Advanced Interagency Consultation Training

Study Guide for Measures of Risk

Objectives of this Module

1. Identify the terms that are used to describe measure species' risk of extinction
2. Discuss the interpretations of the various ways of measuring species' risk of extinction
3. Discuss the strengths and weaknesses of the various methods of measuring species' risk of extinction

Introduction

Section 7 of the Endangered Species Act of 1973, as amended, requires federal agencies to insure that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of threatened species or endangered species or destroy or adversely modify critical habitat that has been designated for these species. The section 7 regulations define *jeopardize the continued existence of* as "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species." The section 7 regulations further defined *destruction or adverse modification* as a direct or indirect alteration that appreciably diminishes the value of critical habitat for both the survival and recovery of a listed species," although that regulatory definition has since been invalidated by Court.

These two regulatory definitions have been the subject of extensive debate and discussion for many years. In particular, the Services and many others have debated the meaning of the term "reduce appreciably the likelihood of both the survival and recovery" in the definition of jeopardy. This module will not revisit or recapitulate those debates. Instead, this module will focus on the units that are used to measure (a) a species' risk of extinction or persistence and (b) the value of habitat for species. Better knowledge of the units that are used to measure a species' risk of extinction will help make future discussions of the proper interpretation and application of the jeopardy definition more productive.

The Measures of Risk Facing Species

The literature of population biology and conservation biology uses six units of measure to represent a species likelihood of becoming extinct in the wild: (1) estimated time to extinction; (2) mean time to extinction; (3) median time to extinction; (4) modal time to extinction; (5) probability of extinction in an interval of time; and (6) probability of extinction over any interval of time (see Beissinger and Westphal 1998, Boyce 1992, Burgman et al. 1993, Caswell 2001, Morris and Doak 2002 for further discussion of these terms and concepts). In many instances, these same units to measure a species' risk of extinction are easily converted into a species' likelihood of persisting in the wild by subtracting the extinction risk from 1 (or likelihood of persistence = 1 – risk of extinction).

It is important to remember that all of these measures are estimates that rely on probabilities. None of these measures, by themselves, assert that a species' risk of extinction is certain. Until the moment that the last individual member of the last population actually dies, there is always a chance of preventing species from becoming extinct.

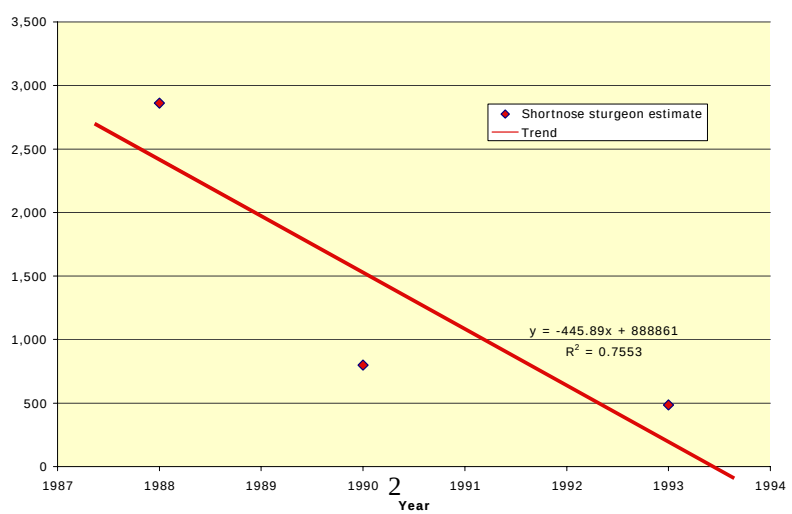
Estimated Time to Extinction

The *estimated time to extinction* estimates the number of years it would take for a population or a species to decline to zero individuals. The correct interpretation of the estimated time to extinction is "Based on current population trends, the species can be expected to become extinct by 2020" or "Based on current population trends, the species has about 20 years before extinction." This measure of risk also appears in the published literature as "The species is estimated to have n years before extinction" or "The species is expected to become extinct by 2020" although these interpretations misrepresent the accuracy and precision of this measure of risk.

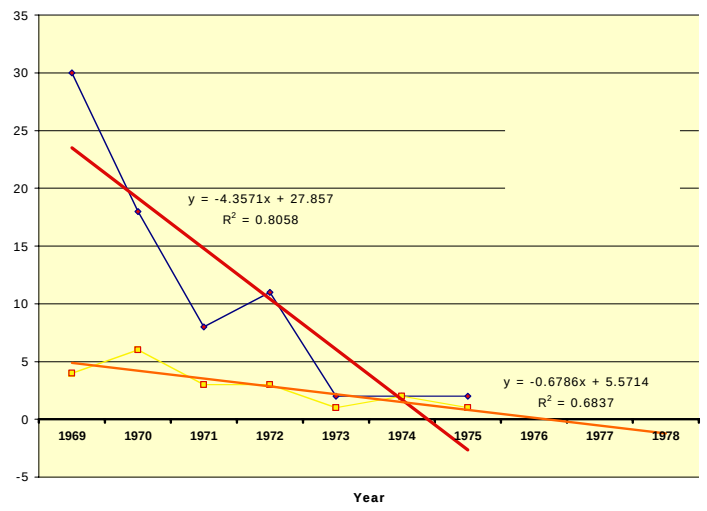
The estimated time to extinction is the simplest way to measure a species' risk of extinction, but it is also the least rigorous or robust of the various estimates. In particular, this measure of risk ignores the effect of population variance on extinction risk (the greater the variance, the greater the risk), ignores the effect of population structure or composition on the population's extinction risk (the greater the variance, the greater the risk), ignores the effect of population structure or composition on the population's extinction risk (for example, it does not distinguish between the number of adults, juveniles, or eggs in a population), and generally does not produce a confidence interval that can be used to assess the reliability of the estimate. Although this measure may underestimate a large population's risk of extinction (populations > 500 individuals), it can produce reliable estimates for small populations (<100 individuals). The estimated time to extinction has been applied to the endangered white abalone (Davis *et al*. 1998), Snake River spring and summer chinook salmon (Mundy 1999), 355 populations of 100 species of British birds (Pimm *et al*. 1988), and Peary caribou (Caughley and Gunn 1994)

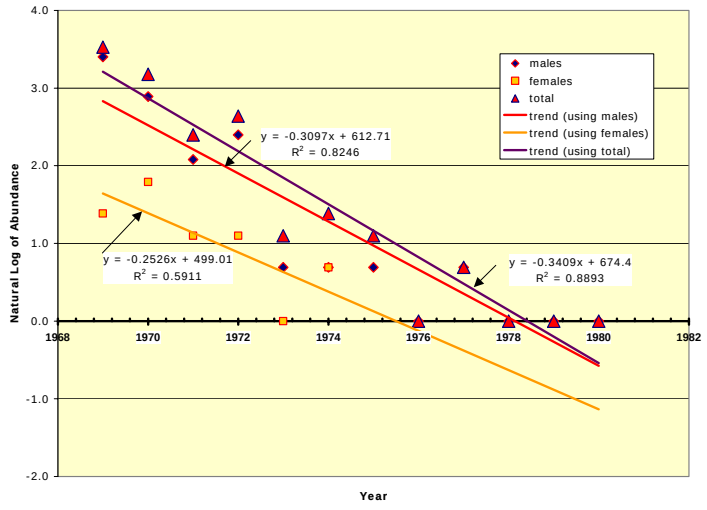
There are several methods of estimating time to extinction that vary in complexity (Goodman 1987, Leigh 1981, Pimm *et al*. 1988); the most common of these methods relies on a linear regression based on abundance information collected over time (Caughley and Gunn 1994). There are two general variations of this regression method: one using unconverted population

Figure 1. Estimated time to extinction for the Altamaha River (Georgia) population of shortnose sturgeon using unconverted population numbers. The year the regression line crosses the x-axis (between 1993 -1994) provides an estimated time to extinction, suggesting that this population may be extinct. The regression coefficient (R^2 = 0.7553) provides a coarse measure of the reliability of the estimate. From data contained in NMFS 1998



Figures 2 and 3. Estimated time to extinction for the Dusky seaside sparrow population on Merritt Island, Florida, using unconverted population numbers. The year the regression line crosses the x-axis provides the estimated time to extinction. This illustrates different estimates that would be produced using males versus females. The regression coefficients (R^2 = 0.8058 for males and 0.6837 for females) provides a coarse measure of the reliability of the estimate. Compare the estimates from the unconverted population numbers with the estimates using data that have been converted to their natural logarithm before building a trend line (lower panel). In this case, converting the population numbers of their natural logarithm improved the estimates using male, but did not improve the estimates using females. From data contained in Sykes, Jr. (1980)





sizes and a second converting population sizes to their natural logarithm; the latter generally produces more reliable estimates.

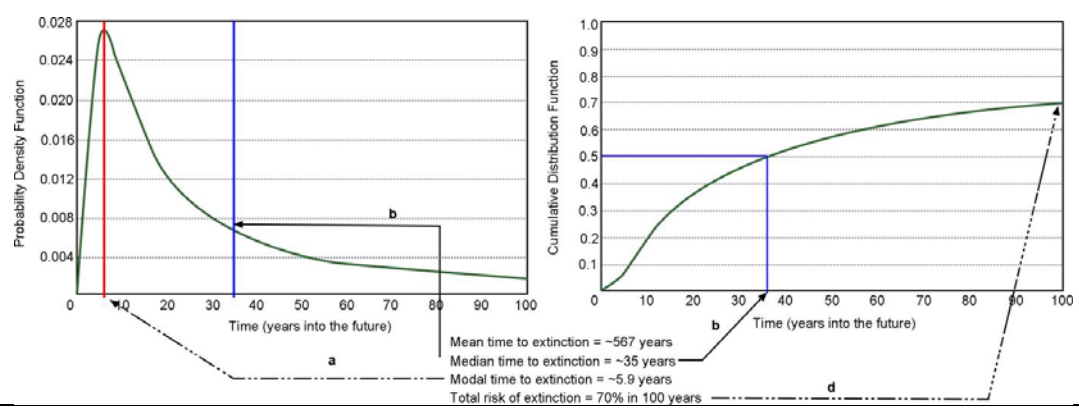
It is fairly easy to estimate a population's or species' time to extinction using the trend function available in most spreadsheet software. Build a table with one column containing the years, accompanied by a second column containing the population estimates for a particular year. Then display the data in a chart (either scatter plot or line chart) and use the "trend" function (linear trend) to create an estimate of the time to extinction (for example, in Excel you would select Chart from the menu and select the command "Add Trendline").

Mean Time to Extinction

The *mean time to extinction* estimates the average number of years it would take for a population or a species to decline to zero individuals. The correct interpretation of the mean time to extinction is "Based on current population trends, on average the species could be expected to become extinct by 2020" or "Based on current population trends, on average the species has about 20 years before extinction." This measure of risk also appears in the published literature as "The species is estimated to have an average of n years before extinction" or "The species had an average risk of becoming extinct by 2020" although these interpretations misrepresent the accuracy and precision of this measure of extinction risk. Our interpretations should specify whether simulations were deterministic (that is, they did not allow variables to vary over time) or stochastic (that is, they allowed one or more variable to vary over time).

The mean time to extinction is the most common way of measuring a species' risk of extinction, although it will tend to underestimate a species' extinction risk compared with other measures of risk (see figure 4). Depending on the method used to calculate this measure, the mean time to extinction might ignore the effect of population variance on extinction risk, ignore the effect of population structure or composition on a population's or species' extinction risk, and might not produce a confidence interval that can be used to assess the reliability of the estimate. Some of these methods are easy to compute using spreadsheet software like Excel or more advanced analytical packages like *Matlab* or *Mathematica* have commands that will automatically compute the mode of a distribution of values (for example, you can compute the mean of any distribution using the *Descriptive Statistics* of the Excel *Data Analysis* add-in).

Figure 4. Different measures of risk illustrated using data from the California clapper rail. The left chart shows a probability distribution function (PDF) for the amount of time required for the population to decline to 5 individuals; the right chart shows the same information as a cumulative distribution function (CDF). The mean time to extinction (line not shown) had been estimated as 567 years; the median time to extinction (which is easily read off of the CDF, line b) is ~35 years; the modal time to extinction (which is easily read off of the PDF, line a) is ~ 5.9 years. The total risk of extinction (line d) is 70% in 100 years. See text for discussion. Figure adapted from Morris and Doak (2002).



Median Time to Extinction

The *median time to extinction* is the time at which half of all simulations estimate it would take for a population or a species to decline to a threshold (this measure usually estimates time to quasi-extinction — or a pre-set, lower population threshold — rather than absolute extinction). The correct interpretation of the median time to extinction is "Based on simulations using the species' current population patterns, the species' median time to extinction is *n*-years." Our interpretations should specify whether simulations were deterministic (that is, they did not allow variables to vary over time) or stochastic (that is, they allowed one or more variable to vary over time). See Line B, Figure 4, for an illustration of median time to extinction.

Dennis et al. (1991) and Morris and Doak (2002) argue that the median time to extinction is one of the best ways to measure a species' risk of extinction and have offered several ways of calculating this risk using census data, life tables, or projections of population matrices. Depending on how it is computed, this measure of risk can include the effect of population variance on extinction risk (the greater the variance, the greater the risk), the effect of population structure or composition on the population's extinction risk, and will produce confidence intervals that can be used to assess the reliability of the estimate. The estimated time to extinction has been applied to Bay checkerspot butterflies (Morris and Doak 2002), desert tortoise (Morris et al. 1999), whooping cranes (Dennis et al. 1991), Palila (Dennis et al. 1991), Puerto Rican parrots (Dennis et al. 1991), red-cockaded woodpecker (Dennis et al. 1991, Morris et al. 1999), and grizzly bears (Morris et al. 1999, Morris and Doak 2002), among others.

The methods used to compute the median time to extinction are more complex than those used to compute the estimated time to extinction, but some of the more commonly-used methods only require census information (see Dennis et al. 1991; Morris et al. 1999; and Morris and Doak 2002). Spreadsheet software like Excel or more advanced analytical packages like *Matlab* or *Mathematica* have commands that will automatically compute the mode of a distribution of values (for example, you can compute the median of any distribution using the *Descriptive Statistics* of the Excel *Data Analysis* add-in).

Modal Time to Extinction

The *modal time to extinction* is the time at which the greatest number of all simulations estimate it would take for a population or a species to decline to a threshold (like median time to extinction, this measure usually estimates time to quasi-extinction — or a pre-set, lower population threshold — rather than absolute extinction). The correct interpretation of the median time to extinction is "Based on simulations using the species' current population patterns, the species' most common time to extinction is *n*-years." Our interpretations should specify whether simulations were deterministic (that is, they did not allow variables to vary over time) or stochastic (that is, they allowed one or more variable to vary over time). See Line A, Figure 4, for an illustration of modal time to extinction.

As you can see from Line A, Figure 4 (preceding page), the modal time to extinction will often overestimate a species' risk of extinction compared to other measures (that is, it will predict the lowest times to extinction). This is primarily because most distributions of a species' time to extinction are right skewed (see the left chart in Figure 4, the risk of extinction is higher in the short-term, then tapers to the right). Depending on how it is computed, the modal time to extinction can include the effect of population variance on extinction risk (the greater the variance, the greater the risk), the effect of population structure or composition on the population's extinction risk, and will produce confidence intervals that can be used to assess the reliability of the estimate.

The methods used to compute the modal time to extinction can be fairly simple: spreadsheet software like Excel or more advanced analytical packages like *Matlab* or *Mathematica* have commands that will automatically compute the mode of a distribution of values (for example, you can compute the mode of any distribution using the *Descriptive Statistics* of the Excel *Data Analysis* add-in).

Probability of Extinction in an Interval of Time

The *probability of extinction in an interval of time* is the a population's or species' probability of declining to a lower population threshold (like several of the earlier measures, this measure of extinction usually estimates time to quasi-extinction — or a pre-set, lower population threshold — rather than absolute extinction). This measure of risk is usually represented as $P(e)_x$ where x is the interval of time.

This measure of extinction risk most commonly appears as "the probability of extinction (or quasi-`extinction) in 100 years" or $P(e)_{100}$ (for example, Gaona *et al*. 1998, Morita and Yokota 2002, Shephard *et al*. 1997). For example, see Line D, Figure 4 (preceding page) which illustrate the California clapper rail's probability of extinction in a 100 years. However, it is important to remember that there is nothing magical about a 100-year forecast; in fact, the further into the future we forecast, the more variance we add to the forecast and the more unrealistic those forecasts can become (Feiberg and Ellner 2000, Morris and Doak 2002). To correct for this problem, estimates of extinction risk should report probability of extinction over a shorter series of time intervals that can include long-term projections (for example, probability of extinction over 10, 25, 50, and 100 years). Because of this problem, we should not use this measure of risk to forecast far into the future (forecasts further than 100 years). Any estimate of a species' probability of extinction over an interval of time should specify whether simulations were deterministic (that is, they did not allow variables to vary over time) or stochastic (that is, they allowed one or more variable to vary over time). To convert the probability of extinction in an interval of time into probability of persistence over that same interval of time, subtract P(e) from 1 (probability of persistence in an interval of time = $1 – P(e)_x$)

The probability of extinction in an interval of time is one of the most common measures of extinction risk in the literature. It has been applied to grizzly bears (Morris et al. 1999, Morris and Doak 2002), Iberian lynx (Gaona *et al*. 1998), white-spotted char (Morita and Yokota 2002), and Westslope cutthroat trout (Shephard *et al*. 1997), any of extinction simulations conducted using VORTEX software (for example, Florida panther, key deer, Karner blue butterfly, or Kirtland's warbler), or simulations conducted for the International Union for the Conservation of Nature Specialist Survival Groups (for example, Ethiopian wolf and African rhinoceros), which also use VORTEX software.

The methods used to compute the probability of extinction in a particular interval of time cover the range of complexity and can rely on census information, life tables, and matrix population models. The methods can be deterministic or stochastic; the latter will often rely on software developed specifically for population projection (for example, VORTEX and Poptools, which have been included on the compact disk distributed in this class).

Probability of Extinction

The *probability of extinction*, also called the *probability of ultimate extinction*, is the probability of extinction at any time in the future. For a variety of reasons, this measure of risk is not as common as the other measures discussed in this study guide. In essence, the probability of extinction is a long-term forecast of a species' extinction risk and, as a result, is very sensitive to any assumptions used to produce the estimate. In addition, most species can be expected to

become extinct over geological time intervals, so this measure of risk tends to incorporate some of that certainty.

The probability of extinction is also a measure of risk commonly applied to metapopulations, multi-site populations, or regional populations (Caughley and Gunn 1994, Gotelli 2001, Morris and Doak 2002). As a result, this measure of risk can be useful when you are dealing with multiple populations or subpopulations and want to estimate how increasing or decreasing the extinction risk to one or more of these populations (or subpopulations) changes the extinction risk of the metapopulation or regional population (see Gotelli 2001, pages 83 – 96 for methods and examples).

Concluding Remarks

In the scientific literature, a species' risk of extinction is captured by a small number of measures: time to extinction, mean time to extinction, modal time to extinction, median time to extinction, probability of extinction in a particular time interval, and probability of extinction. These measures of a species' risk of extinction provide a common set of terms and common units of measure that are essential to interagency consultation, if for no other reason than they unit our discussions with those of the larger scientific community.

Because of the strengths and weaknesses of the methods used to compute these measures of risk, you should use more than one measure of risk in any consultation instead of a single measure. That will allow you to use one measure to verify estimates produced by the second measure. Different authors recommend different measures, but generally

1. Median time to extinction provides the most unbiased estimate of a species' extinction risk.
2. Mean time to extinction will tend to underestimate a species' extinction risk.
3. Modal time to extinction will tend to overestimate a species' extinction risk.
4. Probability of extinction in a particular interval of time is more robust when we do not forecast too far into the future (ideally 10, 25, or 50 years instead of 100 years). The more variance associated with our estimates, the more unrealistic our long-term forecasts become.
5. Several authors have recommended using *median time to extinction* AND *probability of extinction* in a particular interval of time as the most reliable measures of the extinction risk facing species or populations (Beissinger and Westphal 1998, Burgman et al. 1993, Morris and Doak 2002).

Whenever you encounter or use these measures of risk, insist on receiving and providing a confidence interval for your estimate (which the illustrations in this study guide did not provide to make it easier to focus on the actual measures of risk).

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