in Bristol Bay, Alaska, and Fraser River, British Columbia. Fisheries Oceanography 5:137–152.

Beamish, R. J., and D. R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fisheries and Aquatic Sciences 50:1002–1016.

Beamish, R., D. Noakes, G. McFarlane, and J. King. 1998. The regime concept and recent changes in Pacific salmon abundance. Page 1–3 *in* K. Myers (editor). Workshop on climate change and salmon production. North Pacific Anadromous Fish Commission Technical Report Number 1.

Berger, J. O. 1980. Statistical decision theory and Bayesian analysis. Springer-Verlag, New York.

Casella, G., and R. L. Berger. 1990. Statistical inference. Wadsworth & Brooks, Pacific Grove, CA.

Eggers, D. M. 2001. Biological escapement goals for Yukon River fall chum salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Informational Report 3A01-10, Anchorage.

Geiger, H. J. 1994. Recent trends in pink salmon harvest patterns in Prince William Sound, Alaska. Proceedings of the 16th Northeast Pacific Pink and Chum Salmon Workshop. Alaska Sea Grant College Program, Report 94-02, University of Alaska, Fairbanks.

Hare, S. R., and R. C. Francis. 1995. Climate change and salmon production in the Northeast Pacific Ocean. Pages 357–372 *in* R. J. Beamish (editor). Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 122.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069–1079.

McCloskey, D. N. 1995. The insignificance of statistical significance. Scientific American 272(4):34–37.

Quinn, T. J., and R. P. Marshall. 1989. Time series analysis: quantifying variability and correlation in SE Alaska salmon catches and environmental data. Pages 67–80 *in* R. J. Beamish and G. A. MacFarlane (editors). Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Canadian Special Publication of Fisheries and Aquatic Sciences 108.

Rice, S. D., R. B. Spies, D. A. Wolfe, and B. A. Wright. 1995. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18, Bethesda, Maryland.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods, 6th edition. Iowa State Press, Ames, Iowa.

Tukey, J. W. 1977. Exploratory data analysis. Addison-Wesley, New York.

Velleman, P. F., and D. C. Hoaglin. 1981. The applications basics, and computing of exploratory data analysis. Duxbury Press, Belmont, California.

Wells, P. G., J. N. Butler, and J. S. Hughes. 1995. *Exxon Valdez* Oil Spill: fate and effects in Alaskan Waters. American Society for Materials Testing. Special Technical Publication Number 1219, Philadelphia, Pennsylvania.