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# Simple methods for short-term forecasting of catch and biomass

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A simple method for making short-term forecasts of catch and exploited biomass, based on a time-dependent stock-production model, is described. The method can be applied in various ways, depending on the nature of the data available. A short time series of landings estimates is required, and a reliable indicator of recruitment is highly desirable. The level of exploitation must also be estimated, but results are not usually very sensitive to this parameter. Given a good index of recruitment, the method is capable of giving satisfactorily precise catch forecasts even when the level of exploitation is high and recruitment is quite variable. The method can easily be implemented as a spreadsheet, and several examples are presented.

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## 1. Introduction

Short-term forecasts of catch and biomass are often required for fisheries management, particularly when (as in much of the northeast Atlantic) the management regime relies on Total Allowable Catches (TACs) and quotas. The catch and biomass levels for a few years ahead resulting from a range of management options usually need to be examined in order that an option can be selected and an appropriate TAC set. Short-term forecasts of catch and biomass are however also useful in other contexts; for example in order to provide guidance to managers or to the industry on likely catches and thus supplies to the markets, or catch-rates (which for demersal stocks are strongly dependent on stock size and greatly affect profitability).

Nevertheless, the major stimulus for much of the preoccupation with short-term forecasting evident in the ICES area is the need to provide advice for the setting of TACs. As the system of management by TAC has spread, advice has been requested for more and more stocks about which less and less is known. This, coupled with the fact that standard procedures for short-term forecasts are time-consuming, dependent on extensive data, and probably over-parameterized anyway, has resulted in attempts to develop simpler methods. Among these is the so-called SHOT method, originally proposed in an ICES paper (Shepherd, 1984). The acronym apparently derives from "Shepherd's Hang-Over TAC" (J. G. Pope, pers. comm.), which is not entirely inappropriate. The purpose of this paper is to make accessible an updated and slightly fuller explanation of the method to a wider audience, and also to give explicitly a discussion of the calculation of biomasses and the consequences of exploitation at different levels (options), which have not so far been set down in a coherent form.

## 2. Background

There is, in the ICES area at least, a fairly standard procedure for making short-term forecasts, which has evolved over the years in various working groups. This procedure has not been concisely described in the literature, and I therefore give a short account here, primarily as background information for what follows.

The standard method relies on the availability of a time series of total international catch-at-age data, usually for up to about 10 age groups for the longer-lived species, extending over a minimum of 5 to 10 years. These data are examined by virtual population analysis (VPA). This widely used technique was first described by Gulland (1965), whose paper is now accessible in the collection of reprints edited by Cushing (1983). The most comprehensible explanation is however due to Pope (1972), whose paper is also reprinted in Cushing's collection. VPA is really only a transformation of the data, which provides *retrospective* information on levels of fishing mortality (F), exploitation patterns, and population size (especially year-class strength). Of itself it provides no information on current levels of F or population size. The technique now known as Separable VPA (Pope and Shepherd, 1982) makes this very clear, and may be used to find internally consistent interpretations and shed some light on the age-specific exploitation pattern *if* it has remained constant with time.

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External information such as catch per unit effort (c.p.u.e.) at age data for one or more fleets or a research survey (or estimates of stock sizes from ichthyoplankton or acoustic surveys) must be used to "tune" the VPA, in order to estimate fishing mortality and population size in the most recent year. There are various methods for doing this: see e.g. Anon. (1983, 1984, 1986a, 1987), Laurec and Shepherd (1983), Pope and Shepherd (1985). The resultant estimates of the current population age structure are the starting point for the short-term forecast process. The most recent population estimates for the youngest age group(s) are often considered unreliable and are therefore replaced by averages or estimates based on recruitment indices (calibrated against historic VPA results). The forecast procedure for each future year then simply consists of the application of the standard catch equation

$$C = F\,N(1 - e^{-Z})/Z \qquad (1)$$

for each age group. Here C represents catch in number, N is population in number at age, F is fishing mortality, and Z is total mortality. The fishing mortalities in the forecast are usually based on some smoothed age-specific exploitation pattern (e.g. that derived by separable VPA or averaged over about five recent years), together with assumed increases or decreases in overall F (and therefore, implicitly, effort) for each year for which the forecast is required, specified by an "F-multiplier". The yield (catch in weight) and biomass are then obtained by simple sums of products using appropriate weights-at-age for the catch and for the stock (these usually being different).

This standard method therefore requires: (1) a time series of catch-at-age data; (2) independent c.p.u.e.-at-age or survey data; (3) weight-at-age data; (4) some assumption(s) about natural mortality (M) in order to run VPA, etc.

Such an extensive data set is normally only available for stocks of major commercial importance which have been under continuous investigation for many years. The extent to which all this information is really necessary for *catch prediction* has been under discussion for some years. Pope (1983) developed a method colloquially known as the ANOVA TAC method, which required no assumption about M and showed that forecasts for *status quo* conditions depend only weakly on the estimated current level of F (and hence on the c.p.u.e. data and the "tuning" process). The term *status quo* here refers to a forecast made for a level of F which is equal to that estimated for the most recent year, with the same exploitation pattern. The essential point is that the value of F used for prediction is some *proportion* of that estimated (1.0 for strict *status quo* conditions) and not set to some absolute value (e.g. $F_{max}$, $F_{0.1}$,M) which is not directly related to that estimated. Thus some of the data required for the standard method may not be absolutely essential if alternative methods of calculation can be developed.

## 3. The SHOT method

These ideas may be extended by observing that the future catch and biomass from a stock are determined in part by the size of the surviving stock, together with the contribution due to new recruits. Thus it may not be necessary to consider the full age structure: representation of the existing stock, and new recruits to it, may yield a useful approximation.

One may thus consider a simple dynamic stock-production representation. The exploitable biomass B(y) at the beginning of any year is determined by the surviving previous biomass, as modified by growth and mortality, and the increment to it, due to new recruits to the *exploited stock*.

The rate of change of exploitable biomass is in fact

$$\frac{dB}{dt} = -F\,B + P' + (G - M)B \qquad (2)$$

where F is the fishing mortality rate, G is an (exponential) rate of growth in weight, and M is the natural mortality rate, all averaged over the main fully exploited ages. P′ is the rate of production (i.e. recruitment expressed as biomass per unit time). This representation is essentially identical to that used by Russell (1931), Graham (1935), and many other authors since then. Integrating from time y to time y+1 and treating recruitment as a concentrated pulse (a Dirac delta function) one obtains

$$B(y + 1) = \exp(G - Z)\,B(y) + P(y + 1) \qquad (3)$$

where $Z = F + M$, and $P(y+1)$ is the annual production (recruitment in weight) which occurred during year y, which we assume for convenience to occur suddenly at the end of year y (and thus at the beginning of year y+1). It is indexed (y+1) rather than (y) to conform with the usual convention that quantities are indexed to correspond with the beginning of the year to which they relate. This choice differs from that of Shepherd (1984), but is in any case arbitrary. In practice P(y+1) is predicted from an index of recruitment, usually obtained from a young fish survey, and the correct time-lag between the age of the fish surveyed and the mean age of recruitment must usually be determined by inspection of the data rather than by prior calculation, at least when age-composition data are lacking.

Defining G as the logarithm of the weight ratio of successive age groups averaged over the most important part of the exploited stock, which is typically about 0.3 within a factor of two, we also define the "hang-over factor"

$$h = \exp(G - Z) \qquad (4)$$

representing the proportion (in weight) of the exploited stock which survives until the following year. This may vary from year to year, but will often be assumed to remain constant for some time.

Equation (3) may therefore be re-written

$$B(y+1) = h(y)\,B(y) + P(y+1) \tag{5}$$

which is a simple discrete dynamic equation for the evolution of the stock. It may be used for making short-term forecasts of stock size, provided estimates can be made of h and P, and a starting value for B is available. Note that there is no necessity to assume *status quo* conditions in order to use equation (5). *Status quo* conditions (or assumptions) are useful but not vital for these simple methods of forecasting.

The related equation for forecasting yield (Y) is easily derived from Equation (5), by

$$Y(y) = \tilde{F}(y)\,B(y) \tag{6}$$

where $\tilde{F}(y)$ is the yield/biomass ratio (relating yield *during* the year to the exploitable biomass at the *beginning* of the year).

The averaging factor (implied by the tilde) is simply $\{1-\exp(G-Z)\}/(Z-G)$, which is a generalization of the more usual expression $\{1-\exp(-Z)\}/Z$ which applies to numbers rather than biomasses.

Combining equations (5) and (6) leads to

$$Y(y+1) = \frac{\tilde{F}(y+1)}{\tilde{F}(y)}\,[h(y)\,Y(y) + \tilde{F}(y)\,P(y+1)] \tag{7a}$$

$$= \frac{\tilde{F}(y+1)}{\tilde{F}(y)}\,Y_{SQ}(y+1) \tag{7b}$$

where $Y_{SQ}(y+1)$ is the *status quo* yield, defined by

$$Y_{SQ}(y+1) = h(y)\,Y(y) + \tilde{F}(y)\,P(y+1), \tag{8}$$

i.e. the yield expected if the fishing rate is the same in year y+1 as in year y.

The equations permit catches to be forecast without direct consideration or knowledge of biomasses, although they are of course implicit in the calculation and may be deduced if required.

The partitioning of the forecast into two parts (Equations 7(b) and 8) is a matter of convenience, since *status quo* forecasts are often required. Forecasts for other levels of exploitation are easily derived, however, since Equation (7b) may be used directly or converted to

$$Y(y+1) = \frac{F(y+1)}{F(y)}\exp(-\Delta F/2)\,Y_{SQ}(y+1) \tag{9}$$

where $\Delta F = F(y+1) - F(y)$. Note that this is in terms of fishing mortality rate (not yield/biomass ratios). This result follows immediately from the useful approximation for $Z<2$ (Pope, 1979; Gray, 1979).

$$\{1-\exp(-X)\}/X \cong \exp(-X/2) \tag{10}$$

Equations (7b) or (9) permit a full range of catch options corresponding to proportional increases or decreases in the level of exploitation to be explored to sufficient accuracy in practice provided that the estimate of F(y) is not wildly inaccurate.

The SHOT forecast method in general relies on Equations (8) and (9). These may however be applied in a variety of ways according to the circumstances and the data available, so that there is in practice a class of related methods; these are discussed below. However, the general form of Equations (5) and (8) is that of a first-order autoregressive moving average (ARIMA) model (see e.g. Box and Jenkins, 1970) as suggested by Roff (1983), so there is a theoretical basis for using time-series models of this type for such short-term forecasting. Note, however, that here the form of the ARIMA model is largely predetermined from the simple theory given above. Prior information is available on the coefficients of the model, so the usual identification/estimation procedures of time-series analysis are not necessary and probably not appropriate. It may for example be assumed with confidence that both h and $\tilde{F}$ are positive, and between zero and one (and usually within a factor of three of 0.3, in practice).

# 4. Estimation of parameters

## 4.1. The hang-over factor

Equation (4) gives the basic definition of the hang-over factor, which may be used directly if it can be estimated from available data (see below) or if sufficient background information is available. The latter circumstance may arise when an existing assessment has broken down because of deteriorating data, or when only partial data (insufficient for a full analytical assessment) are available.

When G and M are not known or easily estimable, a further approximation is possible. Both are positive and often in the range 0.1 to 0.5 for the main exploited age groups. Their difference will therefore usually not be large and may only be 0.1 or 0.2. One may therefore find a simple approximation for the relationship between h and $\tilde{F}$, since

$$h = \exp(G-Z) = \exp\delta\,\exp(-F)$$

where

$$\delta = G - M$$

Thus
$$\begin{aligned} 1 - h\exp(-\delta) &= 1 - \exp(-F) \\ &= 2\exp(-F/2)\sinh(F/2) \\ &\cong F\exp(-F/2) \end{aligned}$$

But, using the Pope/Grey approximation (Equation (10)) again

$$\tilde{F} \simeq F\exp\{(G-Z)/2\} = F\exp(\delta/2)\exp(-F/2)$$

Thus

$$1 - h\exp(-\delta) \cong \tilde{F}\exp(-\delta/2)$$

and

$$h \cong \exp(\delta) - \exp(\delta/2)\tilde{F} \quad (11)$$

Both exponential terms are likely to be quite close to 1.0. Indeed, the simpler and less precise result

$$h \cong 1 - \tilde{F} \quad (12)$$

follows immediately if $\delta = G - M$ is taken to be zero, and may also be derived more easily for this case (see Shepherd, 1984).

The point of this discussion, however, is not simply to derive Equation (11), which is strongly reminiscent of Pope's "Cohort Analysis" approximation (Pope, 1972), but to show that the parameters h and $\tilde{F}$ are not independent. They are in fact so strongly inversely related that once one of them has been estimated, Equation (11) may be used to deduce the other. This inverse relationship is important because it means that there is partial cancellation of errors in Equation (8). If $\tilde{F}$ is underestimated the first term will be too large and the second too small, and *vice versa* if it is overestimated. This cancellation will be most effective when P is about average and when *status quo* conditions apply. It is only approximate, but does mean that the predictions are often considerably less sensitive to the estimate of $\tilde{F}$, and thus to that of stock size, than might have been expected. Note also that since G and M only arise in the equations as modifiers of the relationship between h and $\tilde{F}$, they are not of central importance for short-term forecasts, provided they do not vary a lot from year to year.

Brander (pers. comm.) has pointed out that h may be estimated from the data during a period in which $\tilde{F}$ (and thus h) may be assumed constant, since h is the coefficient in a regression of $Y(y+1)$ on $Y(y)$. This, however, is only a crude procedure, likely to be perturbed considerably if $\tilde{F}$ is not in fact constant and by the incidence of large and small year classes in a short time series. More elaborate (multiple) regression techniques could be constructed (see below), but a more robust procedure is probably to estimate h from ancillary data, recognizing that an accuracy of $\pm 0.1$ is likely to be perfectly adequate for practical forecasting.

Other possible methods for estimating h directly or indirectly via $\tilde{F}$ are:

1. Use of (aged) survey or c.p.u.e. data to give an indication of Z from the log-catch ratios or the fully recruited part of a catch curve. If catch in weight data (rather than numbers) are used, this will give $G - Z$ and thus $h = \exp(G - Z)$ directly.
2. Use of independent absolute stock size estimates (e.g. from acoustic or ichthyoplankton surveys) to yield approximate estimates of $\tilde{F}$ from the ratio of current yield to stock size.
3. Use of catch-at-age data (even if inadequate for full analytical methods) to give an indication of F and thus $\tilde{F}$.
4. Intelligent guesswork: for various assumptions about the level of exploitation of the stock, approximate rough estimates of $\tilde{F}$ and h may be made, as in the text table below. (At this level of approximation, we take $\delta = 0$.)

| Exploitation | $\tilde{F}$ | h | F (approx.) |
|---|---|---|---|
| Light | 0.1 | 0.9 | 0.1 |
| Moderate | 0.3 | 0.7 | 0.4 |
| Heavy | 0.5 | 0.5 | 0.7 |
| Very heavy | 0.7 | 0.3 | 1.4 |

In many cases there may be little point in seeking higher precision than can be obtained by guessing a value from this table. Such a value may be regarded as a starting approximation to be refined using the methods above if and when appropriate data become available.

## 4.2. Production

By averaging Equation (7) over a period when the level of exploitation is steady, and ignoring end effects, one obtains

$$\bar{Y} \cong h\bar{Y} + \tilde{F}\bar{P}$$

Note that the overbar indicates averaging over many years, whilst the tilde indicates averaging within one year.

Substituting $h = \exp(G - Z)$ in this expression, and recalling that

$$\tilde{F} = F\{1 - \exp(G - Z)\}/(Z - G),$$

it follows that

$$\bar{Y} = \exp(G - Z)\bar{Y} + F\bar{P}\{1 - \exp(G - Z)\}/(Z - G)$$

and therefore

$$\bar{Y} = F\bar{P}/(F + M - G) \quad (13a)$$

When the difference $G - M$ between growth and natural mortality rates is small (compared with the fishing mortality rate), this reduces to

$$\bar{Y} \cong \bar{P} \quad (13b)$$

Equations (13a) and (13b) are of course no surprise: in the steady state the average yield obviously equals average production (recruitment in weight), with an adjustment for growth and natural mortality. Noting however that P is therefore of the same order as Y, it is clear from

Equation (8) that when the level of exploitation is low the bulk of the catch comes from the surviving stock and only a small amount from recruits. Conversely, when the level of exploitation is high, a large proportion (possibly more than half) of the catch is attributable to new recruits. In the former case, a very simple approximation for P (e.g. using the average, $\bar{P}$) may give a short-term forecast of adequate precision. In the latter case the precision of the forecast is heavily dependent on the precision with which $P(y+1)$ can be estimated. Clearly, when exploitation rates are high, both simple and complex methods of forecasting require high quality estimates of recruitment.

When an index of recruitment is available it may be used to predict P in the following way. Given a time series of data (not necessarily very long) and some estimate of h (as a function of time if the necessary data are available) $P(y+1)$ may be estimated retrospectively for each year, except the first, by applying Equation (7a). In most cases no historical estimates of h or $\tilde{F}$ will be available and it will be necessary to use some constant value (i.e. to make the *status quo* assumption), which may lead to non-trivial errors. This, however, is inescapable unless independent evidence for the changes of $\tilde{F}$ is available, in which case the appropriate corrections are implicit in Equation (7a): see below and Anon (1986b) for examples of such calculations. These estimates of $P(y+1)$ may then be related to the recruit indices $r(y+1-\tau)$ by an appropriate calculation (e.g. regression). Note that there will usually be a time-lag $\tau$ (for purely practical reasons) between the date of the recruit index and that when the recruits appear in the fishery. This will often be known approximately, but the best value to use in the calculation is sometimes in doubt and best determined by inspection of the data (formal statistical procedures are available but probably not necessary). The most suitable form for the regression of production on the recruit index is also debatable. The simple theory suggests that the regression should pass through the origin (zero intercept) and that since a prediction of P is required, a predictive regression of P on r would be appropriate. This would imply a slope of $\Sigma Pr/\Sigma r2$. If the larger estimates have larger errors, then the ratio of the means $(\Sigma P/\Sigma r)$ could also be justified as an estimator of the slope (see for example Snedecor and Cochran, 1980, p. 174). However, experience suggests that recruit indices are often more variable than the subsequent recruitment to the stock. This may crudely be allowed for, either by permitting a finite intercept (thus "shrinking" the predictor towards the mean) or by using a logarithmic transform of both variables. None of these procedures can be regarded as wholly justified, but the level of approximation in the method as a whole suggests that seeking an optimal method is unlikely to be worthwhile. The last procedure (use of log transforms, with intercept) is in line with advice on the use of recruit indices in age-structured analyses (Anon., 1984), but in practice using the ratio of the means to estimate the slope is more convenient.

A further consideration is that recruitment of a single year class to the exploited stock will usually occur over two or more years, rather than in one only. This would imply that a more elaborate analysis of the relationship between P and r is required, perhaps using ARIMA methods (Box and Jenkins, 1970), since the process is of lagged moving average type. Van Beek (reported in Anon., 1986b) proposed making a moving weighted average over the recruitment time series using independent estimates of the contributions of adjacent age groups and basing the regression on these averages. This seems particularly appropriate and corresponds to estimating the weights in the averaging process independently rather than from the time series itself.

## 5. Examples

It is apparent from the discussion above that there are several ways in which the basic SHOT Equation (8) may be applied, depending mainly on the data available for estimation of the necessary parameters and quantities. Several methods (proceeding from the simpler to the more elaborate) are illustrated below, using North Sea cod as an example (data from Anon., 1988). All may easily be implemented using a spreadsheet package on a microcomputer, which is in fact how these examples were prepared.

The construction of the spreadsheet (illustrated in Tables 1 to 6, Table 5 showing the most general form) is described below.

Items are identified by means of the spreadsheet cell references.

A12:A25 Contains the dates to which the data relate.

B12:B21 Contains the landings data for each year. The standard spreadsheet allows for a ten-year time series, but this can be altered if necessary.

C12:C25 Contains the recruit index data for each year. The indices are entered alongside the year in which the year class in question would be expected to contribute most to the landings. The indices may be in any units: if not available then 1.0 may be entered for all years (see discussion below).

C5:C7 Recruitment of a year class to the fishery is not usually a knife-edge process, and this may be allowed for by using a running weighted mean recruit index. A three-term running mean is usually adequate but the number of terms could easily be increased if desired: the weights (which should sum to 1.0) are entered as data into cells C5:C7. The weight in cell C6 is that applied to the index entered for the year in question (i.e. the main recruiting year class). That in cell C5 applies to the next older age group (the previous year class) and that in C7 to the next younger age group (the subsequent year class). The order therefore corresponds to the ordering of the year classes and is in reverse order from the point of view of age groups.

D13:D24 The weighted indices obtained by applying the running weights to the recruit indices are calculated and displayed in column D. Note that one year is lost at both the beginning and the end of the time series because of the use of a three-term running mean.

E12:E24 The assumed values of yield/biomass ratio (i.e. $\tilde{F}$, the ratio of total landings to exploitable biomass) are entered as data in column E. These may take any values – they need not be constant, even during the forecast period, although in practice constant values are often used for want of relevant information.

F12:F24 The hang-over factors, h, calculated from the values of $\tilde{F}$ in column E using Equation (11), i.e.

$$h(y) = \exp(\delta) - \exp(\delta/2)\,\tilde{F}(y)$$

are displayed in column F. The values of $\exp(\delta)$ and $\exp(\delta/2)$ are calculated from the assumed value of G – M (entered as data in cell H5) and are displayed in cells H6 and H7.

G13:G21 The actual (posterior) estimates of production are calculated using a rearranged version of Equation (7a), i.e.

$$P(y) = \frac{Y(y)}{\tilde{F}(y)} - \frac{h(y-1)\,Y(y-1)}{\tilde{F}(y-1)} \qquad (14)$$

which is of course identical to $B(y) - h(y-1)\,B(y-1)$. These estimates are made using the values available in columns B, E, and F. Note that a value cannot be obtained for the first year because of the differencing involved in Equation (14).

H16:H24 The (prior) estimates of production required for the forecast are based on the weighted recruit indices (column D), by

$$\hat{P}(y) = r(y)\,\bar{P}/\bar{r} \qquad (15)$$

where the averages are taken over all available previous values for r and P, taken from columns D and G with a minimum number of three pairs of values in the average (so that no estimates are made for the first four years). These prior estimates of P(y) are displayed in column H and differ from the posterior estimates given in column G (which are of course not available for the years when they are needed for the forecast). It would in principle be possible to "tune" the values of $\tilde{F}(y)$ so that the prior and posterior estimates of P agreed, but this is an unreliable procedure unless the recruitment estimates are very precise; it is not recommended.

I16:I24 The estimated *status quo* catches (SQC) are calculated using a re-indexed form of Equation (8), i.e.

$$Y_{SQ}(y) = h(y-1)\,Y(y-1) + \tilde{F}(y-1)\hat{P}(y) \qquad (16)$$

using the prior estimates of $\hat{P}$ (column H). The results are displayed in column I. For the final year (i.e. 1989 in this example) the actual previous landings figure (B23) is not available and the estimate (L23) must be used instead.

L16:L24 The estimates of actual landings are made by applying Equation (7b) (re-indexed), i.e.

$$\hat{Y}(y) = \frac{\tilde{F}(y)}{\tilde{F}(y-1)}\,Y_{SQ}(y) \qquad (17)$$

to the estimates of SQC. There is therefore no need to assume that $\tilde{F}$ is constant (see example in Table 5): any (actual or assumed) changes are taken into account. These estimates of actual landings are the "bottom line" for most purposes and are therefore displayed in the right-most column: the final forecast appears in the bottom right-hand corner.

J12:J21 The data for actual landings and the assumed values of $\tilde{F}$ of course imply values for the actual and exploited biomass from Equation (6)

$$B(y) = Y(y)/\tilde{F}(y)$$

These "actual" values are given in column J.

K16:K24 In addition, the forecast implies predicted values for the exploited biomass, from Equation (5), and also calculable as

$$\hat{B}(y) = Y_{SQ}(y)/\tilde{F}(y-1) \qquad (18)$$

These values are given in column K.

In summary, therefore, the spreadsheet method of calculation is very convenient for the purpose and allows the user to scrutinize the intermediate steps of the calculation. In particular, rows 16 to 21 of columns H, K, and L give historical estimates not actually required for the current forecast. These do permit an immediate retrospective check on the historical performance of the calculation, however, since they may be compared with the "actual" (posterior) estimates of the same quantities in columns G, J, and B respectively. Given suitable software, this comparison may be done automatically using a graphical display of the results.

Example (a) *Basic SHOT forecast: catch data only* (SHOT 1)

Table 1.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | North Sea Cod | | | | | SHOT forecast spreadsheet version 3 | | | | | |
| 2 | | Basic form | | | | | | January 1989 | | | | |
| 3 | | | | | | | | | | | | |
| 4 | | running recruitment weights | | | | | | | | | | |
| 5 | | older | 0.00 | | | G−M = | 0.00 | | | | | |
| 6 | | central | 1.00 | | | exp(d) | 1.00 | | | | | |
| 7 | | younger | 0.00 | | | exp(d/2) | 1.00 | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | Act'l | Est'd | |
| 10 | | | Recrt | W'td | Y/B | | Act'l | Est'd | Est'd | Expl | Expl | Est'd |
| 11 | Year | Landings | Index | Index | Ratio | Hangover | Prodn | Prodn | SQC | Biom | Biom | Landings |
| 12 | 1978 | 261 | 1 | | 0.60 | 0.40 | | | | 435 | | |
| 13 | 1979 | 248 | 1 | 1 | 0.60 | 0.40 | 239 | | | 413 | | |
| 14 | 1980 | 260 | 1 | 1 | 0.60 | 0.40 | 268 | | | 433 | | |
| 15 | 1981 | 301 | 1 | 1 | 0.60 | 0.40 | 328 | | | 502 | | |
| 16 | 1982 | 273 | 1 | 1 | 0.60 | 0.40 | 254 | 279 | 288 | 455 | 479 | 288 |
| 17 | 1983 | 233 | 1 | 1 | 0.60 | 0.40 | 206 | 273 | 273 | 388 | 455 | 273 |
| 18 | 1984 | 206 | 1 | 1 | 0.60 | 0.40 | 188 | 259 | 249 | 343 | 415 | 249 |
| 19 | 1985 | 192 | 1 | 1 | 0.60 | 0.40 | 183 | 247 | 231 | 320 | 385 | 231 |
| 20 | 1986 | 158 | 1 | 1 | 0.60 | 0.40 | 135 | 238 | 220 | 263 | 366 | 220 |
| 21 | 1987 | 174 | 1 | 1 | 0.60 | 0.40 | 185 | 225 | 198 | 290 | 331 | 198 |
| 22 | | | | | | | | | | | | |
| 23 | 1988 | | 1 | 1 | 0.60 | 0.40 | | 221 | 202 | | 337 | 202 |
| 24 | 1989 | | 1 | 1 | 0.60 | 0.40 | | 221 | 213 | | 355 | 213 |
| 25 | 1990 | | 1 | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |

The SHOT forecast in its most basic form is illustrated in Table 1. No recruit index is used, so a "null" value of 1.0 is inserted. $\tilde{F}$ (and therefore the hang-over factor h) has been assumed to be constant over the whole period, and $\tilde{F}$ was guessed at 0.6 for a heavily exploited stock. The differences ($\delta$) between growth and natural mortality has been taken as zero, so that the hang-over factor h is just $1-\tilde{F}$.

The effect of inserting a constant recruit index value is (see Equation (15)) simply to use the average observed production as the estimated production, which is a reasonable "default" choice in the absence of other information. The estimated *status quo* landings values in this case do not therefore reflect any variability of recruitment and are close to one another and to the average catch.

With the benefit of hindsight it is possible to back-calculate what the true *status quo* catch (SQC) values should have been (using actual catches and the fishing mortalities as given in Anon. (1988) in Equation (9)). These true SQC values, and this and various other SHOT estimates described below, are illustrated in Figure 1. It can be seen that the true value declined significantly from 1981 to 1985, but the estimates of Table 1 (labelled SHOT 1) did not decline to the same extent.

Example (b) *Use of a recruit index* (SHOT 2)

In Table 2 the estimates of abundance of North Sea cod as 1-group obtained from the English Groundfish Survey (Anon. (1988) and D. Harding, pers. comm.) have been used as the index of recruitment. The values have been displaced one year to allow for recruitment at two years old: thus there are peaks in the catch in 1978 and 1981 corresponding to the large year classes of 1976 and 1979. The estimated SQC is now much *more* variable than the true SQC (see Fig. 1, SHOT 2) because of the strong dependence on incoming recruitment, and the use of a single "raw" index value in this way, with the assumption of knife-edged recruitment, does not seem to be appropriate for this heavily exploited stock.

Example (c) *Use of a smoothed recruit index* (SHOT 3)

In fact, the age compositions of the catch for this stock show that there is partial recruitment at age 1, and full recruitment to the exploited stock does not in fact occur until age 3. A running weighted average over the recruit index series should therefore provide a better estimate of recruitment. Here weights of 0.25, 0.50, and 0.25 on ages 1, 2 and 3 respectively have been used as a plausible first guess (these weights represent a simple smoothing centred on age 2).

The results of this analysis are given in Table 3 and illustrated in Figure 1 (SHOT 3). The estimated SQC now varies to an intermediate extent, and is within 10% of the true SQC in all years except 1985, when the ICES North Sea Roundfish Working Group was also misled by an anomalously high recruit index. Some fine tuning of this forecast could probably be carried out, by adjusting the

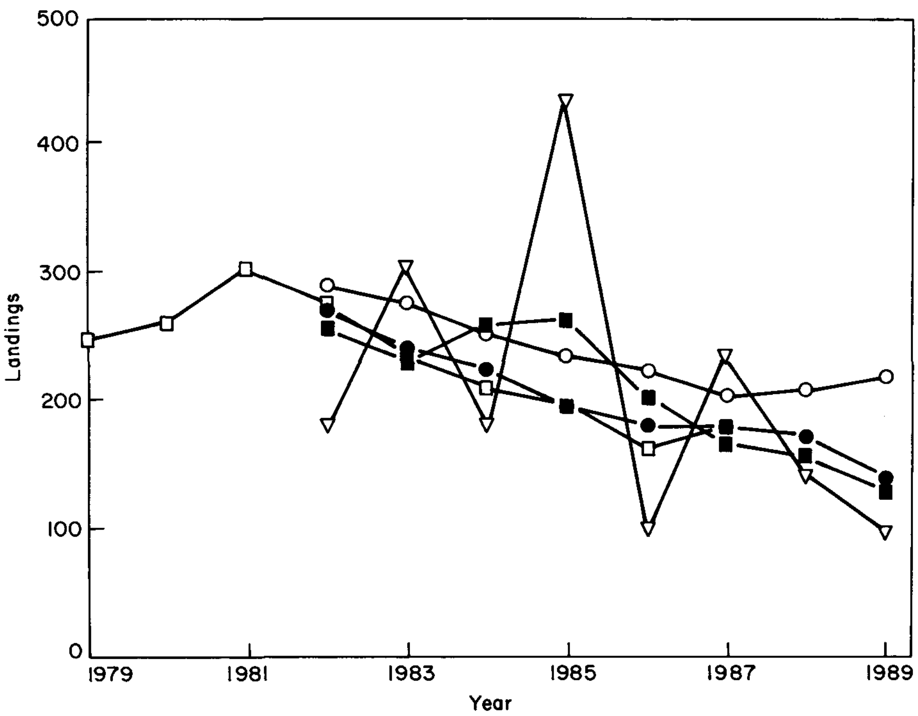


Figure 1. Actual and estimated values of *status quo* landings for North Sea cod for the period 1979 to 1989. The various SHOT estimates correspond to the principal variations of the method presented in Tables 1, 2, 3, and 6. ——□—— = actual, ——○—— = SHOT 1, ——▽—— = SHOT 2, ——■—— = SHOT 3, ——●—— = SHOT 6.

Table 2.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | North Sea Cod | | | | | SHOT forecast spreadsheet version 3 | | | | | |
| 2 | | using raw recruit indices | | | | | | | January 1989 | | | |
| 3 | | | | | | | | | | | | |
| 4 | | running recruitment weights | | | | | | | | | | |
| 5 | | older | 0.00 | | | G−M = | 0.00 | | | | | |
| 6 | | central | 1.00 | | | exp(d) | 1.00 | | | | | |
| 7 | | younger | 0.00 | | | exp(d/2) | 1.00 | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | Act'l | Est'd | |
| 10 | | | Recrt | W'td | Y/B | | Act'l | Est'd | Est'd | Expl | Expl | Est'd |
| 11 | Year | Landings | Index | Index | Ratio | Hangover | Prodn | Prodn | SQC | Biom | Biom | Landings |
| 12 | 1978 | 261 | 63 | | 0.60 | 0.40 | | | | 435 | | |
| 13 | 1979 | 248 | 23 | 23 | 0.60 | 0.40 | 239 | | | 413 | | |
| 14 | 1980 | 260 | 24 | 24 | 0.60 | 0.40 | 268 | | | 433 | | |
| 15 | 1981 | 301 | 51 | 51 | 0.60 | 0.40 | 328 | | | 502 | | |
| 16 | 1982 | 273 | 11 | 11 | 0.60 | 0.40 | 254 | 94 | 177 | 455 | 294 | 177 |
| 17 | 1983 | 233 | 32 | 32 | 0.60 | 0.40 | 206 | 320 | 301 | 388 | 502 | 301 |
| 18 | 1984 | 206 | 15 | 15 | 0.60 | 0.40 | 188 | 138 | 176 | 343 | 293 | 176 |
| 19 | 1985 | 192 | 61 | 61 | 0.60 | 0.40 | 183 | 580 | 431 | 320 | 718 | 431 |
| 20 | 1986 | 158 | 4 | 4 | 0.60 | 0.40 | 135 | 31 | 95 | 263 | 159 | 95 |
| 21 | 1987 | 174 | 34 | 34 | 0.60 | 0.40 | 185 | 277 | 230 | 290 | 383 | 230 |
| 22 | | | | | | | | | | | | |
| 23 | 1988 | | 14 | 14 | 0.60 | 0.40 | | 109 | 135 | | 225 | 135 |
| 24 | 1989 | | 8 | 8 | 0.60 | 0.40 | | 62 | 91 | | 152 | 91 |
| 25 | 1990 | | 25 | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |

Table 3.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | North Sea Cod | | | | | | SHOT forecast spreadsheet version 3 | | | |
| 2 | | | using smoothed recruit indices | | | | | | | January 1989 | | |
| 3 | | | | | | | | | | | | |
| 4 | | running recruitment weights | | | | | | | | | | |
| 5 | | older | 0.25 | | | G−M = | 0.00 | | | | | |
| 6 | | central | 0.50 | | | exp(d) | 1.00 | | | | | |
| 7 | | younger | 0.25 | | | exp(d/2) | 1.00 | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | Act'l | Est'd | |
| 10 | | | Recrt | W'td | Y/B | | Act'l | Est'd | Est'd | Expl | Expl | Est'd |
| 11 | Year | Landings | Index | Index | Ratio | Hangover | Prodn | Prodn | SQC | Biom | Biom | Landings |
| 12 | 1978 | 261 | 63 | | 0.60 | 0.40 | | | | 435 | | |
| 13 | 1979 | 248 | 23 | 33 | 0.60 | 0.40 | 239 | | | 413 | | |
| 14 | 1980 | 260 | 24 | 31 | 0.60 | 0.40 | 268 | | | 433 | | |
| 15 | 1981 | 301 | 51 | 34 | 0.60 | 0.40 | 328 | | | 502 | | |
| 16 | 1982 | 273 | 11 | 26 | 0.60 | 0.40 | 254 | 224 | 255 | 455 | 425 | 255 |
| 17 | 1983 | 233 | 32 | 23 | 0.60 | 0.40 | 206 | 197 | 228 | 388 | 379 | 228 |
| 18 | 1984 | 206 | 15 | 31 | 0.60 | 0.40 | 188 | 272 | 256 | 343 | 427 | 256 |
| 19 | 1985 | 192 | 61 | 35 | 0.60 | 0.40 | 183 | 295 | 259 | 320 | 432 | 259 |
| 20 | 1986 | 158 | 4 | 26 | 0.60 | 0.40 | 135 | 202 | 198 | 263 | 330 | 198 |
| 21 | 1987 | 174 | 34 | 22 | 0.60 | 0.40 | 185 | 162 | 161 | 290 | 268 | 161 |
| 22 | | | | | | | | | | | | |
| 23 | 1988 | | 14 | 18 | 0.60 | 0.40 | | 134 | 150 | | 250 | 150 |
| 24 | 1989 | | 8 | 14 | 0.60 | 0.40 | | 105 | 123 | | 205 | 123 |
| 25 | 1990 | | 25 | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |

Table 4.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | North Sea Cod | | | | | | SHOT forecast spreadsheet version 3 | | | |
| 2 | | | using non-zero G–M | | | | | | | January 1989 | | |
| 3 | | | | | | | | | | | | |
| 4 | | running recruitment weights | | | | | | | | | | |
| 5 | | older | 0.25 | | | G−M = | 0.10 | | | | | |
| 6 | | central | 0.50 | | | exp(d) | 1.11 | | | | | |
| 7 | | younger | 0.25 | | | exp(d/2) | 1.05 | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | Act'l | Est'd | |
| 10 | | | Recrt | W'td | Y/B | | Act'l | Est'd | Est'd | Expl | Expl | Est'd |
| 11 | Year | Landings | Index | Index | Ratio | Hangover | Prodn | Prodn | SQC | Biom | Biom | Landings |
| 12 | 1978 | 261 | 63 | | 0.60 | 0.47 | | | | 435 | | |
| 13 | 1979 | 248 | 23 | 33 | 0.60 | 0.47 | 207 | | | 413 | | |
| 14 | 1980 | 260 | 24 | 31 | 0.60 | 0.47 | 237 | | | 433 | | |
| 15 | 1981 | 301 | 51 | 34 | 0.60 | 0.47 | 296 | | | 502 | | |
| 16 | 1982 | 273 | 11 | 26 | 0.60 | 0.47 | 217 | 198 | 262 | 455 | 436 | 262 |
| 17 | 1983 | 233 | 32 | 23 | 0.60 | 0.47 | 172 | 173 | 234 | 388 | 389 | 234 |
| 18 | 1984 | 206 | 15 | 31 | 0.60 | 0.47 | 159 | 237 | 253 | 343 | 421 | 253 |
| 19 | 1985 | 192 | 61 | 35 | 0.60 | 0.47 | 157 | 256 | 251 | 320 | 419 | 251 |
| 20 | 1986 | 158 | 4 | 26 | 0.60 | 0.47 | 112 | 175 | 196 | 263 | 327 | 196 |
| 21 | 1987 | 174 | 34 | 22 | 0.60 | 0.47 | 165 | 140 | 159 | 290 | 265 | 159 |
| 22 | | | | | | | | | | | | |
| 23 | 1988 | | 14 | 18 | 0.60 | 0.47 | | 116 | 152 | | 254 | 152 |
| 24 | 1989 | | 8 | 14 | 0.60 | 0.47 | | 91 | 127 | | 211 | 127 |
| 25 | 1990 | | 25 | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |

Table 5.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | North Sea Cod | | | | | SHOT forecast spreadsheet version 4 | | | | | |
| 2 | | with variable hang-over factor | | | | | December 1990 | | | | | |
| 3 | | | | | | | | | | | | |
| 4 | | running recruitment weights | | | | | | | | | | |
| 5 | | older | 0.25 | | | G−M= | 0.00 | | | | | |
| 6 | | central | 0.50 | | | exp(d) | 1.00 | | | | | |
| 7 | | younger | 0.25 | | | exp(d/2) | 1.00 | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | Act'l | Est'd | |
| 10 | | | Recrt | W'td | Y/B | | Act'l | Est'd | Est'd | Expl | Expl | Est'd |
| 11 | Year | Landings | Index | Index | Ratio | Hangover | Prodn | Prodn | SQC | Biom | Biom | Landings |
| 12 | 1978 | 261 | 63 | | 0.46 | 0.54 | | | | 567 | | |
| 13 | 1979 | 248 | 23 | 33 | 0.48 | 0.52 | 210 | | | 517 | | |
| 14 | 1980 | 260 | 24 | 31 | 0.50 | 0.50 | 251 | | | 520 | | |
| 15 | 1981 | 301 | 51 | 34 | 0.52 | 0.48 | 319 | | | 579 | | |
| 16 | 1982 | 273 | 11 | 26 | 0.54 | 0.46 | 228 | 209 | 253 | 506 | 487 | 263 |
| 17 | 1983 | 233 | 32 | 23 | 0.56 | 0.44 | 184 | 183 | 224 | 416 | 415 | 232 |
| 18 | 1984 | 206 | 15 | 31 | 0.58 | 0.42 | 172 | 250 | 242 | 355 | 433 | 251 |
| 19 | 1985 | 192 | 61 | 35 | 0.60 | 0.40 | 171 | 271 | 244 | 320 | 420 | 252 |
| 20 | 1986 | 158 | 4 | 26 | 0.62 | 0.38 | 127 | 186 | 188 | 255 | 314 | 195 |
| 21 | 1987 | 174 | 34 | 22 | 0.64 | 0.36 | 175 | 150 | 153 | 272 | 247 | 158 |
| 22 | | | | | | | | | | | | |
| 23 | 1988 | | 14 | 18 | 0.66 | 0.34 | | 124 | 142 | | 221 | 146 |
| 24 | 1989 | | 8 | 14 | 0.68 | 0.32 | | 97 | 114 | | 172 | 117 |
| 25 | 1990 | | 25 | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |

Table 6.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | North Sea Cod | | | | | SHOT forecast spreadsheet version 3 | | | | | |
| 2 | | using true (VPA) recruitment estimates | | | | | January 1989 | | | | | |
| 3 | | | | | | | | | | | | |
| 4 | | running recruitment weights | | | | | | | | | | |
| 5 | | older | 0.25 | | | G−M= | 0.00 | | | | | |
| 6 | | central | 0.50 | | | exp(d) | 1.00 | | | | | |
| 7 | | younger | 0.25 | | | exp(d/2) | 1.00 | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | Act'l | Est'd | |
| 10 | | | Recrt | W'td | Y/B | | Act'l | Est'd | Est'd | Expl | Expl | Est'd |
| 11 | Year | Landings | Index | Index | Ratio | Hangover | Prodn | Prodn | SQC | Biom | Biom | Landings |
| 12 | 1978 | 261 | 710 | | 0.60 | 0.40 | | | | 435 | | |
| 13 | 1979 | 248 | 427 | 505 | 0.60 | 0.40 | 239 | | | 413 | | |
| 14 | 1980 | 260 | 455 | 535 | 0.60 | 0.40 | 268 | | | 433 | | |
| 15 | 1981 | 301 | 802 | 583 | 0.60 | 0.40 | 328 | | | 502 | | |
| 16 | 1982 | 273 | 272 | 476 | 0.60 | 0.40 | 254 | 245 | 268 | 455 | 446 | 268 |
| 17 | 1983 | 233 | 559 | 416 | 0.60 | 0.40 | 206 | 216 | 239 | 388 | 398 | 239 |
| 18 | 1984 | 206 | 274 | 412 | 0.60 | 0.40 | 188 | 212 | 221 | 343 | 368 | 221 |
| 19 | 1985 | 192 | 540 | 362 | 0.60 | 0.40 | 183 | 183 | 192 | 320 | 321 | 192 |
| 20 | 1986 | 158 | 92 | 326 | 0.60 | 0.40 | 135 | 165 | 176 | 263 | 293 | 176 |
| 21 | 1987 | 174 | 581 | 377 | 0.60 | 0.40 | 185 | 188 | 176 | 290 | 293 | 176 |
| 22 | | | | | | | | | | | | |
| 23 | 1988 | | 254 | 324 | 0.60 | 0.40 | | 161 | 166 | | 277 | 166 |
| 24 | 1989 | | 205 | 226 | 0.60 | 0.40 | | 112 | 134 | | 223 | 134 |
| 25 | 1990 | | 238 | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |

hang-over and weighting factors, but the performance of the method is already probably comparable with that of a full "analytical" forecast.

In Table 4 the effect of using a non-zero value of G − M is examined and in this case is found to be small. Similarly, in Table 5 the yield/biomass ratio ($\tilde{F}$) has been assumed to increase over the period, so that the hang-over factor changes too. In this case this also has only a small effect on the SQC estimates, although the "historic" estimates of exploited stock size are of course changed somewhat. In this example (involving a highly exploited stock) these refinements again have little effect, although they may be more significant where exploitation rates are lower, or recruitment is less variable.

Example (d) *Use of "true" recruitment values* (SHOT 6)
The above examples imply that for a highly exploited stock the quality of the SHOT forecast is largely determined by the quality of the recruit indices available. This is confirmed in Table 6, where the actual year-class strengths (as estimated by VPA) have been inserted.

The estimated SQCs are within a few percent of the true values, even for 1985, confirming that the EGFS recruit index value for that year was anomalous. This high precision is achieved without any fine-tuning of the assumed values for the various parameters. One may easily confirm that changing the yield/biomass ratio within the range 0.5 to 0.9 does not alter the SQC estimates by more than about 10%. This very low sensitivity is probably atypical, however, resting on the constancy of the weighted average recruit index, because even though the year-class strengths have been very variable they have followed a pattern of alternating strong and weak year classes for much of the period.

## 6. Conclusions

A class of very simple methods for short-term catch forecasts has been explored: these can be implemented very conveniently using spreadsheet software. Generalizations of the method originally proposed by Shepherd (1984) permit various complications to be allowed for. These include estimation of exploitable biomass, variation in the yield/biomass ratio and thus the hang-over factor, non-knife-edge recruitment, and explicit allowance for growth and natural mortality. The general method is in fact an auto-regressive moving average process, as suggested by Roff (1983), with coefficients determined *a priori* rather than from the data. It should be noted, however, that the moving average here allows for partial recruitment (all coefficients should be positive), not for individual growth as in the method of Deriso (1980). The present method differs from these in that it is particularly adapted to the case where variable recruitment is an important determinant of future catches, so that reasonably precise forecasts cannot be obtained without estimates of actual year-class strength.

The precision of the method is in fact mainly determined by the quality of the indices of recruitment available for highly exploited stocks. Further testing of the precision of this and other related simple methods for catch forecasts has been carried out (Sun and Shepherd, 1991).

Preliminary results agree with those obtained by the ICES Working Group on the Methods of Stock Assessment (Anon., 1984) that the precision is degraded when exploitation rates are very high and recruitment is *very* variable, probably because this produces fluctuations in the effective mean weight of the recruited stock and therefore of the effective growth rate (G) which are ignored by this simple method.

It should be noted that where recruitment estimates are not available the result of a SHOT forecast tends from the most recent landings datum towards the recent average landings in the space of a few years, and will differ little from simply using that average. This is inescapable, however, since one lacks any relevant information to make a more precise forecast.

It is suggested that the method may be particularly useful where only the most basic data are available, and also as a rapid check on the results of more complicated and error-prone calculations. It is possible to carry out a SHOT forecast *before* any lengthier calculations are carried out, and any substantial discrepancies between the results may be investigated before the final results are decided.

The method, however, emphatically does *not* replace the need for a full analytical investigation of the state of the stock concerned. It is based on crude *assumptions* concerning the state of the stock and involves no serious attempt to estimate that state or monitor its evolution. It should be regarded only as a useful tool for the operational task of making short-term catch forecasts, particularly when complete data sets are not available.

## Acknowledgements

I am grateful to Joe Horwood and an un-named referee for finding a small error in the spreadsheet implementation of the method, and to them and Benoit Mesnil and the editor for their helpful comments on an earlier draft of this paper.

## Note in proof

Version 3 of the spreadsheet implementation of this method (SF.CAL, date-stamped February 1989), of which a number of copies are in circulation, contains a small error which manifests itself *only* when the yield/biomass ratio is assumed to have changed in the historic period. This has been corrected in Version 4 of the Supercalc implementation, of which copies are available from the author on request.

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