The effect of census frequency on the detection of trends in the abundance of eastern North Pacific gray whales[1]

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ABSTRACT

The ability to detect trends in gray whale abundance with various census frequencies is investigated. The number of surveys and years needed to detect a trend in abundance, and total change in abundance, are presented in graphs for various rates of change and census frequencies. The estimated annual rate of increase of the population during 1967 to 1980 using a linear model is 0.034. This rate of increase can be detected (power = 0.95) with 14 surveys over 13 years, 9 surveys over 16 years or 7 surveys over 18 years, for census frequencies of every year to every third year, respectively. Graphs are presented showing power of detecting different rates of increase with census frequencies from 1 to 3 years.

KEYWORDS: ABUNDANCE; GRAY WHALE; TRENDS; SURVEY; FREQUENCY

INTRODUCTION

Shore-based censuses of migrating eastern North Pacific gray whales (*Eschrichtius robustus*) have been conducted regularly and often annually by the National Marine Mammal Laboratory since 1967/68. Reilly *et al.* (1983) estimated both abundance and rate of increase in population size for the early censuses (1967 to 1980). A number of other authors have estimated abundance using data from later surveys (e.g. see Buckland and Breiwick, 2002).

Censuses provide point estimates of abundance while long-term studies provide information about trend in population size over time. In many studies, estimating trend in population size is as important as estimating absolute population size in determining the status of the population. A number of papers have investigated the ability to detect trends in marine mammal abundance using regression models (de la Mare, 1984; Gerrodette, 1987; Holt *et al.*, 1987). This paper investigates the ability to detect trends for different frequencies of census.

With respect to eastern North Pacific gray whales, an impact issue is the number of times and how frequently surveys should be undertaken in order to detect when the population is approaching its carrying capacity (IWC, 1990).

If the growth of the population can be modelled by a logistic curve, and the population is approaching an asymptotic stable value (such as assumed by reaching ‘carrying capacity’), then as the slope of the curve, i.e. the growth rate, approaches zero, the number of surveys required to detect a trend will approach infinity. To determine if the population is ‘near’ its carrying capacity, some estimate is needed of that value, or the data must show the beginnings of an asymptote. The window of data available when this study was undertaken did not show an asymptote and may not be sufficient to fit the logistic model. Furthermore, if the population growth rate is near zero, it could be that recruitment failure has occurred owing to environmental or other causes, not necessarily that the population is near carrying capacity.

In this paper, the methods of Gerrodette (1987) are used to look at the power of detecting trends and the trade-off between the frequency of census and the number of surveys needed to detect a trend. The question regarding carrying capacity is not addressed directly, because the available data did not appear to fit a logistic curve.

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METHODS

The probability of detecting a trend, given that a trend exists, is defined as the power of the regression model. The power ($1-\beta$, where β is the type II statistical error) of detecting a trend in abundance is affected by a number of factors: the coefficient of variation of the estimates of abundance; the magnitude of the change in abundance over time; the level for type I (α) statistical error; and the number of estimates of abundance. By setting the values of four of these parameters, the fifth can be determined using formulae derived in Gerrodette (1987).

Gerrodette (1987) presents formulae for determining power for linear and exponential regression models and for three different relationships between coefficient of variation (CV) and abundance. This paper uses Gerrodette’s formula for linear rate of change with constant CV, based on data from Reilly *et al.* (1983).

One of the assumptions of this method is that abundance changes at a constant rate over regularly spaced intervals. This paper assumes that fluctuations in population estimates about the regression line are due to sampling variability alone, although this may not be fully realistic.

A linear model was chosen because the annual rate of change is assumed to decrease over time (when the slope is positive). The exponential model has a constant annual rate of change. If the population is approaching some asymptotic value, the linear model is more appropriate.

There appears to be no relationship between CV and abundance for the 13 years of gray whale data (Reilly *et al.*, 1983), with a mean CV = 0.1143 (Fig. 1). Reilly (1983) used a weighted exponential regression model to estimate a slope of 0.025 (SE = 0.00964) for the 1967-1980 abundance data (Fig. 2). An unweighted linear fit to the data gives an annual rate of increase of 0.034 ($Y = 11{,}112+390.29X$) (Fig. 2).

The formula relating the above listed parameters, for a linear rate of change with constant CV, is from Gerrodette (1987):

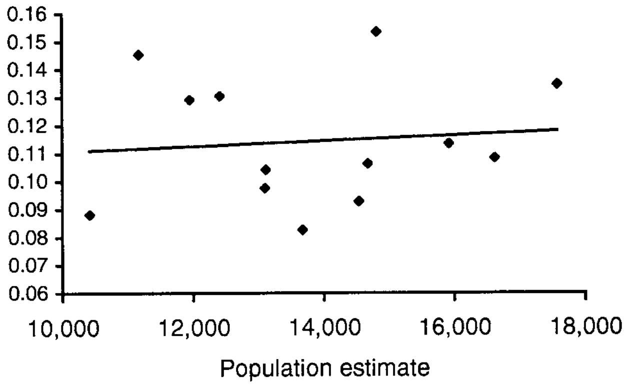

Fig. 1. Relationship between coefficient of variation and population estimates for the 1967/68-79/80 gray whale census data from Reilly *et al.* (1983).

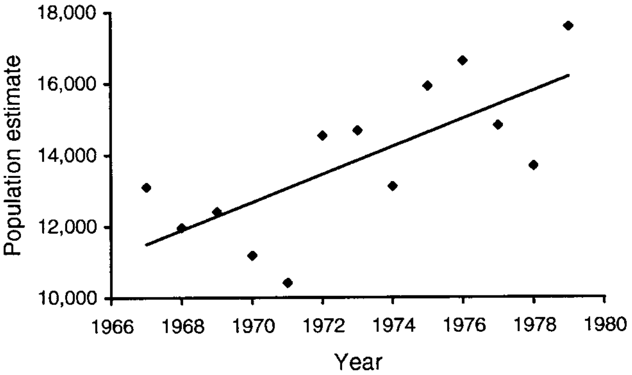

Fig. 2. Straight line regression fit to the gray whale population estimates for 1967/68-79/80. (Y = 11,112 + 390.29 X).

$$r^2 n(n-1)(n+1) \ge 12CV^2(Z_{\alpha/2}+Z_\beta)^2 \quad (1)$$
$$(1+r(n-1)[1+(\frac{r}{6})(2n-1)])$$

where:

n is the number of surveys;
r the annual rate of change in abundance;
CV coefficient of variation;
$Z_{\alpha/2}$ the normal deviate for type I error; and
Z_β normal deviate for type II error (power = 1-β).

The equation can be solved for one parameter given the other four parameters. The type I (α) and type II (β) errors were both set at 0.05, yielding a power of 0.95. $Z_{\alpha/2}$ is therefore equal to 1.96 and $Z_\beta = 1.65$. If a lower power is acceptable, fewer surveys would be needed. The CV was set at 0.1143, the mean from Reilly *et al.* (1983). The number of surveys to detect a trend was estimated for different values of r and different intervals between surveys.

The number of years to detect a trend is estimated by:

$$ny = ([n]-1)\ t$$

Where:

ny is the number of years;
[] indicates the next largest integer;
n the number of surveys; and
t the interval between surveys.

Total fractional change in abundance (R) is estimated by:

$$R = t\ r\ (n-1)$$

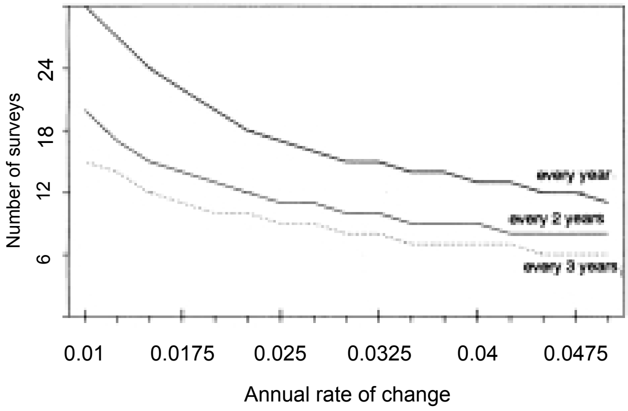

Fig. 3. Number of surveys to detect various positive rates of change and various survey intervals. CV = 0.1143, α, β = 0.05.

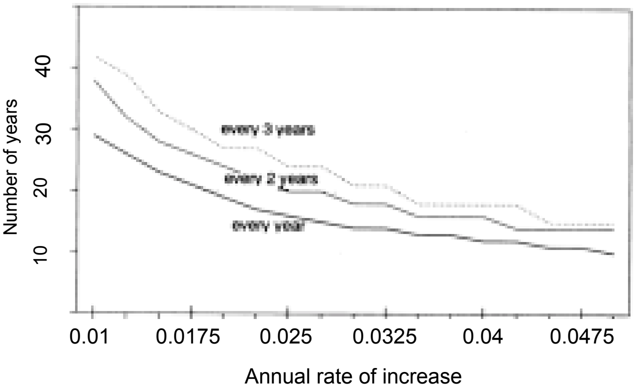

Fig. 4. Number of years before a trend is detected for various positive rates of change and various survey intervals. CV = 0.1143, α, β = 0.05.

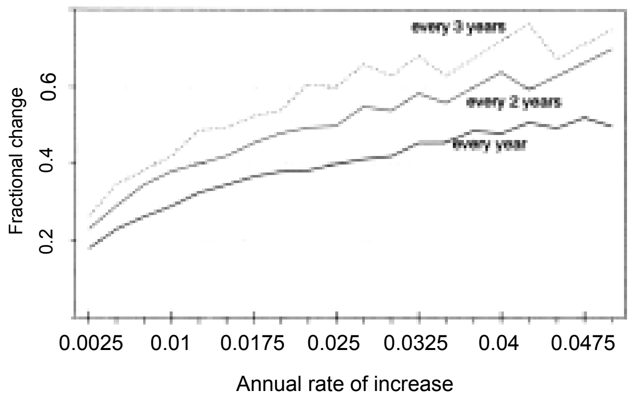

Fig. 5. Total fractional change in abundance over the years elapsed before a trend is detected for various positive rates of change and various survey intervals. CV = 0.1143, α, β = 0.05.

RESULTS

The number of surveys needed to detect a particular rate of change in the population with power = 0.95, decreases as the time between censuses increases (Fig. 3); however, the number of years elapsed increases (Fig. 4). For example, to detect an annual rate of change of 0.034 with power = 0.95, 14 surveys over 13 years would be needed if surveys were conducted every year. The population would increase by 46% over this time period (Fig. 5). If surveys were conducted every other year, nine surveys over 16 years would be needed, and the population would increase by 56% over the time period. If surveys were conducted every three years, seven surveys over 18 years would be needed, and the population would increase by 63%.

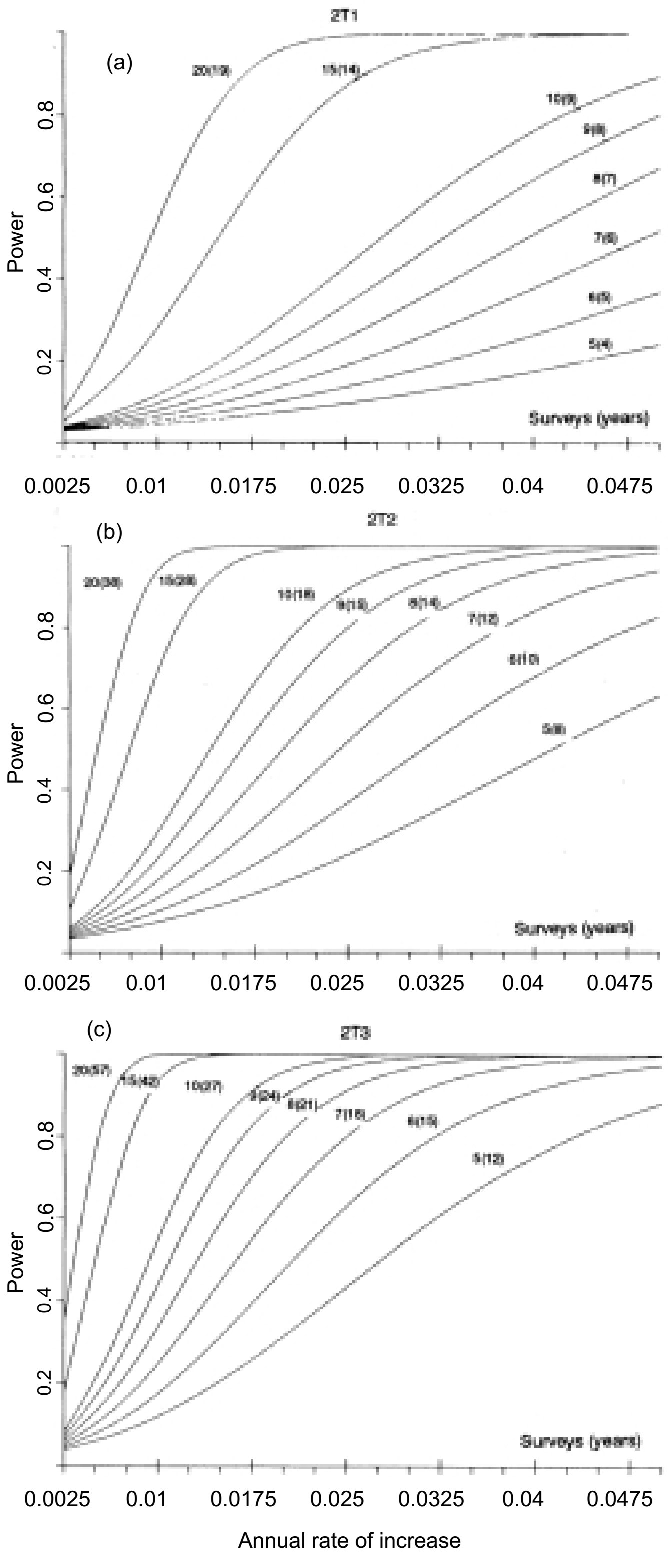

Fig. 6. Estimated power to detect various positive rates of change for surveys conducted (a) annually, (b) every second year and (c) every third year. CV = 0.1143, α, β = 0.005.

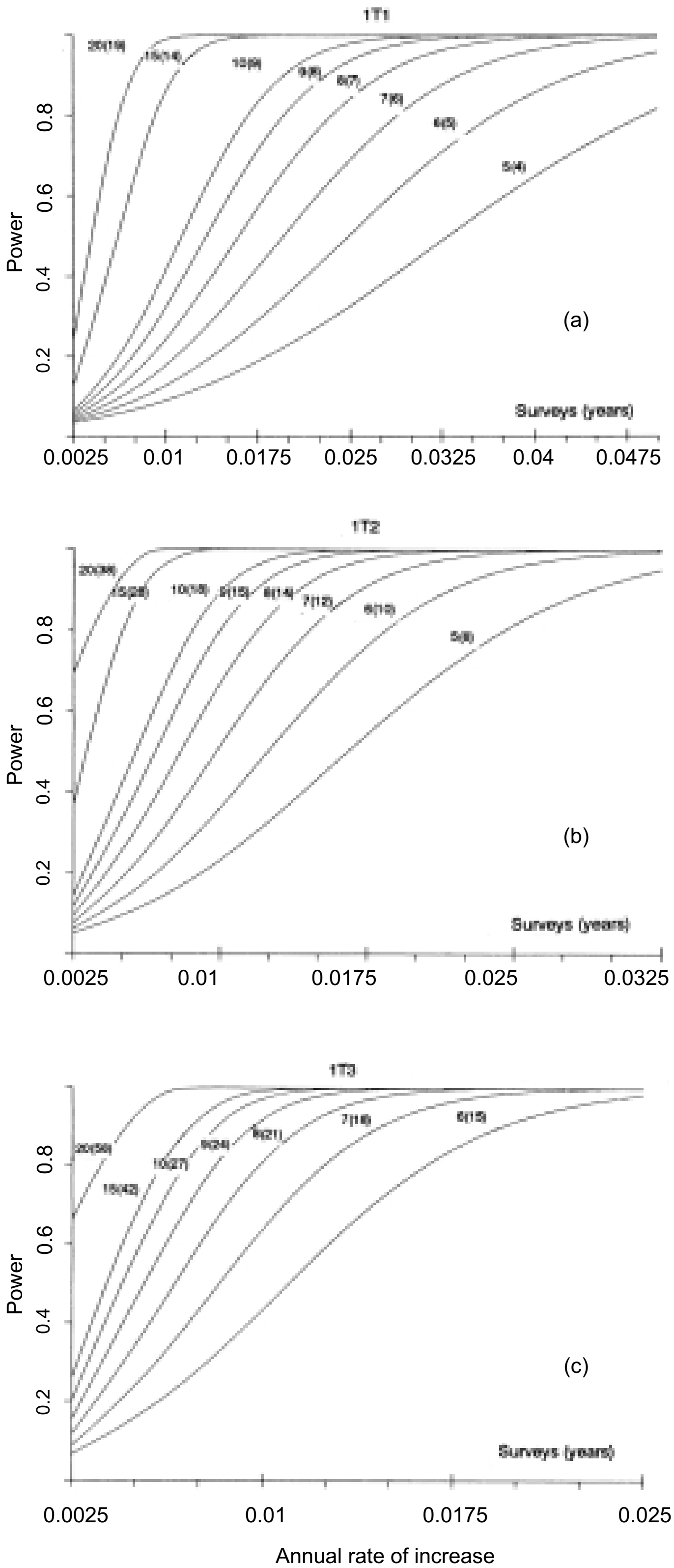

Fig. 7. Estimated power to detect various positive rates of change for surveys conducted (a) annually, (b) every second year and (c) every third year. CV = 0.05, α, β = 0.005.

It is interesting to note how small an annual rate of increase can be detected. Fig. 6 shows the power of detecting different rates of increase using a linear model ($CV = 0.11$, $\alpha = 0.05$) for surveys every 1-3 years. With 20 annual surveys (19 years elapsed), an *r* of 0.0175 can be detected with a power of 0.92. Approximately 13 surveys would be needed every other year (24 years elapsed), and 10 surveys every three years (27 years elapsed) to detect the same trend.

The CV of recent surveys is estimated to be smaller than for the 1967-80 surveys (Breiwick *et al.*, 1988). A smaller CV, such as 0.05, will result in higher power and a need for fewer surveys to detect a given change in the population (Fig. 7). However, that estimate may be too low because no allowance has been made for uncertainty in the matching of pods of gray whales in the mark-recapture methods.

DISCUSSION

A relatively long series of surveys is needed to detect trends in the population, especially if the rate decreases from the present estimate. The analysis shows that at least 13 years (14 annual surveys) would be needed to detect rates of increase similar to those estimated for the 1967-1980 surveys. It is possible to detect the same rate of increase using fewer surveys (e.g. 7 surveys), but it would take 18 years if surveys were conducted every three years.

More time would be required to detect smaller rates of increase. If a smaller CV can be obtained, or if a larger α or a smaller power is acceptable, then a smaller rate of change could be detectable. This paper assumes that the change in true abundance follows a linear trend. If this assumption is not valid, then the power of detecting a trend will be lower than estimated here.

When the interval between surveys increases, the number of surveys in a given time period decreases, and the number of years needed to detect a trend in abundance increases. For an increasing gray whale population, an undetected change in the population will not be as critical as for a decreasing population. If, however, the population is declining, one may want to sample at a frequency that allows detection of a certain percentage decline over the time needed to detect the trend, so that there is time for some action or more intensive study before too large a decline in the population has occurred. We have assumed a normal distribution for the abundance estimates. A bootstrap method (Efron and Tibshirani, 1993) could be used to avoid making assumptions about the underlying distribution.

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