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FORECASTING IN SOUTH AFRICAN PELAGIC FISHERIES MANAGEMENT: THE USE OF EXPERT AND DECISION SUPPORT SYSTEMS

J. L. KORRÛBEL, S. F. BLOOMER†, K. L. COCHRANE‡, L. HUTCHINGS¶*
and J. G. FIELD§

Understanding long-term variability of pelagic fish populations is important in developing forecasting strategies for fisheries management and planning. However, many current fisheries models have only short-term datasets available, whereas those of suitable duration often lack reliability. As resources are placed under increasing pressure, all available information should be used to assist management. Two simple rule-based deterministic modelling approaches are described, which use semi-quantitative and qualitative rules to relate recruitment success of South African anchovy *Engraulis capensis* to physical and biological indices. The first model relates recruitment success to indices of wind and sea surface temperature by way of a rule-based decision support system. In the second model, significant environmental and biological factors were identified and related to anchovy recruitment by way of an expert system approach. These two approaches are evaluated and compared. It is suggested that these types of models, when satisfactorily validated, have great potential in supporting the future management of the South African anchovy fishery in the dynamic environment of the Benguela Current.

Pelagic fish, particularly clupeoids, form the basis of many important commercial fisheries. Reproductive success of most clupeoid fish with planktonic larval stages is influenced by the environment (Blaxter and Hunter 1982, Armstrong and Shelton 1990). Bakun (1985) and Anderson (1988) reviewed hypotheses concerning the environmental regulation of recruitment success. Although the role of the environment is emphasized when considering fluctuations in pelagic stocks (see Kawasaki *et al.* 1991), researchers generally acknowledge that no single, clearly defined variable is responsible for determining year-class success (Sharp *et al.* 1983, Anderson 1988, Campbell and Graham 1991).

Many marine fish stocks experience a wide range of variability in the strength of successive year-classes (Wooster and Bailey 1989). Indeed, variability in recruitment is assumed to be the primary source of uncertainty in most fisheries (Csirke 1980, Doubleday 1985). The central question for fisheries management is therefore "what controls interannual variation in recruitment?"; i.e. management needs to be able to predict strong and weak year-classes.

The Cape anchovy *Engraulis capensis* is a relatively short-lived species that experiences large variations in recruitment from year to year. Recruitment in any one year has a marked impact on the population biomass (Cochrane and Hutchings 1995). However, recruitment is not correlated to the spawner biomass of the previous year ($r = 0.24$, $n = 10$, $p > 0.25$); in fact, the largest recruitment recorded was generated by the smallest spawner biomass (Fig. 1).

Simulation studies by Cochrane and Starfield (1992) indicated that a valuable increase in the mean annual yield of anchovy could be achieved if recruitment variability could be predicted correctly at the start of the fishing season. Conservative estimates indicated a 16% increase in mean annual catch if forecasts could differentiate between "below average" or "average or above" recruitment.

In an attempt to cope with resource fluctuations, a number of approaches have been proposed to aid decision-makers in the management of dynamic resources. Starfield and Bleloch (1983), Starfield *et al.* (1985), Starfield and Louw (1986) and Starfield (1990) discuss the utility of semi-quantitative and qualitative models for systems that are assumed to be well understood, but difficult to measure quantitatively. A management strategy that makes use of qualitative models as tools for incorporating subjective informa-

* Formerly Marine Biology Research Institute, Department of Zoology, University of Cape Town, South Africa; now Department of Mathematics and Applied Mathematics, University of Natal, Private Bag X01, Scottsville 3209, South Africa. Email: korrubelj@science.unp.ac.za
† Formerly Sea Fisheries, Private Bag X2, Rogge Bay 8012, Cape Town South Africa
‡ Fisheries Department, F. A. O. Via delle Terme di Caracalla, 00100, Rome, Italy. Email: kevern.cochrane@fao.org
¶ Sea Fisheries, Private Bag X2, Rogge Bay 8012, Cape Town, South Africa. Email: lhutchin@sfri.wcape.gov.za
§ Marine Biology Research Institute, Department of Zoology, University of Cape Town, Rondebosch 7701, South Africa. Email: jgfield@ucthpx.uct.ac.za

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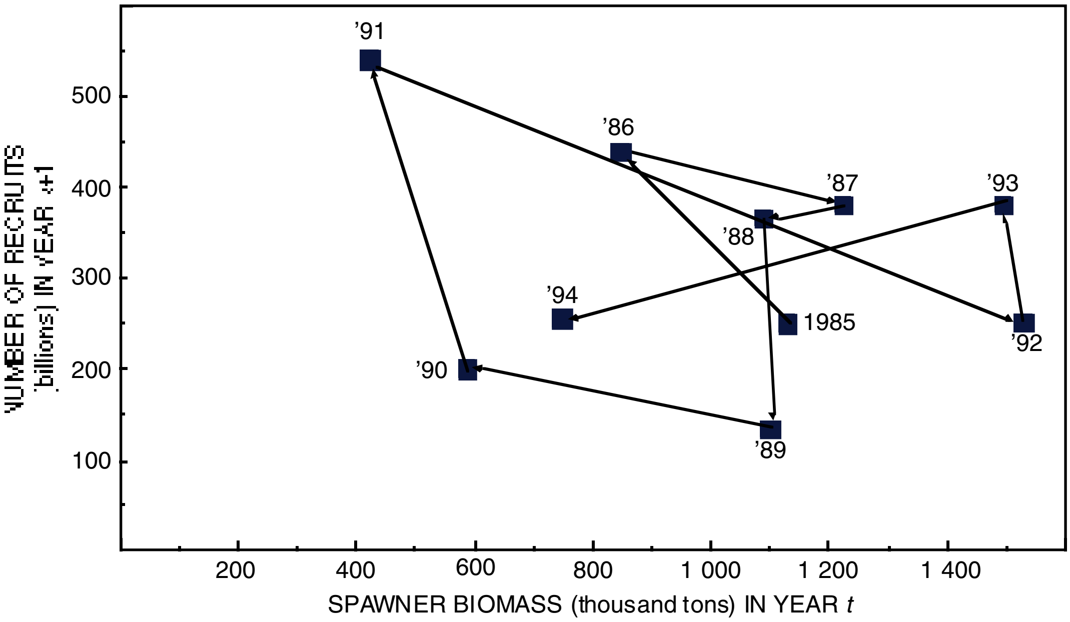

Fig. 1: Relationship between recruitment and spawner biomass of the previous year for Cape anchovy *Engraulis capensis*. Numbers at the data points refer to the year of the recruitment estimate

tion about systems that conventional modelling techniques have difficulty in including, accepts uncertainty as a fundamental characteristic. From this perspective, the goal of management shifts from quantitative prediction to judicious management (Bottom *et al.* 1993), providing a formal method to allocate priorites and provide justification of research effort (Wilimovsky 1985). Such an approach requires an integration of technical analysis and human experience to find solutions (Francis 1990).

As part of the Benguela Ecology Programme, research efforts were directed at explaining fluctuations in recruitment of Cape anchovy. Some of the approaches dealt with the identification of environmental and biological variables thought to be important in controlling anchovy recruitment, and in particular, determining the effect of these variables on the recruitment process (Bloomer *et al.* 1994, Korrûbel 1995). Models predicting/forecasting departures from median recruitment were developed and used to arrive at semi-quantitative and qualitative forecasts of future anchovy recruitment success (Bloomer *et al.* 1994, Korrûbel 1995). By highlighting the variables believed to play a role in anchovy recruitment, both approaches endeavoured to provide information on recruitment in the southern Benguela anchovy stock at an earlier stage than was possible by conventional methods. Such information could advise on setting the pelagic Total Allowable Catch (*TAC*) for the next commercial harvesting season, and could substantially increase the yield from the fishery (Cochrane and Starfield 1992).

The aim of this paper is to compare and evaluate the two above-mentioned approaches, and to discuss the potential of such decision support systems for South African pelagic fisheries management.

METHODS, DATA AND ASSUMPTIONS

Since 1984, shipborne acoustic surveys of clupeoid spawner and recruit biomass have been undertaken respectively during November and May/June/July off the South African coast (Hampton 1987). No reliable information on recruitment prior to 1984 is available. The November "spawner biomass" survey monitors a number of biological and environmental parameters suspected of influencing clupeoid recruitment. The "recruit" survey takes place later, to ensure that the bulk of the recruits (caudal length 5 cm and approximately three months old; Prosch 1986) are acoustically detectable. The survey is aimed at estimating the biomass and mean fish density of recruits resulting

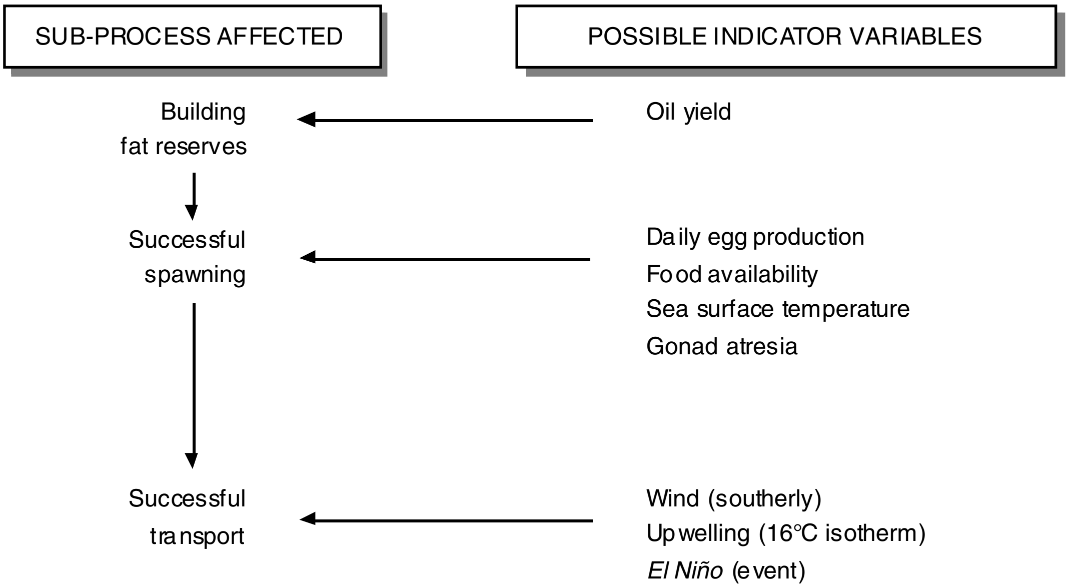

Fig. 2: Conceptual model of the major sub-processes, and possible indicator variables influencing recruitment

from the preceding spawning season.

The model of Bloomer *et al.* (1994) used biological and environmental variables/processes in the spawning, transport and recruitment (nursery) areas of the anchovy to predict recruitment. The model used indices of sea surface temperature, wind (frequency and velocity) and an index of spawner biomass as input variables. Output is a semi-quantitative prediction of recruitment, in numbers of recruits (billions of fish).

The models of Korrûbel (1995) used both environmental and biological variables to predict anchovy recruitment. A number of workshops were utilized to compile data for the model; scientific experts were invited to provide variables that could be used to predict anchovy recruitment. For a variable to be useful, it should at least:

(i) show a clear cyclical pattern that is repeated annually, with suitable differences between smallest and largest values;
(ii) be relatively easy to measure and use;
(iii) be measured before the *TAC* is set and the fishing season commences (i.e. in January).

The initial (long) list of possible predictors was collectively reviewed and revised on the basis of data availability and ease of monitoring. A subset of predictor variables was selected and are assumed to influence recruitment via the links shown in Figure 2. Quantitative thresholds were set for each variable, defining whether individual data points could be considered "extreme" (i.e. lie above or below the threshold value), and therefore have an impact on recruitment. It is assumed that only those variables influence recruitment. Output is a qualitative forecast of recruitment, either ABOVE or BELOW the long-term median value. A third output – UNSURE – is possible, should the system be unable to provide a justifiable forecast.

CONSTRUCTION OF THE MODELS

The models described in this paper fall into the category of "Production Systems" which store knowledge in production rules. A production rule is of the type:

IF A [and/or B and/or . . . .n] THEN Y .

Therefore, IF condition A (and/or condition B, and/or condition . . . n) is fulfilled, THEN conclusion Y is assumed to hold true. Such a system can be used to simulate a variety of "IF (condition) – THEN (conclusion)" scenarios. In the context described in this paper, the system culminates in a forecast of whether recruitment should be below average.

Details of the rule-based model are described in Bloomer *et al.* (1994), but they will be briefly outlined here. Rule-based models consist of three different

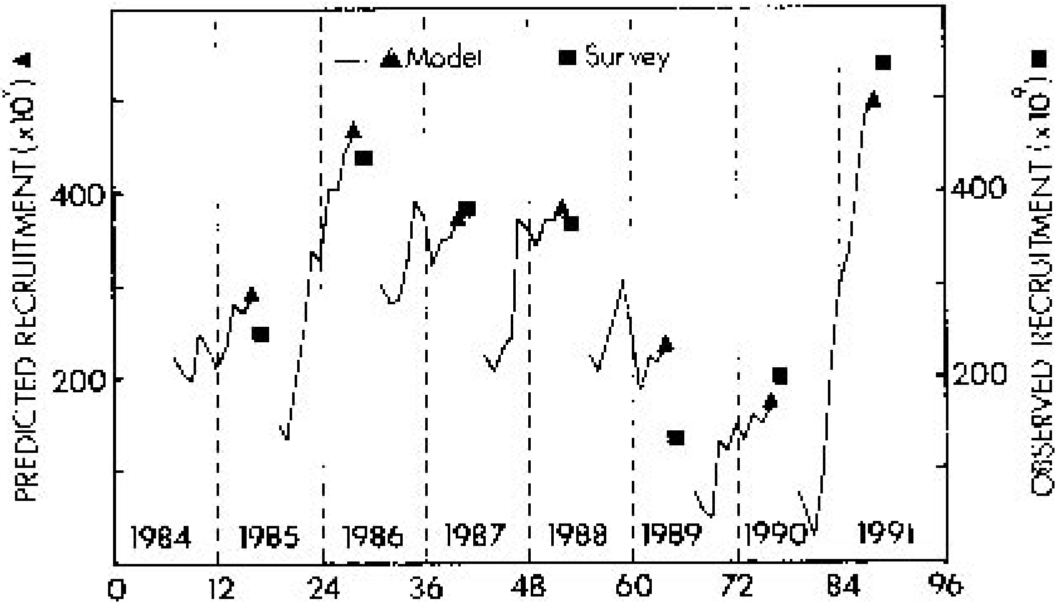

Fig. 3: Second run of the rule-based model of Bloomer *et al.* (1994), incorporating a spawner biomass index. The model's final recruitment figure for each year is indicated by the triangles. (after Bloomer *et al.*1994)

types of variable: the state variable is the output of the model, the driving variables are inputs, and time is defined by the time variable (i.e. the time between successive increments of the model). In the current model, the state variable is recruitment, the driving variables are the indices of wind and sea surface temperature (SST), and the time step is monthly. At each time step, the model examines the status of the driving variables, triggering rules accordingly. When the rule set is completed, the model goes onto the next time step.

The expert system of Korrûbel (1995) is designed to alert management when below-average recruitment is expected. Forecasts from the system are:

- UNSURE – unable to make forecast.
- AVERAGE / ABOVE-AVERAGE RECRUITMENT – no chance of below-average recruitment.
- BELOW-AVERAGE RECRUITMENT – below-average recruitment should be observed.

Because the system is qualitative, it is difficult to assign a probability to a forecast of below-average recruitment. To obtain a more informative forecast, three qualitative levels of confidence are used for forecasts of below-average recruitment:

BELOW-AVERAGE RECRUITMENT
– *Possible*
– *Likely*
– *Very likely*

These levels are obtained by dividing the number of variables thought to be impacting recruitment by the total number of variables used in the system. If this ratio is one-third, the forecast will be *possible*; if it is between one- and two-thirds, the forecast will be *likely,* and if it is greater than two-thirds, the forecast will be *very likely*.

During model trials, it was found that a single impacting variable could affect whether the forecast was average/above-average or *possible* below-average recruitment. As a consequence, the category of *possible* below-average recruitment was not used in further trials to indicate below-average recruitment.

The software used to develop and run the expert system described here was "WinEXP, a small expert system for Windows", the MS-WINDOWS® version of a shell designed for developing simple expert systems on MS/PC-DOS® computers (see Adams 1985 and Starfield *et al.* 1985 for a description of the early, DOS-based version of the shell).

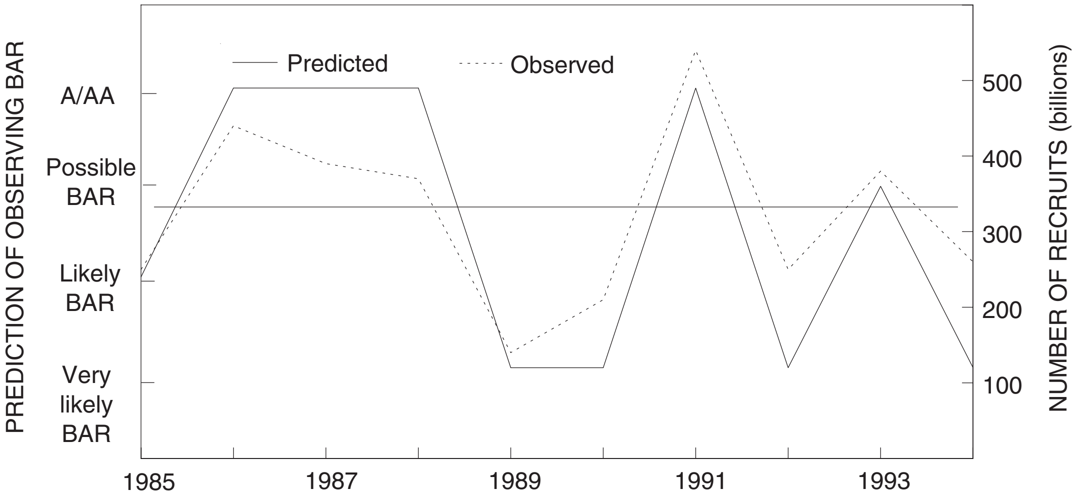

Fig. 4: Observed and predicted recruitment, as provided by the "best case" expert system of Korrûbel (1995). Median recruitment is shown by the horizontal line. Recruitment data from the Sea Fisheries (unpublished). BAR = below-average recruitment; A/AA = average/above average

RESULTS

Testing and tuning of the models

Using only the physical indices of wind and sea surface temperature, the rule-based model of Bloomer *et al.* (1994) resulted in a poor fit of predicted to observed recruitment. However, the fit improved when an index of spawner biomass was incorporated in the model. Subsequent tuning gave the results illustrated in Figure 3.

A number of expert systems were developed by Korrûbel (1995). Initial systems used only three variables, whereas later systems used up to seven variables. Unweighted variable systems were used as "base-case" scenarios before a differential weighting strategy (Kopcso *et al.* 1988) was devised. Systems were also developed that incorporated fuzzy logic (Kosko and Isaka 1993) by utilizing "fuzzy thresholds", i.e. threshold values with an allowed percentage variation. Executing the different model systems allowed the sensitivity of the model to be assessed. After tuning, the final model version used the following four differentially weighted indicator variables:

(i) Egg production by spawning anchovy;
(ii) Distance offshore of the 16°C isotherm (on the west coast);
(iii) Percentage female gonad atresia;
(iv) *El Niño*-Southern Oscillation (ENSO) events.

Results from applying this expert system are shown in Figure 4. There is a close match between predictions of recruitment for all years in the time-series of observed (estimated) recruitment (1985–1993).

Model forecasts

Both model systems were tested and tuned using data that had been used in constructing the models. The rule-based model of Bloomer *et al.* (1994) used recruitment data for the period 1984–1991 and the expert system of Korrûbel (1995) used recruitment data for the years 1985–1993. By the time each study was complete, a new recruitment datum was available, and it was used for as an initial examination of the forecasting potential of the models. Data from the 1991/1992 spawning season, and 1993 time-series data (along with the 1994 recruitment estimate), were used for the rule-based model and expert system respectively.

The forecast by the rule-based model showed an error of 58 × 10^9 recruits, which translates into a difference of 17.6% of mean recruitment, or 14.8% of the recruitment observed in 1992 (Fig. 5). Based on the 1993 time-series data, a forecast of "very likely below-average recruitment" was tendered for 1994 by the expert system (Fig. 6). When the 1994 estimate of recruitment was later made available, the forecasts were seen to be justified.

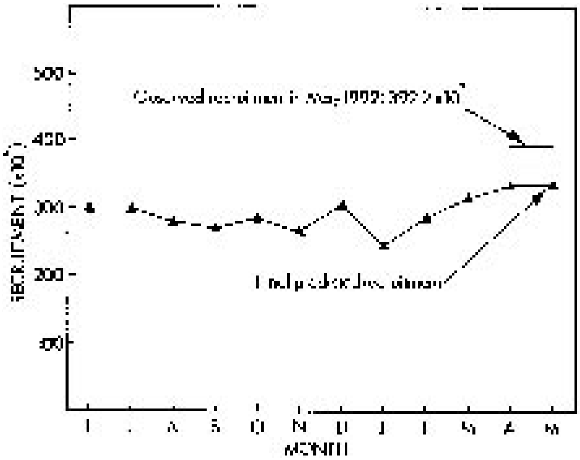

Fig. 5: Testing the performance of the rule-based model of Bloomer *et al.* (1994) with the 1991/1992 recruitment data not used in the construction of the model (from Bloomer *et al.* 1994)

DISCUSSION

In the existing management procedure for the South African anchovy, an initial *TAC* is set at the start of the commercial fishing season in January, before the year's recruitment of 0-year-old fish (an important component of the catch; Bergh 1986) is known. The *TAC* is calculated from the estimate of spawner biomass (obtained in November) and by assuming that recruitment of 0-year-old fish will be equal to the observed long-term median. The *TAC* may be revised between May and July, after the actual recruitment has been estimated acoustically. This procedure therefore incorporates a risk that, if recruitment is below the median, the stock could be adversely depleted before the results from the recruitment survey justify the January *TAC*.

An important goal in fisheries management is the minimization of risk (Stewart in press). Modelling studies usually play an important role in investigating ways to achieve this goal, and the use of simulation models is one approach in an attempt to cope with uncertainty (see Korrûbel 1992). However, studies attempting to relate fish recruitment to environment using conventional empirical techniques (e.g. virtual population analysis, see Lapointe *et al.* 1992), and other more esoteric approaches (e.g. Lochner 1980, Newman *et al.* 1980) have not been very successful thus far. This has resulted partially from the short time-series available for analysis (Bakun 1985), and because, when they are available, data are often only semi-quantitative or qualitative. Also, much specialist knowledge is not in a form suitable for use directly for management purposes (Silvert 1989). However, such information may constitute real and valuable information that should be utilized (Hilborn 1992).

Rule-based systems are thought to be the best approach for formalizing and codifying problem-solving expertise (Hayes-Roth *et al.* 1983). The benefits of using rule-based systems (Hayes-Roth 1985) include:

(i) they are easy to construct;
(ii) they provide an easy way to furnish explanations;
(iii) new rules can be easily added with little disturbance to the rest of the system.

Expert and decision support-systems have been used to predict the effect of biotic and abiotic factors on biological systems (Starfield *et al.* 1989, Starfield 1990, Collopy and Armstrong 1992). The concept of such a system for fisheries management is not new (Ryan and Smith 1985). In the local context, the systems presented here also are not the first to attempt development of a decision support tool incorporating environmental parameters for the South African pelagic fishery (see Wickens and Field 1990 for descriptions of earlier attempts at rule-based models). It is hoped that these initial steps will serve as a basis on which to implement future developments in expert/decision support systems in South African fisheries management.

This paper describes and compares two attempts at providing semi-quantitative and qualitative information on recruitment success in Cape anchovy to managers of the fishery. By linking recruitment to environmental and biological variables, models were constructed to forecast actual recruitment and departures from median recruitment. This information could be available at an earlier stage than is possible in the present management strategy. In South Africa, these models are first attempts at predicting anchovy recruitment, and although testing has been limited at this stage, the predictions generated by these two systems compare well with the time-series of observed recruitment. The expert system of Korrûbel (1995) also performed well on the dataset generated by South Africa's Sardine and Anchovy Recruitment Programme (SARP, Painting and Korrûbel 1998).

This paper also reports the first local survey of expert scientific opinion with respect to the development and implementation of an expert/decision support system for pelagic fisheries management. From an academic point of view, this research can therefore be seen as an extension of previous research on South African pelagic fisheries management (e.g. Bergh and Butterworth 1987, Butterworth and Bergh 1993,

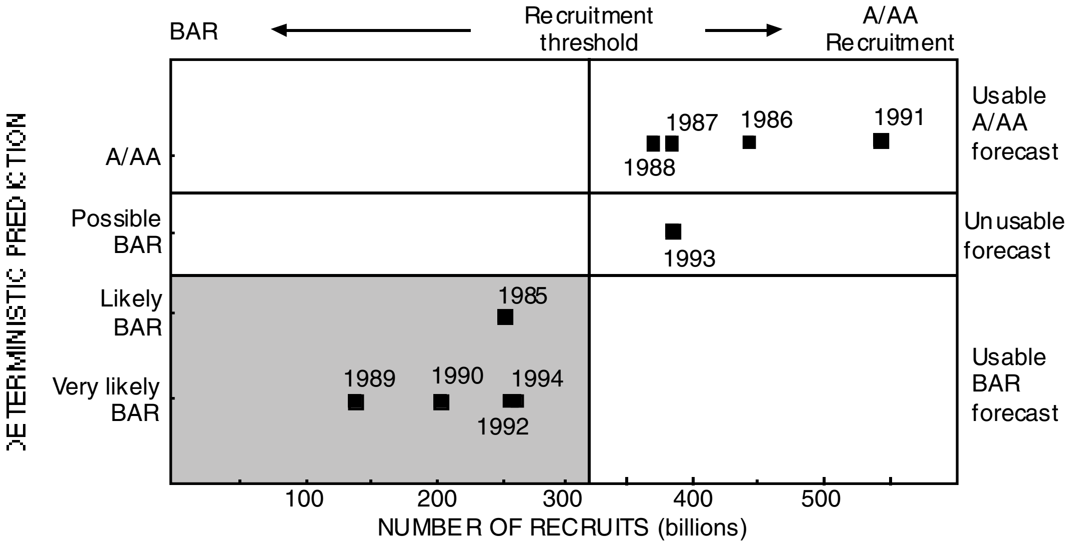

Fig. 6: Graphical representation of the forecasts generated by the "best" expert system of Korrûbel (1995). The below-average forecast of 1994 is validated with observed below-average recruitment. The shaded area is the area of interest, delineated by the thresholds for usable / unusable forecasts and below average / average/above-average recruitment. BAR. = below-average recruitment; A/AA = average/above average

Butterworth *et al.* 1993).

In summary, resource managers need enhanced tools to help them keep ahead. Annual fluctuations in pelagic fish stocks are of considerable commercial interest and, as a consequence, the need for scientific knowledge to manage this exploitation has grown. There is a need to centralize expertise and to have it easily accessible to users. An expert/decision support system, designed to assist managers by implementing the accumulated (qualitative and quantitative) data into a forecasting system, could address these needs. This should contribute towards better handling of information using effective and handy tools, and promoting effective management.

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