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On the analysis of monitoring data: Testing for no trend in population size

Benedikt R. Schmidt[a,b,*], Andrea H. Meyer[c]

[a]*KARCH, Passage Maximilien-de-Meuron 6, CH-2000 Neuchâtel, Switzerland*
[b]*Zoologisches Institut, Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland*
[c]*Abteilung Klinische Psychologie und Psychotherapie, Fakultät für Psychologie, Universität Basel, Missionsstrasse 60/62, CH-4055 Basel, Switzerland*

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Summary

The goal of a monitoring program is to find out whether the size of a population is stable, declining, or increasing over time. Whereas statistical tests for temporal trends are straightforward, there is no test for no change or stability. We propose that the combination of traditional trend analyses such as linear regression and tests for density dependence may be used for population stability analyses. We illustrate the approach by analyzing a data set from an orchid monitoring program. Combining statistical tests for temporal trends with tests for statistically significant density dependence is a useful and simple tool in the analysis of monitoring data.

Introduction

Monitoring is an important tool in biological conservation to assess the status and dynamics of populations, communities, and ecosystems (Elzinga, Salzer, Willoughby, & Gibbs, 2001; Nichols & Williams, 2006; Thompson, White, & Gowan, 1998; Yoccoz, Nichols, & Boulinier, 2001). The goal of a monitoring program of endangered species is to find out whether a population is stable, declining, or increasing over time. A temporal decrease in population size will generally be a reason to implement a recovery plan or to change the current management of the population (Nichols & Williams, 2006). Thus, habitat management and monitoring are intimately linked, since monitoring tells us whether the management of sites or species has been successful (Hintermann, Weber, & Zangger, 2000; Nichols & Williams, 2006).

The analysis of monitoring data should provide information about whether a population is stable or changing in size. Whereas it is straightforward to test for a change in population size, it is not possible to test directly for stability, i.e., whether

*Corresponding author. Tel.: +41 0 1 635 4984; fax: +41 0 1 635 6821.
E-mail address: bschmidt@zool.uzh.ch (B.R. Schmidt).

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the size of a population has not changed over time (Buckley & Beebee, 2004; Dixon & Pechmann, 2005; Wade, 2000). If a statistical test fails to yield a significant result (i.e., a non-significant "trend"), one might be tempted to conclude that a population is stable. Such a conclusion, however, may be wrong. A non-statistically significant change does not mean that population does not exhibit any real trend (Dixon & Pechmann, 2005; Morrison, 2007; Reed & Blaustein, 1995). Statistical power may be too low to detect a true temporal trend. Power depends on the type I error probability (α), the sample size, and the effect size. It is possible to estimate the power of a statistical test retrospectively (Thomas, 1997; but see Gerard, Smith, & Weerakkody, 1998), but this requires deciding upon an a priori effect size (e.g., rate of decline) that one is willing to accept as biologically relevant. For example, an annual decline of 5% may be acceptable. A power analysis may yield as result that the smallest detectable decline (i.e., significant with a power of 0.8 and $\alpha = 0.05$) is 10% per year. The conclusion would then be that one cannot make a statement whether the population is declining and thus at risk. In conclusion, even if the monitoring program was carefully designed, one may be left with a population whose status one wishes to assess, but for which the statistical test for a change in population size is not significant and the power of the statistical test is too low to safely conclude that there is neither the danger of a type I nor a type II error. This is clearly not satisfying. Therefore, several authors have proposed alternative methods for testing for the presence or absence of a trend (Buckley & Beebee, 2004; Dixon & Pechmann, 2005; Sauer & Link, 2002; Schmidt, Feldmann, & Schaub, 2005; Wade, 2000).

What we need is a method that tests for no trend in monitoring data. Here, we propose a two-step approach to the analysis of monitoring data that allows conclusion that there is no trend in population size and we will provide an exemplary analysis of a plant monitoring program. Our approach involves two steps. First, we perform a linear regression analysis testing for a trend in population size. If there is no clear evidence for a trend, we then continue in a second step to perform a test for statistically significant density dependence (SSDD) as developed by Dennis and Taper (1994). We argue that the test for SSDD can be used to assess the stability of a population indirectly (Solow & Sherman, 1997). The test for SSDD is not new but our interpretation in a monitoring framework is. The test for SSDD asks if the size of a population negatively affects its subsequent growth rate. If the relationship is negative, then there is a return tendency in the monitoring data, i.e., the population fluctuates around a return point which can be regarded as a kind of long-term mean level of population density (fluctuations in abundance *per se* do not imply a lack of stability). It also implies that the population is stationary which is what conservationists would call "stability"; such a definition of "stability" is also in line with ecological theory (May, 1973). We also show how to calculate a probability for "no trend" that takes the results of both tests into account.

Step one: testing for a temporal trend in population size by using a linear regression model

The first step of the analysis is to perform a commonly used trend analysis (Elzinga et al., 2001; Hatfield, Gould, Hoover, Fuller, & Lindquist, 1996; Thompson et al., 1998; Wade, 2000). One compares two linear regression models. The first model is an intercept only model that states that there is no change over time (but the population is still allowed to fluctuate in size), whereas the second model states that population size (N_t) changes over time

$$N_t = a + Z_t \quad (1)$$

$$N_t = a + b * \text{year}_t + Z_t \quad (2)$$

Coefficients a and b are the intercept and the slope of the regression, respectively, and Z_t is a normally distributed random variable with a mean of 0 and a variance of σ^2. We suggest using Akaike's information criterion adjusted for small sample sizes, AIC_c, to assess which model has more support from the data (Burnham & Anderson, 2002, 2004). Such a simple model selection analysis also gives Akaike weights (Burnham & Anderson, 2002) for each model which can later be used to combine the results of both steps of the analysis (see below). Akaike weights represent the weights of evidence in favour of a particular model and will sum up to 1 across all models. Akaike weights can be viewed as equivalent to Bayesian posterior model probabilities (Burnham & Anderson, 2004).

In the analysis of monitoring time series, one may find that residuals are autocorrelated (Dixon & Pechmann, 2005). If autocorrelation is a concern, then one may use other models such as a first-order autoregressive model instead of the linear regression (Eq. (2)). Dixon and Pechmann (2005) describe the use of autoregressive models and provide SAS code for the analysis. In the example described below, we found that linear regression and