ICES WKPOOR1 REPORT 2009

ICES ADVISORY COMMITTEE

ICES CM 2009\ACOM:29

Report of the Workshop on analytical methods for evaluation of extinction risk of stocks in poor condition (WKPOOR1)

18-20 May 2009

Copenhagen, Denmark

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2009. Report of the Workshop on analytical methods for evaluation of extinction risk of stocks in poor condition (WKPOOR1), 18-20 May 2009, Copenhagen, Denmark. ICES CM 2009\ACOM:29. 21 pp.

Contents

Executive Summary

This report summarizes key findings and recommendations of the Workshop on analytical methods for evaluation of extinction risk of stocks in poor condition [ICES WKPOOR1] held in Copenhagen, Denmark, 18-20 May 2009. The report examines a number of general methods to estimate the risk of extinction in exploited marine populations and provides guidance for their application to actual fish stocks.

The three general methods examined were: (1) screening methods, (2) simple population viability analysis based on time trends, and (3) age structured population viability analysis. These methods were evaluated in terms of information needs, reliability of estimates of extinction risk, and the rates of false positives and negatives. Application of the guidance provided by this group for specific fish stocks will be made during a second workshop (ICES WKPOOR2) scheduled for August 2009.

A total of five scientists from five countries participated in the workshop. One working document on simulation studies of stock dynamics and routes towards extinction was presented during the WKPOOR1 workshop, and a series of oral presentations dealt with additional simulation studies conducted for the meeting, a general review of population viability analysis, an application of population viability analysis and minimum viable population estimation, and general issues raised in the literature distributed prior to the meeting. This workshop was the result of a request to ICES from Norway for evaluation of the International Union for Conservation of Nature (IUCN) criteria used for redlisting of marine fish species. These criteria are based on screening methods and population viability analysis to classify populations. These criteria have been difficult to apply to exploited marine fish populations in general. This workshop did not create a competing classification system, but rather focused on the provision of pro-active management advice.

The workshop ranked screening methods, simple population viability analysis, and age structured population viability analysis low to high for information needs and reliability and high to low for rates of false positives and negatives, respectively. However, none of the methods were considered to produce accurate quantification of the risk of extinction. Screening methods can be misled by expected large changes in exploited marine populations that are not associated with extinction risk. Population viability analysis can be used to compare relative risks of different management options, but absolute risk cannot be estimated due to the final step to extinction usually being caused by a catastrophe, which by definition is a rare event and difficult to predict. The workshop instead suggested examination of the dynamic response of the stock to management as the guiding principle and concluded that fishery models should be used to explore the potential for stocks becoming depleted and potentially going extinct due to a catastrophe.

1 Opening of the Meeting

Chris Legault (USA) welcomed participants to Copenhagen for the meeting of WKPOOR1, a workshop on analytical methods for evaluation of extinction risk of stocks in poor condition. There were five scientists from five countries participating in the meeting (Annex 1).

2 Agenda

A formal agenda was not prepared for this workshop. Instead the participants met each day Monday 18 May 2009 through Wednesday 20 May 2009 to discuss topics related to the TOR. Presentations were made on the first day and report writing the focus of the last day.

3 Introduction

This workshop was the result of a request to ICES from Norway for evaluation of the International Union for Conservation of Nature (IUCN) criteria used for redlisting of marine fish species. The specific tasks to be considered in the request were:

1. Review of the IUCN criteria and evaluate the suitability and usefulness of using these on marine fish species. Comparison with the ICES system of reference points.
2. Evaluate whether the risk analytical methods currently used by IUCN are suitable for marine fish species, and, if necessary, suggest other and more appropriate methods and procedures.
3. Discuss and suggest procedures and methods within ICES to gather and provide useful biological information about non-commercial species that may improve the redlist evaluation of these species.

In response, ICES arranged for two workshops. The first, WKPOOR1, would address methodological issues, while the second, WKPOOR2, would apply the results of the first workshop to a number of species of interest to Norway and ICES. The WKPOOR2 workshop will be held in Bergen, Norway in August 2009 chaired by Dankert Skagen (Norway).

3.1 Terms of Reference

The TOR for WKPOOR1 were

a) Review candidate methods for evaluation of risk of extinction for marine fish and shellfish including
   - i) screening methods, such as those based on relative stock size, the rate of stock decline, etc.
   - ii) methods that estimate population viability and extinction risk using empirical models that project trends, and
   - iii) methods that estimate population viability and extinction risk using age structured models and demographic information.

The methods should be evaluated in terms:

- information needs,
- reliability of estimates of extinction risk, and
- the rates of false positives (when a warning of extinction risk is triggered but should not have been), and false negatives (when a warning is not triggered but should have been). This question should also be addressed for situations when it is not possible to evaluate the extinction risks;

b) Identify among the reviewed methods those that are appropriate for marine fish and shellfish in the ICES area;

TOR a) is addressed in section 4 of this report. The three candidate methods are described in sections 4.1, 4.2, and 4.3, respectively, with a comparison of methods provided in section 4.4. TOR b) is addressed in sections 5 and 6 of this report. Guidance for WKPOOR2 is provided in section 7 of this report.

3.2 Role of ICES and IUCN

A role of ICES is to provide advice on managed marine fisheries. The goals of the IUCN Red List are to: identify and document those species most in need of conservation attention if global extinction rates are to be reduced; and provide a global index of the state of change of biodiversity. While related, these are two separate roles, as demonstrated by the difficulty IUCN has experienced trying to apply their listing criteria to managed marine fish species. This meeting was triggered by a request that ICES has not dealt with previously, evaluation of risk of extinction. The participants in this workshop do not want to create a set of competing listing criteria, but rather ensure that ICES will detect signals for appropriate management advice. In this way, even if the methodologies and working procedures used by the IUCN and ICES are the same, the way of dealing with the analysis results is quite different.

Many working groups in ICES have suggested the simultaneous use of multiple models when assessing the status of a stock. Similarly, this workshop suggests using more than one approach to get the widest overview of the situation of the stock and detect most of the signals that could lead to a potential extinction. This does not mean that any of the detected signals will necessarily imply the extinction of the stock by itself, but it could be the point to start investigating the situation. For example, ICES WGMG has looked at screening methods in terms of detecting changes but not in terms of risk of extinction (ICES 2008b). It is very difficult to relate a shift to an extinction risk, but it is important to be aware of what is happening and, if needed, develop a management action to response to the change.

3.3 Methodology

There are a wide range of approaches that try to deal with the dynamics of stocks that are in poor conditions. All of these approaches attempt to evaluate the potential for extinction of the stocks, either in a qualitative or a quantitative way. The typical way of working is to look at the available data and then determine the most complex modelling approach possible in the time available, but a possible alternative could be to look at each method and see when it is useful and when it is not.

Starting from the most basic data requirements are approaches based on screening procedures of the population, such as the relative stock size or the rate of stock declining.

These procedures have been used to create the IUCN redlist and other classifications, but ICES prefers to use them as an indicator for the advice. This approach should only be used as being complementary to others and not as an alternative when estimating risk of extinction. This is because it is only a point in time analysis, not a projection, meaning it cannot be used to make statements about future risk of extinction directly, but only by analogy. Since large declines in abundance are expected in even well managed fisheries, while small declines may cause a population to pass a tipping point and lead to an increased chance of extinction, these screening methods are not considered sufficient measures of extinction risk on their own.

Population Viability Analysis (PVA) is a method that projects a population forward using uncertainty to make statements about the probability of a population size falling below some predetermined level within a given number of years. PVA is commonly recommended as a means to compare proposed management options, instead of an absolute measure of the risk of extinction. The model structure for a PVA is determined by the question at hand, the available data, and important characteristics of the species.

The first of these approaches is the Simple Population Viability Analysis using Time Trends. The only data needed for this approach are a measure of population size over time to estimate the population growth rate and its uncertainty. Closed form solutions to the probability of the population falling below a given size within a fixed number of years can be made. One feature of these simple models is that the confidence intervals for the population expand with each additional projected year. These approaches are usually the prognostic of what would happen if conditions remain the same. The limiting factor of this type of approach is the stationarity assumption, meaning the conditions that generated the observed values will continue into the future.

The second approach of this group is the Age Structured Population Viability Analysis. There are diverse ways to deal with this approach: the standard procedure that extends the simple PVA to account for life stages or age structure allowing density dependence and other forms of non-stationarity in the projections; and adaptation of standard fisheries models used for management purposes can also be considered a form of PVA, as described below. Related to the standard procedure, there are some software packages available in the market, both commercial (e.g. RAMAS) and free use (e.g. Vortex), but none of them is open source. Alternatively, case specific PVA models can be developed from scratch. These standard PVA approaches are all based on the paradigm of projecting a population and calculating the probability that the population size will fall below some pre-determined size within a fixed number of years. Standard fishery models can easily be adapted to calculate these probabilities. The main advantage of adapting fishery models is that they have features specific to usual needs in this field, e.g. stock recruitment relationships with the potential for depensation. The alternative approach to using standard fishery models to evaluate the risk of extinction is to compare the stock and recruitment estimates with a replacement line for the current mortality rate. When total mortality is too high, the replacement line will be to the left of recruitment values associated with low stock size, causing the population to decrease. If depensation is present in the stock-recruitment relationship, or if the stock-recruitment relationship changes over time causing a smaller slope at the origin, too high a given mortality rate will cause the population to eventually go extinct. There is no time period involved in this comparison because it will depend upon the life history characteristics of the species, but continued recruitment below the replacement line will put the stock at risk of extinction.

4 Candidate Methods to Evaluate Risk of Extinction

4.1 Screening Methods

Screening methods are those that use point-estimates in time, or snapshots, to estimate current population status. These methods are not able to forecast information about the population regarding risk of extinction. Examples of screening methods include relative stock size, rate of stock decline, length/age distributions, and life history characteristics (growth rates, age-at-maturity, etc).

Approaches such as these have been used by other organizations, such as IUCN, to create redlists and other classifications. A previous ICES working group (WGMG) has also looked at screening methods, but only in terms of detecting changes, not in terms of predicting extinction (ICES 2008b). It is difficult to relate shifts in one or more of these parameters directly to a risk of extinction. They can only highlight that something has happened within the population, which could require a change in management.

Mechanisms that could lead to extinction, such as a change in the stock-recruitment relationship or spawning stock biomass per recruit, could cause a stock to be less resilient to fishing and potentially vulnerable to catastrophe; leading to extinction (see Section 4.3.2). Managers should look for signals related to these parameters using the screening methods. For example, changes in recruitment, fishing mortality, loss of habitat, alteration of migratory corridors, serial depletion of fish which is undetected by CPUE (congregated in space and time), changes in predator-prey interactions, or ecosystem contamination, could create problems that render a population more susceptible to extinction.

It is difficult to relate any of these screening methods directly to a risk of extinction. However, they can be a warning signal for managers and stimulate further investigation, such as age structured PVA or standard fishery projections, to consider the ability of the stock to sustain current or changed fishing mortality. When direct measurement of some parameters is not possible, Baysian approaches can be used to narrow down the range of possible values, especially when estimating parameters from distant time periods when data are sparse.

Since screening methods are snapshots only, they have very low reliability in predicting extinction and would therefore have high rates of false positives/negatives. However, these methods can provide the required insight into the current status of the population which can warn managers that something negative may be impacting the population and potentially increasing the risk of extinction.

4.2 Simple Population Viability Analysis Using Time Trends

This approach is often referred to as the Dennis diffusion model (Dennis et al. 1991). It is a simple approach that assumes an exponential growth model for the population. The mean (μ) and the variance (σ^2) for the population growth rate are used to project the population into the future as $N_{t+1} = N_t{*}\exp(\mu+\sigma)$, where N_t is the population at time t. Due to its simple formulation, analytic solutions can be found for distribution of abundance at any given time in the future. The simple form of the model also means that little data or knowledge about the species of interest is required, only a time series of abundance is needed. Typically, the number of reproductive adults or total adults is used as the metric of population abundance.

Due to the exponential form of the equation, the population cannot decline all the way to zero, so a quasi-extinction threshold is typically assumed which corresponds to a level from which the population is not expected to recover. The population projections can be made to examine the distribution of quasi-extinction times or the risk of extinction within a fixed number of years.

The mean and variance of changes in population abundance can be estimated from a time series of census or survey data. These estimates are often biased if measurement error is large, leading to over estimation of extinction risks. The Dennis-Holmes model addresses this issue by partitioning the error into process and observation error using a running sum transformation of the data (Holmes 2004). Risk estimation is still conducted using the mean and variance of an exponential growth function, it is just a different way to estimate the mean and variance that is less biased when measurement error is present.

When applying these methods to actual cases when populations went extinct, it has been found that extinction events are typically outside the range of observed variation (Simberloff 1988; Caughley 1994; Holmes et al. 2005). These extinction events were caused by catastrophic events that could not be predicted based on previous observations. This means that populations can fluctuate at low levels for an indeterminate amount of time until a catastrophic event causes the actual extinction. Since prediction of catastrophes, by definition very rare events, is difficult, quantitative estimates of extinction risk cannot be made.

Use of these simple PVA models typically requires a long time series of data. General rules of thumb include recommendations that for projecting T years into the future, at least five to ten times T years of observations are needed. The predictive power of these models decreases dramatically with shortened time series. Even with long time series, these models can have large errors in extinction rate predictions. Due to the mathematical construct of the model, all projections with zero or negative population growth rate will eventually have some portion of the projected distribution drop below any positive quasi-extinction threshold. Thus, the time horizon for projections is an important consideration when using this approach.

Rules of thumb for setting the quasi-extinction threshold and the number of years in the projection horizon have not been fully described in the literature (Beissinger and McCullough 2002). Typical values for the time horizon are 50 or 100 years, or some multiple of generation time for the species under consideration. The quasi-extinction threshold is either set based on an absolute value thought to have significance for the case under consideration or else as a proportion of the unexploited or previously observed values. Due to the large differences in life history strategies among animals, it has been difficult to create general rules of thumb that apply in all situations (Beissinger and McCullough 2002).

The major assumption made in these simple PVA approaches is that all processes are stationarity or that non-stationary processes can be directly linked to changes in the population growth rate and variance. This assumption has been questioned for these simple approaches (Coulson et al. 2001). In the context of managed marine fisheries, it is highly unlikely that fishing mortality rates would be stationary when a stock reaches a low enough level to be under consideration of extinction risk. However, making the connection between past estimates of population abundance given a range of previous fishing management actions relative to proposed future management actions in terms of the population growth and variance is not easy.

Catastrophic events cannot be easily included in these simple PVA approaches because by definition they fall outside the range of normal variability in the population growth rate. The ability to predict catastrophic events is low. According to Coulson et al. (2001), attempting to include a probability distribution for future catastrophes amounts to little more than guesswork. Given both the difficulty in meeting the stationarity assumption and the inability to predict catastrophes, it has been recommended that these simple PVAs not be used for direct estimation of extinction risk but rather be used as a tool to compare the relative risk of alternative management options (Coulson et al. 2001).

False positives (warning of an extinction risk when it is not warranted) can arise in this method if the population growth rate variance is overestimated. This can occur due to large measurement errors, as discussed above, which would be expected to occur in marine fishery surveys. Large year classes, highly variable fishing intensities, or strong environmental effects during the observation period could also artificially inflate the population growth rate variance, leading to false positives. False negatives (failing to warn of an extinction risk) will occur when the time series of observations results in a mean population growth rate that is zero or positive but the stock gets low enough for depensation to occur, causing a sudden and unexpected decline. Additionally, false negatives can arise due to unforeseen catastrophes that suddenly reduce the population size to an unsustainable level.

To date, only relatively simple statistical approaches have been used to estimate the population growth rates and variances for diffusion models. More advance statistical techniques, such as the Kalman filter or recursive residuals, could be borrowed from other fields, such as econometrics, to improve the predictive capabilities of these models.

Generally these approaches are applied to populations with low absolute numbers, not populations with large absolute numbers, due to the need to assume stationarity. If a population changes size dramatically during the observation period, the productivity of the population may change. In the marine fish context, compensation is expected in the stock-recruitment relationship as the stock is fished down from unexploited conditions. If depensation occurs at low stock size, this simple approach will have difficulty detecting it. Given this and the expectation that future management responses will also break the stationarity assumption, the simple PVA using time trends approach is not generally an appropriate fallback for marine fishery populations if age structured approaches cannot be used. For non-targeted species, e.g. bycatch or protected species, with no directed management actions, the stationarity assumption may be a more tenable assumption and application of this approach may be warranted.

4.3 Age Structured Population Viability Analysis

4.3.1 Standard PVA Methods

The standard approach to age structured population viability analysis is just an extension of the simple PVA described in Section 4.2. It uses the same framework of estimating probability of extinction by projecting a population forward in time and determining the proportion of projections that fall below a quasi-extinction threshold within a given timeframe (or the distribution of number of years it takes for the population to have a given probability of falling below the quasi-extinction threshold). As such, it suffers from the same difficulty of setting the appropriate time horizon and quasi-extinction threshold as the simple PVA.

The age structured PVA approach differs from the simple PVA by including specific processes that cause the population to increase or decrease instead of just a mean and variance of the population growth rate. This added complexity means that analytical solutions cannot be used, except in rare occasions, and many trajectories of possible future population sizes must be made to estimate the risk of extinction. The benefit of the this added complexity is that the stationarity assumption can be met for individual parameters or specific changes to parameters can be made to account for known or expected changes in these values. For example, if individual growth rates are known to increase when the population size decreases, this feature could be included relatively easily in an age structured PVA, while it would be much more difficult to estimate its impacts on the mean and variance of the population growth rate in the simple PVA approach.

There are a number of canned software packages available to conduct age structured PVA, such as RAMAS (Ferson and Akcakaya 1989; http://www.ramas.com/riskcalc.htm) and Vortex (Lacy 1993; http://www.vortex9.org/vortex.html). These packages enable users to enter the information available for a species relatively quickly and conduct projections to estimate risk of extinction. The advantage of these packages is their large user base, standardized reporting, and general acceptance. However, these programs are generic and may not lend themselves easily to issues faced by managed marine fisheries.

Alternatively, custom built age structured PVA programs have been created many times for specific cases (Beissinger and McCullough 2002). These applications often focus on relative risks of extinction of different management options instead of focusing on absolute extinction risk, as described in Section 4.2 for simple PVA. Also similar to the simple PVA approach, catastrophic events cannot be forecast with any reliability, making the absolute risk estimates highly suspect. However, the added complexity of age structured PVAs allowing the stationarity assumption to be better met would imply higher reliability of this approach relative to the simple PVA approach.

The added complexity of age structured PVAs allows closer approximation to reality than simple PVA approaches, but comes at the price of having to supply more information to the model. Many processes must be defined and perhaps just as importantly, the uncertainty of the parameters and any covariances among parameters must be included. In the marine fishery context, obvious sources of uncertainty arise in the stock recruitment relationship, but more difficult to estimate are covariances among parameters such as the natural mortality rate and growth. Additional problems can arise due to misageing or incorrect classification of maturity stages in the marine fisheries context. When four generic software packages were compared using the same real world data, they performed similarly for simple data situations. However, when applied to more complex data situations, there was a wide range of results (Brook et al. 1999).

In the age structured PVA, not all data inputs need to be direct estimates. Life history parameters can be borrowed from similar species or expert knowledge can be utilized to fill in data gaps. However, less precise input data will lead to wider confidence intervals in the projections and increase the possibility of false positives. Alternatively, ignoring uncertainty of many parameters could artificially decrease the confidence intervals in the projections increasing the possibility of false negatives.

However, this approach is still considered the most reliable of the three approaches at estimating the risk of extinction and is expected to have the lowest rates of false positives and negatives (Maunder 2004).

4.3.2 Adaptation of Standard Fishery Models

For fisheries management advice, a number of computer programs have been developed that simulate the time course of a stock in response to management actions. The basic elements in these methods are similar to that in standard PVAs. Such simulation programs could be used, with some adaptation, for evaluating stocks with respect to risk of extinction.

Typically, these programs have an operating model, which projects an artificial 'true' stock forwards in time with the decided removals, and a decision model that derives removals according to the management rules under study. The operating model is usually age-structured, although age-length structured as well as biomass based models also exist. Most models are single species, but multi-species models are also exist (e.g. Gadget and SMS), although these would be more difficult to apply in a PVA context. The models include stochastic elements and are run as a bootstrap with a large number of realizations of the stochastic terms. Statistical measures of the results are derived from the distribution of results between the realizations. The typical time frame is 10 - 30 years, but that can easily be extended.

Observations that form the basis for management decisions are derived from the 'true' population with noise, either directly as numbers or biomasses with added noise, or as noisy 'observations' that are fed into an assessment tool. The programs have decision rules that lead to decisions on removals. The real removals are then derived from the decided ones by an implementation step, where noise and/or bias can be introduced. The real removals are fed into the operating model.

A number of such methods have been developed and used within the ICES community in recent years (FLR, FPRESS, STPR, HCS, PROST, SMS, etc.). All these methods have the same basic algorithms and can (at least in principle) be used interchangeably. In practice, many analysts prefer to use their own programs, since it very often is necessary to make modifications for each stock under study, both to include specific dynamic properties and to include various harvest rules under discussion. Details can be found in the reports from SGMAS (ICES 2006, 2007, 2008a).

The dynamics of the operating model is specified through a stock-recruitment function, a selection at age in the fishery, natural mortality and weight and maturity at age, in addition to level of fishing mortality coming from the decision/implementation step. Stochastic terms are introduced through random multipliers (according to a specified distribution) to the deterministic values for recruitment, weight, maturity, observations and decided removals. To use these methods, plausible choices of the parameters have to be made. The information for that may come from analytic assessments, or from other sources of information about stock dynamics and the fishery. Some inferences may be valid over a wide range of parameter choices. Hence, some useful inferences can be made with these simulation tools even if the supporting data are incomplete. On the other hand, the results will be critically dependent on some other parameter choices, in particular the stock-recruitment b-parameter (the level of SSB where the recruitment becomes impaired), relative to the stock-recruitment a-parameter (the parameter determining the level of the recruitment), as the ratio between these determines the maximum sustainable fishing mortality.

As the stock-recruitment function is specified directly in these methods, and the SSB per recruit as a function of fishing mortality is easily derived, it is straightforward to relate the outcome to the replacement line corresponding to each level of fishing mortality to stock-recruitment specifications, which is a major advantage over the commercial PVA packages. This relationship will indicate whether a fishing mortality rate is sustainable or not independent of the time horizon, while the commercial PVA packages are based on the time horizon paradigm.

In studying possible extinction, these models can serve two purposes:

1. With the necessary modifications of the dynamic parameters, the effect of e.g. trends or drops in the recruitment or changes in weights at age or the selection pattern can be studied. For example, the recruitment function may include a trend or a shift in the a-parameter, occasional very strong year classes, periodic variations in the recruitment, depensation towards low spawning biomasses etc. The effects can be studied both with respect to rates of increase or decline, and to the long term outcome, including recording realizations that get trapped in a continuous decline towards very low levels of abundance.
2. The effect of management measures can be simulated, as well as the robustness of management rules to changes in stock dynamics, leading directly to outlining necessary management actions with respect to exploitation.

4.4 Comparison of Methods

4.4.1 Screening Methods Compared to Simple PVA

Screening methods use information from the present and past to make a statement about current conditions, but do not attempt to quantify the future levels. They also allow the use of qualitative information which can easily be incorporated in the PVA modeling approaches. Simple PVA using time trends is applied to absolute or relative time series of stock abundance, typically reproducing adults. No knowledge of the biology of the species is required and the model can be verified with artificial data using an age structured operating model. While only relatively simple data are required for these methods, there are a number of shortcomings to both approaches that limit their applicability to marine fishery populations.

For the screening methods, simple population simulations can easily demonstrate large declines in a population followed by large increases due to recruitment pulses, changes in management, changes in natural mortality rates, etc. Conversely, simulations which include depensation in the stock recruitment curve and a high mortality rate will cause the population to go extinct, even though the relative change in abundance may only slowly decline. A categorization of a risk of extinction based on screening methods would be expected to have high rates of false positives and negatives for managed marine fisheries.

For the simple PVA, the stationarity assumption is a strong requirement, especially in the context of managed stocks which should change F in response to declining populations. If there are indications that the assumption of stationarity is violated, then this method is not recommended. If the stock is a non-commercial species, e.g. bycatch or protected species, it may be possible to make the assumption of stationarity and apply this approach.

If it is known that something has changed and when it has changed, then it is possible to account for this change and only use the data since the change, at the cost of a shorter time series of data to estimate the population growth rate and uncertainty. This approach has been recommended as a relative metric to compare scenarios instead of using it as an absolute estimate of the risk of extinction. When used in relative terms, the stationarity assumption is less critical.

If either approach is used, WKPOOR1 does not recommend specific values for the amount of decline necessary in a screening method to warrant concern, or the number of years in the projections, how to set the quasi-extinction threshold, or the appropriate level of risk in a simple PVA. This is because all these values will depend heavily on the specific case under consideration. In particular, in a simple PVA, the risk of extinction, e.g. probability of falling below the quasi-extinction level, will depend on both the time horizon and the quasi-extinction level due to the ever expanding confidence intervals over time.

4.4.2 Simple and Age Structured PVAs

A difference between the time series and age structured PVA approaches is the ability of the age structured approach to incorporate non-stationarity directly. For example, management changes which reduce F can explicitly be incorporated instead of indirectly related to an expected change in the population growth rate. Similarly, depensation at low stock size or compensation at high stock size in the stock-recruitment relationship can be explicitly examined in an age structured PVA instead of trying to externally change the population growth rate as a function of stock size in a simple PVA.

Both PVA approaches project the population forward, one as a distribution of ages while the other projects individual trajectories with random parameters. Projections of biomass aggregated assessments would fall in between these two approaches. The simple PVA approach expands the confidence interval with each additional projected year while the age structured approach confidence intervals typically stabilize at some point in time. Both approaches attempt to quantify the risk of extinction using probability statements for the population abundance falling below some predetermined level. Age based projections are usually scenario based while the time series approach are usually prognostic of what would happen if conditions remain the same.

4.4.3 Detailed Pros and Cons of the three approaches

Data needs

- Screening: anything related to ability of the stock to sustain itself.
- Simple PVA: time series of measures of abundance: reproductive adults (best); absolute or relative magnitude.
- Age Structured PVA: enough to parameterize the model being used, not necessarily an age based assessment but at least a proxy for it, can use guesstimates for some parameters if necessary.

Limitations

- Screening: no projections so cannot forecast extinction.
- Simple PVA: assumes stationarity (difficult in commercially fished stocks).
- Age Structured PVA: have to explicitly deal with non-stationarity and parameter covariances.

Incorporation of management measures

- Screening: indirectly. Can act as warning signal for further investigation which may/not be related to management (or lack thereof).
- Simple PVA: difficult to translate specific management measures into changes in the population growth rate and sigma.
- Age Structured PVA: yes with fishery types of models, may be more difficult with generic PVA software packages.

Need to develop software/programs

- Screening: not necessary but could be done for specific questions or data situations.
- Simple PVA: existing software, easy to create own basic approaches, difficult to extend theory to utilize more advanced statistical techniques.
- Age Structured PVA: Existing software packages for standard approaches, but may get inconsistent results from the varying generic packages. Customized fishery specific models will require minor modifications to existing fishery packages.

Time requirement to conduct analysis

- Screening: short to long depending on how many factors considered and how detailed in consideration, will take at least some time because a diversity of information is needed.
- Simple PVA: quick once time series assembled.
- Age Structured PVA: involved due to large number of options, settings, and scenarios, can be quick if just drop existing data into a program (but need to use caution).

Ability to estimate risks and timeframes

- Screening: no
- Simple PVA: yes, computes probability of being below quasi-extinction threshold within a given timeframe. Should not produce quantifiable level of risk from this approach.
- Age Structured PVA: yes, the generic software computes probability of being below quasi-extinction threshold within a given timeframe. This approach can also be done with fishery specific software. Both age structured PVA approaches require that uncertainties and covariances are properly addressed.

Foundation for classification of risk of extinction?

None of these methods gives a firm basis for classifying stocks according to estimated levels of risk. This is because actual extinction of the stock will probably result from a catastrophe that cannot be predicted or foreseen in these types of calculations. Management should prevent stocks from decreasing to a level where it is vulnerable to a catastrophe. These methods should provide guidance to managers to take adequate action to ensure sufficient protection for the stock.

4.4.4 Summary of methods with respect to TOR:

Based on discussions by the WKPOOR1 participants, the information needs, reliability, and rate of false positives and negatives for the three methods were ranked in the table below. However, these rankings do not imply endorsement of any of these methods for evaluation of the risk of extinction. None of these methods can produce accurate quantifiable levels of risk of extinction. WKPOOR1 suggests instead examination of the dynamic response of the stock to management as the guiding principle, with emphasis on preventing stocks from becoming so reduced that there is concern about extinction.

Method	info needs	reliability	false +/-
Screening	Low	low	high
Simple PVA	intermediate	intermediate	intermediate
Age Structured PVA	High	high	low

5 Discussion

5.1 Methodology

When applying screening methods, consideration should be given to developing hypotheses relative to forcing functions. A given time trend can be explained many different ways, with large differences in management responses expected depending on the true cause. The dynamics of exploited marine populations lead to expectations of large changes in abundance. As demonstrated by many simulations, large declines in abundance can be insignificant relative to risk of extinction while long slow declines may be the precursor to an actual extinction caused by a catastrophe. There are no records of extinction in commercially exploited marine fish to date, so empirical evidence of causes of future extinctions will necessarily be extrapolations.

The conservation biology literature agrees with the use of PVA as a method to compare alternative management strategies with respect to risk of extinction, but rarely recommends using the actual quantitative risk estimates directly. WKPOOR1 agrees with this approach, but extends it to focus on stock-recruitment dynamics and replacement lines as a better indicator of when concern should be raised of the possibility of extinction. The numeric calculation of an extinction risk can be made with standard fishery models, but will be highly dependent on the assumptions made regarding recruitment at low stock sizes and the arbitrarily chosen quasi-extinction level and number of years in the projections. Focusing instead on the management response to indications that stock dynamics have changed is a pro-active approach that is more aligned with the role of ICES than simply creating artificial cut-offs for classifications of risk of extinction. This basic philosophy can be summarized as do not ask how much of a decline has occurred, ask why did the decline occur.

In all the methods examined, it is important to consider the specifics of the stock under consideration. Blind application of any of these methods will almost certainly cause nonsensical conclusions to be reached. Even informed application of these methods can lead to conflicting advice, as demonstrated by the application of four generic PVA software packages to the same complex data (Brook et. al 1999). Focusing on the response of the stock to management interventions should prevent stocks from becoming so low that risk of extinction is a reality.

5.2 Implications for Management Advice

In order to cause a stock to go extinct, it requires a fishing mortality rate too high leading to a progressive recruitment failure. A catastrophe occurring when the stock is at an extremely reduced level could then cause it to go extinct. Management should take action to prevent this situation long before the population is in such a low state.

The management advice does not follow directly from the results of the methods described above. The typical PVA estimation of extinction risk is not directly applicable to advise on managed marine fisheries. Rather, it will to a large extent depend on the underlying stock dynamics, in particular the fishing mortality and the relation between stock and recruitment. The following factors should be relevant for the advice:

1. The state of the stock (satisfactory or reduced)
2. The recruitment dynamics (normal or reduced recruitment rel. to SSB)
3. The current fishing mortality relative to highest sustainable F.
4. Whether there is a functioning management in place.

If the state of the stock is considered satisfactory (for example SSB > Bpa), the current management in general can be maintained. However, if there are indications that the fishing mortality is above the sustainable level and/or the recruitment is poorer than normal, the fishing mortality should be reduced to a level that is sustainable under the prevailing conditions, even before the stock has reached a low level.

If the stock is reduced, current management may still be adequate. That will depend on the cause of the reduction, which can be reduced recruitment, high fishing mortality or both. The reduction in stock may also be caused simply by normal variations in recruitment, or by the gradual reduction of an outstanding year class, none of which should cause alarm.

If the reduction of the stock is caused by a fishing mortality that has increased towards or beyond sustainable levels, the fishing mortality needs to be reduced. If the recruitment dynamics still are normal relative to the SSB, recovery can be expected and the time to recovery can to some extent be predicted. If the decline is caused by a reduced recruitment beyond what can be regarded as normal recruitment variation, the fishing mortality also needs to be reduced, taking into account that this may have led to a change in the highest sustainable fishing mortality. Additional measures, to improve the environment for the stock should be considered, if possible. If it appears likely that the reduced recruitment is caused by permanent changes in the ecosystem, one may aim at adapting the exploitation to the new recruitment regime. However, if the cause of the recruitment failure is unclear, the fishing mortality should be reduced aiming at maintaining the SSB at a level that will facilitate a normal recruitment under normal conditions.

If the stock has severely declined, the obvious advice is to close the fishery. An exact limit for when a stock can be regarded as collapsed can hardly be given, in practice this would be when the stock is reduced to a small percentage of what it would be under optimal exploitation and normal recruitment. Future recovery can be expected if the stock-recruit relationship still is intact. If depensation or other change in stock recruitment dynamics that produces lower than expected recruitment occurs, then the future recovery may no longer be expected. Rebuilding the stock abundance will depend on factors that are poorly known, which makes the time to recovery quite unpredictable.

Changes in growth and maturity, as well as in the selection at age in the fishery may contribute to shifts in the highest sustainable fishing mortality, both through the time it takes to reach maturity and through the survival in that period. These factors should be considered, but will typically have less impact than the recruitment dynamics as such.

If a proper management is not in place, and the fishing mortality cannot be brought within a sustainable level, the stock will inevitably be progressively reduced. Some fisheries that apparently are self-regulating at a sustainable level may become unsustainable if the recruitment dynamics change or if there are incentives to increase the fishing mortality.

The final outcome of a progressive decline will depend on how the fishing mortality develops relative to the highest sustainable fishing mortality as the stock becomes very small. The highest sustainable fishing mortality may change if the stock-recruitment dynamics change as the stock becomes small. The actual fishing mortality may also change, depending on factors like profitability, whether the small stock tends to cluster or spreads out in the area and other factors, all of which may be hard to predict, with a catastrophe the likely final straw leading to extinction.

6 Conclusions

WKPOOR1 considers that for exploited marine populations the current screening methods and population viability analysis in general do not provide reliable estimates of population viability or extinction risk. Therefore, WKPOOR1 concludes that adapted fishery models be used to explore the potential for stocks becoming depleted and potentially go extinct due to a catastrophe. This situation will arise when the replacement line for current management actions is to the left of all recent stock and recruitment values, meaning that the stock is unable to replace itself. Use these methods to flag needs for advice to avoid developments that lead to depletion and potentially even extinction. Use all available information including screening methods to help define hypotheses related to the cause(s) of population declines.

The approach suggested by WKPOOR1 deviates from the approach taken by IUCN and other organizations. This is because emphasis has been on pro-active advice to avoid situations that can lead to extinction instead of classification. The intention here was not to create a competing classification system, but rather to focus on pro-active advice.

7 Guidelines for WKPOOR2

- Need to consider the stock, what do you know about it. No method should be applied without an understanding of the biological and fishery data.
- Consider a range of approaches. For screening methods, apply multiple metrics not just one.
- Try to do an age structured PVA approach if data are available.
  - Use both generic canned programs and the adapted fishery modeling approach, if possible, to compare risk predictions.
  - Fishery based approach preferred over generic PVA approach due to ability to examine standard management regulations and alternative stock-recruitment relationships.
- If use time horizon and probability of dropping below quasi-extinction threshold, then need to standardize time horizon and method of determining quasi-extinction threshold among all stocks considered.

8 References

Beissinger, S. R., and D. R. McCullough. 2002. Population viability analysis. University of Chicago Press, Chicago.

Brook, B.W., J.R. Cannon, R.C. Lacy, C. Mirande, and R. Frankham. 1999. Comparison of the population viability analysis packages GAPPS, INMAT, RAMAS and VORTEX for the whooping crane (*Grus americana*). Animal Conservation 2: 23-31. doi:10.1017/S1367943099000323

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology. 63: 215-244.

Coulson, T., G.M. Mace, E. Hudson, and H. Possingham. 2001. The use and abuse of population viability analysis. Trends in Ecology and Evolution 16(5): 219-221.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61: 115–143.

Ferson, S. and H.R. Akcakaya. 1989. RAMAS/Age user manual. Modeling fluctuations in age-structured populations. Applied Biomathematics: Setauket, New York.

Holmes, E. E. 2004. Beyond theory to application and evaluation: diffusion approximations for population viability analysis. Ecological Applications 14: 1272–1293.

Holmes, E.E., W.F. Fagan, J.J. Rango, A. Folarin, J.A. Sorensen, J.E. Lippe, and N.E. McIntyre. 2005. Cross validation of quasi-extinction risks from real time series: an examination of diffusion approximation methods. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-67, 37 p.

ICES. 2006. Report of the Study Group on Management Strategies (SGMAS), 23 - 27 January 2006, ICES Headquarters. ICES CM 2006/ACFM:15. 157 pp.

ICES. 2007. Report of the Study Group on Management Strategies (SGMAS), 22 – 26 January 2007, ICES Headquarters. ICES CM 2007/ACFM ;04. 59 pp.

ICES. 2008a. Report of the Study Group on Management Strategies (SGMAS), 17-21 November 2008, Lisbon, Portugal. 74 pp.

ICES. 2008b. Report of the Working Group on Methods of Fish Stock Assessments, (WGMG), 7-16 October 2008, Woods Hole, USA. ICES CM 2008/RMC:03. 147 pp.

Lacy, R.C. 1993. VORTEX: A computer simulation model for population viability analysis. Wildlife Research 20: 45-65.

Maunder, M.N. 2004. Population viability analysis based on combining Bayesian, integrated, and hierarchical analyses. Acta Oecologica 26(2): 85-94.

Simberloff, D. 1988. The contribution of population and community biology to conservation science. Annual Review of Ecology and Systematics. 19: 473-511.

Annex 1

List of Participants

NAME	ADDRESS	PHONE/FAX	EMAIL
Eider Andonegi	AZTI-Tecnalia AZTI Sukarrieta Txatxarramendi ugartea z/g E-48395 Sukarrieta (Bizkaia) Spain	Phone +34 94 602 9400 Fax +34 94 687 0006	eandonegi@suk.azti.es
Joachim Gröger	Johann Heinrich von Thünen-Institute, Institute for Sea Fisheries Palmaille 9 D-22767 Hamburg Germany	Phone +49 4038905266 Fax +49 4038905263	joachim.groeger@vti.bund.de
Christopher Legault Chair	National Marine Fisheries Services Northeast Fisheries Science Center 166 Water Street Woods Hole MA 02543-1026 United States	Phone +1 508 4952025 Fax +1 508 4952393	chris.legault@noaa.gov
Dankert Skagen	Institute of Marine Research P.O. Box 1870 N-5817 Bergen Norway	Phone +47 55 238419 Fax +47 55 238687	dankert.skagen@imr.no
Melanie VanGerwen-Toyne	Fisheries and Oceans Canada Central & Arctic Region 501 University Crescent Winnipeg Manitoba R3T 2N6 Canada	Phone +1 204 983 5137	melanie.toyne@dfo-mpo.gc.ca