1 INTRODUCTION

1.1 OVERVIEW

There are a variety of VPA-type methods, which form powerful tools for stock assessment. At first sight, the large number of methods and their arcane names can put off the newcomer. However, this complexity is based on simple common components. All these methods use age-structured data to assess the state of a stock. The stock assessment is based on a population dynamics model, which defines how the age-structure changes through time. This model is the simplest possible description of numbers of similar aged fish where we wish to account for decreases in stock size through fishing activities. The diversity of VPA methods comes from the way they use different types of data and the way they are fitted.

This manual is structured to describe the different components that make up a VPA stock assessment model:

> **Population Model** (Analytical Model) The population model is the common element among all VPA methods. The model defines the number of fish in a cohort based on the fishing history and age of the fish. A cohort is a set of fish all having (approximately) the same age, which gain no new members after recruitment, but decline through mortality. The fisheries model attempts to measure the impact catches have on the population. The population model usually will encapsulate the time series aspects of change and should include any random effects on the population (process errors), if any.
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> **Link Model** Only rarely can variables in which we are interested be observed directly. Usually data consists of observations on variables that are only indirectly linked to variables of interest in the population model. The models linking the population model to observable variables are many and varied. They, in general, separate the different VPA approaches. The most common observable variable is CPUE (Catch per Unit of Effort), which is often thought to be related to stock size. The link model in most cases will be associated with an observation error.
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> **Error Model** Finally, the model needs to be fitted to observations. The error model defines the criteria to do this, so that some objective best-estimate for the parameters and stock status are obtained. In VPA, weighted least-squares is often used as the fitting procedure, and this is the method discussed in this manual. A broadening of this approach allows the population and link models to describe parameters in any likelihood function. Although this latter approach may be preferred, it is more complicated and not discussed in detail in the manual.

The reason for discussing the models as separate components is because there is no general prescriptive VPA method. Instead, the readers should be able to use the components to develop VPAs suitable for their own fisheries. This manual aims to provide the readers with a degree of understanding so that they will be able to use spreadsheets and other software tools to carry out the numerical procedures necessary to conduct a non-standard VPA.

The methods explained are for illustration only and should not be taken as an endorsement of any method in any particular case. In some of the examples, data presented were extracted from ICES assessment working group reports. These data do not represent all information available for stock assessment, as they were selected to illustrate the methods only. The results differ from the ICES stock assessment results and should not be used for anything other than illustrating calculations. It is hoped that the readers will be given enough insight to evaluate methods for themselves and see whether any technique is applicable to their own data and fishery.

1.2 BACKGROUND

Virtual or Sequential Population Analysis (VPA or SPA) was introduced in fish stock assessment by Gulland (1965) based on older work (e.g. Fry 1949). The classical VPA analysis is not a statistical analysis, however, it is an important basis for the ADAPT and other statistical methods presented in the manual. The method is also very useful in itself as a tool for exploratory data analysis. For heavily exploited fish stocks, the method provides a good estimate of the recruitment of cohorts that have passed through the fisheries. Similarly, the estimate of fishing mortality for years dominated by cohorts that have passed through is fairly reliable provided the exploitation rate is high compared to the natural mortality. For a general discussion of the behaviour of the VPA technique, see Megrey (1989) and Mesnil (1989).

The population or analytical model applies to the unit stock (Cushing 1981). The unit stock is a group of fish of the same species that forms a reproductive unit (e.g. shares spawning grounds). A unit stock is assumed to have the same life cycle, similar growth rates and in general to be a single biological unit. It is assumed that there is no emigration or immigration (closed populations). However, some types of emigration can be incorporated in the model by assuming it as part of the age-dependent natural mortality. Explicitly including immigration and emigration requires that both the stock losing fish and the stock receiving fish be assessed simultaneously.

The unit stock is broken down into cohorts. A cohort is a group of fish that have the same age. This means that a cohort will have more or less the same size and will often be found in the same area at any point in time. Furthermore, a cohort will mature at the same time. The use of the cohort model requires an empirical method to separate different cohorts, usually through ageing based on otoliths or scales (Holden and Raitt 1974).

The population model is most often used in a single-species version. It is usually assumed that species interactions do not introduce variation in mortality or growth rates between years (i.e. M is constant from year to year). This assumption is relaxed in multispecies VPA (briefly described in Section 4.8).

VPA methods have been grouped in a number of ways:

- Based on the restrictions imposed in the data model; for example, Extended Survivor Analysis (XSA) does not include biomass indices for tuning the VPA.

- Based on the assumptions imposed, particularly on fishing mortality; for example, the ICA and CAGEAN methods assume that the fishing mortality can be decomposed (separated) into an age and a year effect.

- Based on how the calculations are organised. For example, the Virtual Population Analysis (VPA) solves the Baranov equation directly by numerical methods, whereas Cohort Analysis, based on the same data model as VPA, uses an approximate solution to this equation. ADAPT, based on VPA, uses the fishing mortality of the terminal year and of the oldest age as the unknown parameters, whereas the XSA method uses the number of survivors of the each age group as the unknowns.

These differences revolve around the way the models are fitted and solved. In terms of results, they are of little principal importance, but often reflect the available data.

The VPA method in fish stock assessment is widely used. For example, it is used in assessing most fish stocks in the Northeast and Northwest Atlantic, and many other stocks in the Northern Pacific, Australia, New Zealand, South Africa, Argentina, Chile, Peru, in CCAMLR and CECAF. The classical presentations of this model and its applications are Beverton and Holt (1957) and Ricker (1975), who describe the single species version in detail and Jones (1984). Modern presentations are given in many textbooks (e.g. Gallucci *et al.* 1996, Hilborn and Walters 1992, King 1995, Sparre and Venema 1998). The VPA analytical model has been expanded to include multispecies interactions (Magnusson 1995, Sparre 1991). The estimation procedures used in assessment work when using the analytical model for fish stock assessment have been developed in the 1980s and early 1990s (see Conser 1993, for a historic review of ADAPT). These new methods include least-squares estimation of the state of the stock using both catch/effort and survey data in an integrated fashion. In more recent years, Bayesian methods have been introduced to fish stock assessment for estimation of parameters and their variances by calculating the full parameter joint probability distributions (Walters and Punt 1994, Punt and Hilborn 1997, and Virtala *et al.* 1998 for an application to VPA). Bayesian methods are more complicated than the procedures presented in this manual. However, the methods used here would, in almost all cases, be a recommended preliminary analysis in a Bayesian assessment.

VPA is not the only approach to fish stock assessment. Alternative approaches include dynamic biomass models, (e.g. Punt and Hilborn 1996), length-based methods, (e.g. Sparre and Venema 1998, King 1995), heuristic analysis of trends in catch and CPUE data (King 1995, Gallucci *et al.* 1996) and production approaches such as the ECOPATH model (Christensen and Pauly 1992).