Computer Aids in Fisheries Management

Adaptive Research

Project R. 5050CB

Final Report for the Overseas Development Administration

Fisheries Management Science Programme

MRAG Ltd

October 1995

CONTENTS

CEDA version 2The revised CEDA manual

LFDA version 4The revised LFDA manual

Appendices

FINAL REPORT

R. 5050CBComputer Aids in Fisheries Management - Adaptive Research

1. Objectives of the project

1.1 Background

This project is the adaptive phase of an earlier project completed under the Fisheries Management Science Programme: Development of Computer Aids for Fish Stock Assessment and Management Policy (R. 4517).

Two pc-based software programs for running stock assessment procedures were produced under project R. 4517:

CEDA-Catch and Effort Data Analysis: A software package designed to facilitate the implementation of complex methods of analysing catch, effort and abundance index data by non-programmers. The outputs included estimates of current and unexploited biomass, catchability and associated population dynamics parameters.

LFDA-Length Frequency Distribution Analysis: A software package designed to facilitate the implementation of complex methods of analysing length frequency data by non-programmers. The outputs included estimates of growth and mortality.

More than 50 copies of the software packages were distributed to scientists and scientific organisations in developing countries during the year after their first release (. Comments on the software packages resulting from their use with real datasets were solicited on an informal basis. A review of the full extent of the dissemination programme to date is provided in section 2.3 of this final report.

1.2 The Adaptive Phase

Objectives of the Adaptive Phase were as follows:

1. Evaluation of the stock assessment software packages produced under ODA project R4517 to test:

Their applicability to the assessment of commercial fish stocks in tropical developing countries and;

their applicability for use by fisheries scientists working in tropical developing countries.

2. Preparation of revised versions of the software packages CEDA and LFDA, taking into account the results of the evaluation carried out under objective (1) above.

This adaptive phase was therefore designed as a comprehensive evaluation of the software packages, through their application in a number of specific fisheries stock assessment and management studies. The principal objective was the preparation of extensively revised versions of the two software packages. The new versions of CEDA and LFDA and the new user manuals therefore form the principal outputs of the project. Secondary outputs are the published and reported results of the data analyses which have been performed using the software.

2. Work carried out

The strategy devised to achieve the objectives of the project was basically divided into three phases. The first phase involved a number of case studies in which the performance of the software packages in real stock assessment work in tropical developing countries was evaluated. The second phase was the collation and evaluation of feedback material on the performance of the software during these case studies, and other studies which were not part of the main project. These other studies came about largely through the use of the software on other projects by scientists at MRAG and Imperial College, and also through the wide dissemination of the software and manuals. The third and final stage was the production of the revised software.

This section presents a description of the work carried out to implement this strategy. It is organised in four parts. The first part presents details of the work carried out on three detailed case studies in Thailand, Turks and Caicos Islands (Caribbean) and Zimbabwe. The second part presents a summary of other stock assessment work in which CEDA and LFDA have been used since their first release in January 1992. These studies were not funded under this project, but they contributed significantly to the body of information on which the revision of the software was based. Part three describes the work involved in disseminating the first release of the software packages. This includes stock assessment and training workshops at which CEDA and LFDA were used. The fourth and final part describes the work involved in preparing the new versions of the software.

2.1 The Case Studies

2.1.1 Anchovies in Thailand

The final report of the Thailand based project 'Alternative management strategies for small pelagic fish' is provided in Appendix I. Both CEDA and LFDA were utilised as part of this project. However, for reasons explained below, the final report does not provide details of the work carried out using CEDA and LFDA. This section therefore explains in some detail the background to the Thailand project and the activities undertaken by MRAG as part of the work on this project.

Background

Eleven of the eighteen species of the genus Stolephorus (anchovies) found in the Indo-Pacific region occur in the Gulf of Thailand. The fishery for anchovy in this area principally targets one species *Stolephorus heterolobus*, which constitutes as much as 90% of the total catch. A variety of fishing gears are used, including the major fishing gears anchovy purse seine and pair trawl, and the small scale gears bamboo stake trap, push net and light luring drift net. The most widespread method currently in use is the anchovy purse seine with luring lights.

Against a background of fluctuating catches, there was an increasing trend in annual fishing effort and landings during the 1970's and 1980's. The highest annual catch recorded to date for the whole of Thailand was 124,000 tonnes in 1990. In late 1992 the Faculty of Fisheries at Kasetsart University, Bangkok, designed a project 'Alternative Management Strategies for Small Pelagic Fish' in collaboration with the Department of Fisheries of the Government of Thailand. This project aimed to develop a new management strategy for the Thailand coastal anchovy fishery, taking into account both biological and socio-economic considerations.

Previous stock assessment of the Thai anchovy fishery had been undertaken using production models fitted using simple equilibrium and regression techniques. Modern stock assessment techniques have demonstrated the inadequacies of these methods of parameter estimation (see Hilborn and Walters 1992 for review). Anchovy length frequency data had been analyzed using an early version of Elefan (Pauly and Morgan 1987).

The new project was considered to be a useful opportunity to significantly improve the quality of the stock assessment through the use of CEDA and LFDA. It was therefore agreed that these packages would be used, as part of the project, to assess the status of the stocks and to develop appropriate bioeconomic models. The computer packages would be used by the Thai researchers at Kasetsart University and the Department of Fisheries, thus providing a thorough and realistic test of the software. In this way any requirements for revision of the software would be identified.

Activities

Initial visit to Thailand

The project in Thailand formally started on 1 January 1993 and finished on 31 December 1994. The Project Manager from MRAG visited the Faculty of Fisheries at Kasetsart University in January 1993 in order to introduce the Thai researchers to the CEDA and LFDA packages and to discuss their usage on the anchovy project. Much of this initial visit was spent investigating the extent of the available data on the anchovy fishery and the scope for stock assessment using CEDA and LFDA.

The Government of Thailand Department of Fisheries made available aggregated catch/effort and length frequency data in spreadsheet format for the anchovy fishery off the eastern coast of the Gulf of Thailand (the most important anchovy fishing area) in the period 1970 to 1991. During preliminary examination of the dataset it became clear that a significant amount of pre-processing of the original catch/effort and length frequency datasets would be required before CEDA and LFDA could be used.

In the case of the catch/effort data, there had been a number of significant changes in the fishing methods used in the fishery over the course of the dataset. It was therefore necessary to devise some method of standardising the index of fishing effort, in order to obtain a realistic picture of the effects of fishing on the stock(s). In addition the stock structure itself was not well defined and it was uncertain what would be the most appropriate spatial scale on which to aggregate the data.

In the case of the length frequency data, samples taken at landing sites from boats which had been fishing on a number of different fishing grounds, had been aggregated by simply adding together the numbers of fish in the samples. A preliminary investigation indicated that the length distributions of different samples varied considerably and aggregating them in this simplistic way significantly reduced the information content of the data. There was also the question of stock structure and seasonal migration patterns. It was considered that analysis of dis-aggregated length distributions might provide some insight into this problem.

The sort of detailed analyses of the spatial and temporal structure of the data required prior to the use of CEDA and LFDA would have been extremely difficult and time consuming using the spreadsheets provided by the Department of Fisheries. It was therefore decided that a dedicated relational database would be designed and constructed for the compilation, storage and handling of the catch, effort and biological sampling (length frequency) data.

Database development

During the initial visit to Thailand the MRAG Project Manager was shown the formats in which the dis-aggregated 'fine scale' data were available. The structure of the data was considered suitable for the analyses required, however the amount of data available was uncertain at that stage. Work on the design and construction of the database was started immediately in the expectation that as much data as possible would be transferred into the database. The process of converting the spreadsheet data to the format necessary for input into the database provided an opportunity to review the data and check for any errors. On completion of the transfer of all the available data to the new database it would be possible to undertake a thorough examination of patterns and trends in different subsets (e.g. particular fishing grounds fished at particular times of the year with particular types of gear) prior to the preparation of input files for CEDA and LFDA.

None of the Thai researchers involved in the anchovy project had any prior experience of using modern relational database packages. Prior to this project all data handling and analysis had apparently been carried out using spreadsheets. The Project Manager made a number of visits to Kasetsart University over the next 12 months, during which the researchers were instructed in the theory of relational databases and the use of Rbase version 4 (the commercial database package used for the anchovy database). The researchers were also instructed in the use of CEDA and LFDA, using the tutorial sections provided in the manuals and preliminary trial analyses on local datasets.

Progress towards the data analysis phase in which CEDA and LFDA would be used on the anchovy data was slow. This was partly the result of health problems experienced by the Thai researcher with the authority and the background knowledge necessary to access the data stored in spreadsheets at the Eastern Marine Fisheries Development Centre (EMFDC) in Rayong. This reliance on individual researchers was one of the main drawbacks associated with using spreadsheets to create *ad hoc* databases, which was pointed out at the start of the project. One of the aims of the new database was to overcome problems of this type.

In May 1994 one of the junior Thai researchers (Methee Kaewnern) visited MRAG in London for two weeks to work on the database. He brought with him the fine scale catch/effort and length frequency data for 1990 and 1991. These data were successfully loaded into the database and checked.

One of the problems identified at this stage was the use of vessel name as one of the key fields in the relational structure of the database. The vessel names in the database were, by necessity, the phonetic translation into the Roman Alphabet of the Thai names. In some cases different spellings had been used for the same vessel. Problems of this nature were corrected by the Thai researcher and a master directory of vessel names and up to date characteristics was created.

A system for coding fishing grounds was also devised. The fishing grounds in the database had been entered as general descriptions of particular areas (eg. 'In front of Rayong'). All of these locations were plotted onto a chart and individually coded. These codes were added to the database, which enabled the user to make structured queries to select data from one or more fishing grounds as required. Length frequencies and corresponding catch/effort data could therefore be selected easily from individual fishing grounds rather than just the region in which the fish were landed and sampled.

During this visit it was apparent that Mr Methee had considerably developed his understanding of databases in general, and Rbase in particular. He was clearly going to be able to make good use of the database and assist the senior researchers in their analysis of the anchovy data using CEDA and LFDA. At the end of the visit several recommendations for further development of the database were made. Principal amongst these was the transfer of more of the fine scale data (believed to be available back to 1986) into the database. This required Mr Methee to work closely with Mr Sommai at the EMFDC.

In mid 1994 it became clear that it was not going to be possible for any more data to be transferred from the old spreadsheet format into the new database. There were problems between the institutions in Thailand relating to data access. This was a major problem for the project. The large number of separate and poorly organised spreadsheets would make it very difficult to undertake the type of detailed examination of the fine scale data necessary before CEDA and LFDA could be used effectively. Despite these concerns, the data analysis proceeded and the results were reviewed by the MRAG Project Manager during a visit to Kasetsart University in November 1994. At the time of the visit, the report was only available in Thai. As expect, the anchovy database had not been used, but attempts had been made to use both CEDA and LFDA for the data analysis. All the analyses had been undertaken on aggregated data. There had been no re-analysis of the fine scale data. A series of comments on the use of the computer packages and suggestions for improvements in future versions had been compiled.

Use of CEDA

The Thai researchers had attempted to use CEDA to fit the Shaefer and Fox production models to the anchovy data, but were unable to obtain any reasonable results. They had used only the aggregated dataset which comprised total catches and cpue of the anchovy purse seine fleet in terms of catch per day. They had used the software package in the correct way, however the data were too poor to yield any acceptable parameter estimates. Given the changes in fishing methods over the course of the data time series, and the lack of any attempt to standardise the effort indices, this result was not surprising. Unfortunately, in order to arrive at an answer, rather than undertaking the preliminary data analysis necessary to improve the information content of the dataset, they abandoned CEDA in favour of the more traditional regression method of parameter estimation. This method makes fewer demands on the data, at the expense of greater assumptions. The results of this analysis are presented in the final report of the project (Appendix I). Parameter estimates and estimates of MSY and optimum fishing effort are provided, however, the information content of the dataset is such that these are considered to be unreliable.

In their excellent book on Quantitative Fisheries Stock Assessment, Hilborn and Walters state: 'When a dynamic method gives you an absurd answer [as was the case here with CEDA] you should conclude that there is little useable information in the data rather than fall back on a method that will give you a believable but likely wrong answer' (Hilborn and Walters 1992).

Use of LFDA

The Thai researchers had also undertaken an analysis of length frequency distributions using LFDA. The length distributions for 1990 and 1991 had been aggregated by month and region (Rayong and Trat) using the simplistic method described earlier. The 'best' results had apparently been obtained using the LFDA version of ELEFAN. The resulting growth parameters were apparently in line with previous results. The growth curves had been plotted over the length frequency histograms, using one of the facilities in LFDA, to show the comparison between the length distributions and the growth curves, but unfortunately these plots indicated that the data and the model did not correspond very well.

During the visit in November 1994, the MRAG Project Manager and the Thai researchers attempted to reproduce the results presented in the Thai report, but they were unsuccessful. A visual examination of the length distributions showed no clear patterns of growth, as would be indicated, for instance, by modal progression through the distributions. Various analyses were undertaken, using all of the data combined and using a number of subsets. It was not possible to estimate growth parameters with any degree of confidence. The most frequent problems were score function surfaces which were either very flat or very confused and had multiple maxima.

Because of this inability to reproduce the earlier growth parameter estimates, no results of the analysis of length distributions is presented in the final report of the project (Appendix I).

Discussion and Conclusions

The Thailand Anchovy case study revealed more about general difficulties in stock assessment in tropical developing countries than it did about the specific performance of CEDA and LFDA. The principal problem encountered was the need for prior organisation and processing of the data, before CEDA and LFDA could be used effectively. This is a common situation. Considerable amounts of fisheries data are collected for a variety of purposes in developing countries, however they are frequently not organised in such a way that makes them readily accessible for detailed analysis.

There is a central database at the Government of Thailand Department of Fisheries in which all of the data collected under the national data collection scheme (mainly the catch and effort data) are stored. In addition researchers at the various coastal Marine Fisheries Development Centres (eg EMFDC Rayong) undertake their own data collections for detailed studies of catch/effort and/or biological characteristics (eg length frequency). The central database is an 8 year old system, custom built using the COBOL programming language. Outside the central database unit there is very little experience of modern relational databases. There is, however, widespread use of spreadsheets. Unfortunately this has frequently led to substantial 'databases' being built up by individual researchers in large numbers of oversized spreadsheets. Most of the fine scale dis-aggregated data required for this study were stored in this way, under the charge of a single researcher at EMFDC.

A spreadsheet package is inappropriate for storing large quantities of data. It is not designed for this purpose. Any data storage system developed in a spreadsheet format, which contains substantial quantities of data, ultimately becomes a large, complex and unmanageable facility which is only understood, and therefore is only accessible, by the person who created it. It then becomes practically impossible for anybody else to access the valuable data resource which has been created. This was a particular hinderance during the Thailand anchovy case study, because the Thai researcher from

EMFDC developed severe eye problems, rendering him effectively blind for nearly a year of the project.

The requirement for preliminary data organisation, validation and pre-processing is not exclusive to analyses using CEDA and LFDA. This is the type of preparation which should underpin any detailed analysis of fisheries data. One of the reasons this is not always done is because, unless the data are stored in a well designed database, it is a very difficult and time consuming process.

The proposal to develop a relational database using a modern commercial database package, such as Rbase, was a practical and cost-effective solution to this problem. Unfortunately, after substantial delays, the Thai researcher with access to the data was ultimately unwilling to develop and utilize the database. This is believed to have been borne out of a reluctance to transfer the data to a system which would not have been under his exclusive control. There was also a degree of resistance to learning a new computer package. In this particular case there was perhaps more of a personality problem than anything else, since other members of the project team in Thailand showed great enthusiasm for learning about databases and developing a database for the anchovy project.

Future work

This case study highlighted the need for pre-processing of data before they are analyzed using CEDA and LFDA. It is perhaps overly optimistic to expect that all prospective users of the software, particularly in developing countries, will possess the necessary tools, skills and experience to undertake this work. However, the types of data analyzed by CEDA and LFDA are often collected on a routine basis from commercial and artisanal fisheries in many countries in more or less standard formats. There is perhaps scope for developing a generic computer database system which could be used 'off the shelf' by assessment scientists in developing countries to assist them in the necessary pre-processing of fisheries data prior to the application of assessment packages like CEDA and LFDA.

2.1.2 Lobster in the Turks and Caicos Islands

Background

There is a long history of lobster fishing in the Turks and Caicos Islands (TCI), dating back to the early 1930's. A variety of fishing techniques have been used during the course of the fishery's history, but the dominant method today is free diving from fibreglass skiffs, using a hook to impale the lobsters.

A substantial catch and effort data series extends back to 1957. The catch data are more or less complete, while the effort data are available for the periods 1966 to 1969, 1974 to 1983 and 1986 to the present.

In early 1993 a Memorandum of Understanding was signed between MRAG and the Fisheries Department of the Government of Turks and Caicos regarding research on the Caicos Bank fishery in the TCI. As a result a stock assessment project was undertaken as part of the adaptive phase of the Computer Aids project. This project ran from May 1993 to February 1994.

Activities

Stock assessment work on the lobster fishery was undertaken by the TCI Fisheries Department using CEDA as the main data analysis tool. The staff of the Fisheries Department are highly experienced in stock assessment methods, particularly those implemented in CEDA. There was therefore no necessity for MRAG staff to instruct the researchers in the use of the software and the interpretation of the results.

As with the Thailand anchovy project, the main activity required at the start of this project was compilation and organisation of historical data. In this case the data were not in digital format and needed to be entered into a database. In fact at the start of the project the full extent of the data in a format appropriate for analysis using CEDA was not known. In the event some 24,000 records were entered into a specially designed database. These data covered the period August 1978 to July 1984. The more recent data were already entered before the start of the project. The data available for analysis therefore covered the period 1978/79 to 1992/93 inclusive.

During the course of the project substantial additional data for the lobster fishery were discovered, which would extend the time series back to 1973/74 for complete coverage, and back to 1966/67 for partial coverage. However, entry of these data into the computer system was beyond the scope of the project. A further project would be required to undertake this work and extend the scope of the data analysis.

The data entry phase was completed by the start of January 1994. The data analysis using CEDA was undertaken during January and February 1994. The results of the lobster assessment work were presented at the Gulf and Caribbean Fisheries Institute (GCFI) conference in Corpus Christi, Texas in mid February 1994. The report presented at this meeting forms the substantive part of the final report, presented in Appendix II.

Discussion and Conclusions

As is shown in the final report of this project, this practical application of the CEDA package was considerably more successful, in terms of stock assessment results, than the Thailand anchovy case study. Although the CEDA models were largely inappropriate for the lobster data, the scientists working on the project were able to quickly assess firstly that a surplus production model did not fit the dataset, and secondly that a model incorporating a recruitment index was the correct approach. This was made possible through the rigorous use of CEDA's model fitting utilities, such as the three alternative error models and the ability to analyse residual patterns graphically. Following their work with CEDA, the stock assessment scientists in TCI have developed a very useful spreadsheet based population dynamics model for their lobster resource, incorporating a recruitment index.

This successful application of CEDA in TCI may be largely attributable to the experience of the researchers involved in the stock assessment work. It is interesting to note that, as with the anchovy dataset, there were problems with fitting models to the annual aggregated lobster data, and that these problems are at least partially attributed in the report to changes in catchability (eg. due to changes in fishing practices). It was not until the no-recruitment and constant recruitment models were applied to the short time scale data that satisfactory results were obtained.

The discussion section of the lobster report provides an appraisal of the utility of CEDA as a stock assessment tool. It is stressed that despite many useful features to assist in the rigorous fitting of the models, the package still requires a good background knowledge of statistical modelling and fisheries stock assessment. It is suggested that the package would be significantly enhanced by the addition of context-sensitive on-line help. This is one of the improvements to the new version of CEDA, described in later sections.

Future work

One area for future work identified in the final report of the lobster assessment is the entry and analysis of the additional data uncovered during the project. The scientists involved in the project estimated that the data entry component alone would take an additional 8 months.

Also, as a result of their experiences with the lobster data, the scientists in the TCI Fisheries Department decided to use CEDA for an assessment of their conch (*Strombus gigas*) fishery. The assessment was successful and the results have been used to set the export quota for conch required by the Convention on the International Trade in Endangered Species (CITES) (see also section 2.2.9).

2.1.3 Lake fisheries in Zimbabwe

The third case study differed significantly from the other two in that the analysis of the data was undertaken at MRAG and not by researchers in the country from where the data originated. Previously un-analyzed length distribution data for one species of Kapenta, two species of *Tilapia* and one species of *Haplochromis* from two lakes (Kariba and McIlwaine) were provided by Dr Brian Marshall from the Department of Zoology, University of Zimbabwe. These data were analyzed using LFDA.

Whereas the other case studies tested the applicability of the software both for use by scientists in developing countries and for analysing data for exploited species from these countries, this study tested only the latter. However this in itself was useful for providing an insight into the extent of the problems which are encountered when analysing this type of data. A particular conclusion of this work was that inclusion of a seasonal growth model in the LFDA suite would be extremely useful.

A description of the work undertaken on this case study and the results obtained are provided in Appendix III. The results for Kapenta in Lake Kariba were provided to Dr Marshall, who passed them on to the Lake Kariba Research Unit. The results were compatible with Dr Marshall's previous work on Kapenta length distributions using graphical methods. The results for Lake McIlwaine were passed to the Fisheries Department in Harare, which is responsible for the management of the fisheries in that area.

Future work

The LFDA package was also sent to the Ministry of Wildlife and National Parks Fisheries Centre in the Nyanga National Park, in the eastern highlands of Zimbabwe. Rainbow trout have been released into streams in this area as part of a stock enhancement programme, which has resulted in the establishment of a self sustaining population. The management of the fishery on this population involves the selling of licences as part of a self financing community management scheme. It is hoped that LFDA will be used as part of the assessment process to calculate sustainable yields.

2.2 Other Studies using CEDA version 1 and LFDA version 3.1

Since the first release of CEDA version 1 and LFDA version 3.1, the computer packages have been used in a number of studies other than the case studies funded under this adaptive phase of the project. This work has been undertaken in fisheries all over the world in both developing and developed countries. All of these studies contributed significantly to the body of information which was used in the design and production of the new versions of the software. This section provides a summary of some of the most significant stock assessment work which has been undertaken using CEDA and LFDA between 1991 and 1995.

2.2.1 Small Pelagic Fish in the Adriatic

Since 1975, the Italian institute Instituto di Richerche sulla Pesca Marittima (IRPeM) has been collecting extensive biological and commercial catch/effort data for anchovies and sardines in the Adriatic Sea. Over the past few years, MRAG has conducted various analyses on these data, in collaboration with IRPEM scientists, in order to estimate the biomass and exploitation rate of the stocks, and to calculate target fishing effort levels compatible with management goals.

For anchovies, the availability of age and length data meant that age-structured assessments could be performed. For sardines, however, reliable age data were not available. Fortunately, an alternative method of analysis, available in the CEDA package, was possible for both species, using total catch, catch per unit effort and recruitment index data. Use of this method of analysis with anchovy data yielded very similar assessments to those using age-structured assessment methods (using Virtual Population Analysis - VPA). An assessment of the sardine stock was also successfully completed. The early success of this work was in fact one of the reasons why the assessment of anchovy in Thailand was used as one of the case studies.

Data continue to be collected and future stock assessments, to be undertaken annually by IRPeM staff will involve the use of CEDA. A series of workshops is being held by MRAG to train scientists from IRPeM in stock assessment methods, including the use of CEDA. The package will be used on a regular basis to assess the status of the stocks of both species, to make projections under various catch and effort scenarios, and evaluate the effects of different management strategies.

2.2.2 Spiny lobster around Tristan da Cunha

The Tristan da Cunha group of islands, located between 37^{o} and 40^{o} S in the temperate waters of the south-east Atlantic, comprises four volcanic islands; Tristan, Inaccessible, Nightingale and Gough, of which only Tristan is permanently inhabited. A pot and tangle-net fishery targeting the spiny-lobster, *Jasus tristani*, has been operating around the islands almost continually since 1949; in the 1994/95 season 300 tonnes were landed. A single fishing company, South Atlantic Islands Development Company (SAIDC) is currently licensed to exploit the resource around three islands, but access to the fishing grounds off Tristan Island is restricted to the islanders.

Spiny lobster is a highly valuable product which is increasingly in short supply worldwide. In South Africa, where a similar species, *J. lalandii*, has recently undergone a population collapse, demand for *J. tristani* is particularly great. Resources of *J. tristani* are of central importance to the economy of Tristan and there are few economic activities available to the population that do not involve the lobster fishery in one way or another. Revenue from the fishery is derived from two sources; access royalties paid by SAIDC and the personal income generated by the islanders fishing around Tristan who sell their catch direct to SAIDC, or who work in the lobster processing factory on the island.

Two principal management measures are currently applied in the lobster fishery. Total Allowable Catches (TACs) are applied annually to each of the main islands and there is a minimum size-limit of 70mm carapace length. There are a number of sources of data on which stock assessments are based and on which additional management advice is offered. Logbooks in which catch and effort (trap numbers, depth, area) are completed by the Masters of the two vessels fishing around Nightingale, Inaccessible and Gough. Catch and effort (number of boats fishing) for the Tristan fishery are recorded in logbooks at the processing factory. Biological data, in the form of length-weight relationships and length-frequencies by sex and island, are collected at sea and ashore on Tristan.

These data are used for a number of analyses. Growth parameters are estimated from numbers at length and gross weights are converted to numbers of animals. Substantial time-series exist for both biological and catch/effort data sets. The catch/effort data extends back to 1970 on an island specific basis and back to 1950 as aggregate values for all islands.

Since 1989 MRAG has undertaken a number of rock lobster stock assessments on behalf of the Government of Tristan da Cunha, and the Foreign and Commonwealth Office. Initially assessments were performed using bespoke algorithms but following the completion of CEDA Version 1 in 1992, this has become the main tool by which the analyses of the fisheries data has been undertaken. CEDA offers a user-friendly work environment and an extensive range of analysis options which permits extensive but relatively quick investigation of the catch and effort data. Two of the models available in CEDA have been used: the Constant Recruitment Model and the Fox Biomass Dynamic (Production) Model.

Reports on the analyses of catch and effort data using CEDA are presented annually to the Government of Tristan da Cunha and are part of the basis for decisions taken by the Administrator of Tristan on the levels of TAC for the following year. The final decision on the level of TAC is determined according to a range of decision making criteria, of which the output of CEDA is only one. The effects of various future levels of TAC are investigated using the CEDA Projection Function to assist in this process.

2.2.3 Multispecies tropical reef fisheries

This is an ODA project, funded under the Fisheries Management Science Programme, undertaken by MRAG, which aims to provide guidelines for the management of tropical multi-species fisheries. The focus is on demersal deep slope reef and banks fisheries, and the management goal is to achieve sustainable social and economic benefit from the resource.

Multi-species fisheries are very difficult to model because of the complex interactions that can take place between species, such as predation and competition. Part of the project entails examining two case study areas around the islands of Tonga and Seychelles to see how well the theoretical multi-species results can be applied to such fisheries. LFDA was used extensively to estimate growth parameters from catch-at-length data that had been collected previously and were provided for the project. These parameters are an important component of the assessment of the fisheries. They are also essential inputs to the theoretical modelling work which is being done. CEDA was also used to undertake a number of single-stock assessments. This work provided estimates of initial population sizes and will be used for comparisons with the outputs of the more complex multi-species models that are being developed.

2.2.4 Pelagic fish stocks in the south of Lake Tanganyika

Lake Tanganyika is one of several vast inland water bodies in the East African Rift Valley. It is a complex water body in terms of fisheries management, being bounded in the east by Tanzania, the north east by Burundi, the west by the vast country of Zaire and in the south west by Zambia.

In 1992 CEDA was used in the assessment of the fisheries in the south of the lake, in the area controlled by Zambia. The work was done by Dr M.J. Pearce of the Department of Fisheries, Mpulungu, Zambia. The fishery in this part of the lake has been subject to change in recent decades, both in terms of focus and practice. Traditionally, the target was two species of Kapenta *Limnothrissa miodon* and *Stolothrissa tanganicae*. Recently *Luciolates stappersi* has increased in popularity. The fishing gear used by the original artisanal component of the fishery has changed from scoop net to beach seine and catamaran and lift nets. The industrial component of the fishery first appeared in the 1960's and increased dramatically throughout the 1980's. By 1989 a fleet consisting of 14 ring net units and one chiromila net were operating. The number of vessels has since continued to increase.

In the artisanal fishery, CEDA was used to evaluate three scenarios for the species *L. miodon*, namely steadily reducing beach based effort (as catamarans become more popular); constant effort; and increasing effort. Projections of stock size were made on the basis of each of these scenarios. Although some of the data used were less than ideal, the analysis revealed a general picture of population size declining rapidly towards commercial extinction. According to the results of the CEDA analysis, urgent measures were required to reduce artisanal fishing effort to within sustainable limits.

CEDA was also used to analyse industrial catch and effort data for the species *L. miodon* and *L. stappersi*. Future biomass of *L. miodon* and *L. stappersi* was projected under four scenarios of fishing effort: a sudden reduction in effort; a gradual reduction in effort; stabilising effort at present levels; and open access. The results indicated that for both species, although the current level of effort appeared to be sustainable, a slight decrease in effort would be prudent. Any increase in effort will lead to dwindling stocks.

To summarise, CEDA proved to be a practical and effective stock assessment tool and provided useful information for management. However, there is clearly scope for further work in this area, particularly on the interaction between the artisanal and industrial fisheries.

2.2.5 Shrimp on the Pacific coast of Mexico

The shrimp fishery on the Pacific coast of Mexico is the most important source of export earnings and one of the most significant sources of employment. The fishery is split into two components, an inshore artisanal sector, which targets juvenile shrimp in lagoons, and an industrial sector which harvests adults further offshore. The dominant shrimp species in the catch are white shrimp (*Penaeus vannamei*), brown shrimp (*Penaeus californiensis*) and blue shrimp (*Penaeus stylirostris*).

The 1970's and 1980's saw the industrial fleet double in size, with increased catches. More recently fleet size has decreased. The inshore situation is more complex, with a multitude of gear and vessel types being used. In addition, an unregulated fishery for shrimp larvae has developed to supply the burgeoning number of aquaculture ventures in Mexico. Since 1982, catches in the Mexican Pacific shrimp fishery have declined steadily, leading to great concern within both the fishing community and management authorities.

Dr Diaz de Leon Corral used CEDA to analyse catch and effort data from the fishery during his PhD research at Imperial College in 1992/93. The results of the analysis demonstrated conclusively that the fishery was heavily over-exploited. The work was acknowledged as being extremely important and formed the basis for the design of management measures to allow stock recovery and to improve the status of the fishery.

2.2.6 Icefish around South Georgia (Antarctic)

Three species of icefish (Channichthyidae) are found commonly around the island of South Georgia in the Atlantic sector of the Southern Ocean: *Champsocephalus gunnari*, *Chaenocephalus aceratus* and *Pseudochannichthys georgianus*. All three were targeted by distant water commercial fishing fleets from the former Soviet Union and Eastern Bloc countries during the 1970's and 1980's. Catches have declined in recent years, partly due to overfishing and partly due to the decline in the fishing fleets of eastern Europe.

Icefish have no scales. The determination of age has therefore been restricted to the interpretation of growth rings on otoliths. Exchange of otoliths from icefish between different laboratories and scientists, however, has shown that growth rings are very difficult to interpret and the results are extremely subjective. Analysis of length distributions can provide a means of independent verification of age measurements through the estimation of growth parameters. Compared to other Antarctic fish species icefish grow relatively quickly and they have a more or less discreet annual spawning period. Length distributions tend to show clear modes for at least the first two or three age classes.

LFDA was used by scientists at Imperial College, London and MRAG to estimate growth parameters from length distributions derived from length data collected on a series of scientific surveys around South Georgia during the late 1980's and early 1990's. This work provided a series of estimates of growth parameters for the three species, which will feed into further research, including an assessment of the duration of the adolescent phase in the icefish life cycle, currently being undertaken by the British Antarctic Survey. The results have also provided a very useful independent comparison with the age data derived from otolith material, which have been used extensively in the assessment of the fishery over the past few years. A paper is in preparation for publishing in the scientific literature.

2.2.7 Spiny Lobster in the Mexican Caribbean

Spiny lobster have been fished off the Caribbean coast of Mexico since well before the Spanish conquest of this area. The lobster fishery is still important to this region of Mexico and the crustaceans are now caught using traps, by scuba-diving, skin diving and diving with a continuous air supply (Hookah), using a gaff and tangle nets. The fishery can be characterised as 'partially exploited', since strong sub-surface currents effectively prevent fishing in certain areas, however the effect of this upon stock levels depends crucially upon migratory movements to and from these areas.

Dr Gonzalez-Cano used LFDA during his PhD research at Imperial College to obtain growth parameter estimates from length distributions of spiny lobster collected in the Mexican Caribbean. The work investigated how these parameters might be affected by two types of migratory movements (migratory movements within each sex have shown to be responsible for the type of information recorded in the length frequency distributions). The package was also used to differentiate mortality rates and thereby allow the assessment of the effects of both migration and refuge on natural mortality and fishing mortality. This information is necessary for developing a management strategy for a partially exploited fishery. The effects of refuges on mortality rates was poorly understood and this work was of considerable importance. The results of this research have been taken back to Mexico and used to guide the management of the fishery.

2.2.8 Assessment of fisheries in NAFO waters

The fishing grounds off the Atlantic coast of Canada are among the most productive in the world. The fishing grounds straddle the Canadian EEZ and the high seas, making effective management very difficult, as shown by the recent fisheries dispute between Canada and the EC. Exploitation of Cod, American Plaice, Redfish and Yellowtail Flounder have reached very high levels in the past, leading to drastic declines in stock levels and harvests. The area is now managed at an international level by the North Atlantic Fisheries Organisation (NAFO), which imposes TACs. However, these quotas have not been very successful in aiding stock recovery, due to under reporting of catches by up to 50% and because quotas only apply to vessels flagged by NAFO member states. Fishing vessels have been known to change allegiance, flying flags of nations not party, and therefore not bound, by management agreements signed by NAFO member states, thereby bypassing all harvest restrictions.

In an EC funded project undertaken by MRAG, CEDA was applied to catch and effort data for the respective species harvested commercially in this area. The consequences of different catch strategies in forthcoming years were then assessed by plotting biomass projections. It was considered that these projections could form the basis of the total allowable catches to be set for each species in the following fishing season. The estimated TACs were presented to the EC in the project report "*The Assessment of NAFO Zone Fishery Resources*" (MRAG, 1992) and it is hoped that recommendations and methods used will form the basis of future policy.

2.2.9 Conch in the Turks and Caicos Islands

As a result of their experiences with the lobster data (see section 2.1.2), the scientists in the TCI Fisheries Department decided to use CEDA for an assessment of their conch (*Strombus gigas*) fishery. Conch accounts for 30 to 60% of the landed value of the fishery on the shallow Caicos Bank. It is caught by fishermen free diving to depths usually less than 10m. CEDA was used to fit a biomass dynamic (surplus yield production) model to conch catch and effort data for 1970 to 1993. The assessment indicated that current catches are below MSY and are unlikely to result in depletion of the stock. The results of the assessment have been used to set the export quota for conch required by the Convention on the International Trade in Endangered Species (CITES).

2.2.10 Routine Stock Assessments in Developing Countries

National Marine Information Research Centre, Namibia.

Fisheries scientists at the National Marine Information Centre in Namibia, routinely use CEDA in stock assessments of a wide range of fisheries including crab, horse mackerel and other small pelagics and demersal stocks.

Reservoir Fisheries in India

LFDA was used to estimate growth parameters of Catla, Mrigal and Roho in the Chulliar reservoir as part of the GTZ funded Indo-German Reservoir Fisheries Development Project, Kerala. The programme is now one of the standard tools used in the stock assessment of these species in this part of India.

2.3 Dissemination

2.3.1 Packaging and distribution

CEDA version 1 and LFDA version 3 were packaged using funds provided from ODA's dissemination fund. A specialist printing company was engaged to produce presentation boxed sets, containing for each program, a ring bound user manual with one 5 ¼” and one 3 ½ “ computer diskette placed in pockets on the inside back page. A distribution note informed the user that the computer package (software programs and manual) had been produced by the Marine Resources Assessment group Limited as part of the Fisheries Management Science Programme under the Strategy for Research on Renewable Natural Resources of the British Overseas Development Administration. 100 boxed sets were ready for distribution by May 1992.

Initially, MRAG drew up a list for distribution partly based on demand resulting from advance knowledge of development of the program’s through the Fisheries Science Management Programme. Additionally, a list of fisheries research institutes in developing countries was drawn up by MRAG and approved by the ODA for distribution. Following this initial phase of distribution, further dissemination continued throughout the adaptive phase in response to demand resulting from promotion by MRAG staff in a number of fisheries institutions in developing countries. When all of the boxed sets had been issued, MRAG continued distribution by issuing software and the user manuals on a computer diskette, along with a text file with instructions for the printing the manuals.

Table 1 shows the numbers of sets of CEDA and LFDA which have been distributed by country and type of institute.

Table 1. Regional and Institutional Breakdown of CEDA and LFDA Dissemination in Developing Countries. Numbers of packages distributed between 1 January 1994 and 31 December 1994. The figure for the period 1 June 1992 to 31 December 1993 are given in brackets.

Institute Type	Central America / Caribbean	South America	Africa	Bangladesh / India	Indian Ocean	S.E. Asia
University	4 (3)	1 (0)	2 (2)	5 (3)	0 (0)	2 (0)
Fisheries Laboratory	7 (5)	4 (3)	9 (7)	2 (1)	3 (2)	7 (4)
Development Agency	1 (0)	1 (1)	11 (9)	4 (4)	0 (0)	7 (5)
Other (NGO etc)	0 (0)	1 (1)	0 (0)	3 (3)	0 (0)	0 (0)
Total	12 (8)	7 (5)	22(18)	14 (11)	3(2)	16 (9)

In addition to the distribution indicated in table 1, CEDA and LFDA have also been distributed to individuals and institutions working on fisheries development in a number of developed countries and regions. (Table 2)

Table 2. Regional Breakdown of CEDA and LFDA Dissemination in Developed Countries and Regions

Country or Region	Number of packaged distributed
United Kingdom	24
Western Europe	8
Northern Europe	12
Central Europe	1
United States of America	6
Canada	3
Australia	2
Total	56

The software and manuals were distributed free of charge to interested users. The recipients in turn have been allowed to distribute it to other interested parties with the proviso that any copies should maintain the acknowledgement to the ODA, MRAG Ltd and the authors. The numbers of copies of the software in circulation and available for use is therefore undoubtedly considerably larger than the numbers in tables 1 and 2.

2.3.2 Courses, Workshops and Presentations

CEDA and LFDA have been used and demonstrated on a number of fish stock assessment courses and workshops and in presentations made in association with other work undertaken by MRAG. This section provides a brief review of some of these. As with the studies described in section 2.2, this proved to be a very useful source of feedback on the performance of the packages, and particularly their applicability for use by fisheries scientists in developing countries.

MSc Fisheries Biology and Management, Bangor University. 1991 -

CEDA and LFDA have been used as part of the Fisheries Data Analysis module of the MSc in Fisheries Biology and Management at Bangor University since 1991.

IUCN Training Workshop, Pakistan Marine Fisheries Department, Karachi. May 1993

A four day workshop funded by the World Conservation Union (IUCN) Pakistan and NORAD was run by MRAG at the Pakistan Marine Fisheries Department Training Centre in Karachi from 17 to 20 May 1993. The main purpose of the workshop was to train a number of fisheries scientists from local institutions in the use of computers in fish stock assessment. Most of the workshop was devoted to the presentation and demonstration of CEDA and LFDA as computer based tools for stock assessment. The participants were exactly the type of fisheries scientists from a developing country at which CEDA and LFDA had been aimed. The workshop therefore proved to be a very useful test of how well the objectives of the strategic phase of the project, in which the software was first developed, had been achieved. The reaction to the packages was generally very favourable. A high level of understanding of the workings of the software and the application of the methods in practical fish stock assessment was reached by most participants in a very short time. The only problems encountered resulted mainly from the computer facilities available at the training centre and the very wide range of previous experience of working with computers within the group of participants . A full report of the workshop, including a list of participants is provided in Appendix IV.

Gulf and Caribbean Fisheries Institute (CGFI) meeting, Corpus Christi. February 1994

The work on lobster undertaken in the Turks and Caicos Islands (see section 2.1.2) was presented as a paper at the 46th Annual Gulf and Caribbean Fisheries Institute meeting, Corpus Christi, Texas. 13th - 17th February 1994. **46** (Publication in preparation - Medley P.A.H., C.H. Ninnes and S. Raven Analysis of the Turks and Caicos Islands Lobster Fishery using the CEDA Package. Proceedings of the 46th Annual Gulf and Caribbean Fisheries Institute).

A poster was prepared by MRAG in support of this paper, which was presented at the meeting by Dr Medley. The poster demonstrated and explained the application and benefits of both CEDA and LFDA. A one page handout was also produced to promote awareness of the computer aids project and the Fisheries Science Management Programme. Copies of the poster, in sections, and the handout are provided in Appendix V.

EC Eastern Mediterranean Stock Assessment Workshop, Genoa. September 1994

In association with the Instituto Scienze Ambientale Marine (ISAM) of the Universita di Genova, MRAG ran an EC funded workshop in September 1994 to demonstrate and familiarise participants with software packages appropriate for use with existing fisheries data in the Eastern Mediterranean (EC project TR/MED93/021). Three packages were used at the workshop: CEDA, the MAFF VPA package (Ministry of Agriculture Fisheries and Foods, Lowestoft, UK) and FiSAT (FAO-ICLARM Stock Assessment Tools). The manuals, disks and tutorials of each package were circulated and all participants given instructions and supervision during the practical demonstrations and training sessions. The conclusion of the workshop was that CEDA was easy to use, well documented and it performed well. The package was considered to be appropriate for analysing existing data in the Eastern Mediterranean. Where catch per unit effort data were considered unreliable, the package had a facility for using relative abundance indices from Italian and Greek cruise survey data. The package was also considered to be suitable for use at forthcoming regional workshops.

Population Dynamics of Culture-Based Reservoir Fisheries - Udon Thani Fisheries Research and Development Centre, Thailand. March 1995.

As part of the FMSP Project Culture Based Fisheries Assessment Methodology (R5958), a course was run in Thailand to introduce the key elements of the population dynamics of culture-based fisheries to local scientists. As a part of the course the 25 Thai participants were trained in the use and application of LFDA for the estimation of growth parameters. Copies of the software were distributed to the participants for use in their own work. The training course schedule and list of participants is provided in Appendix VI.

Joint FFA/SPC Workshop on the Management of South Pacific Inshore Fisheries, Noumea. June/July 1995

Dr Chris Mees of MRAG attended a Workshop on the management of South Pacific inshore fisheries, held in Noumea between 26th June and 7th July 1995. He presented a paper on the optimisation of yield of *P. filamentous* from the Tongan seamount fishery as part of the FMSP project Multispecies Tropical Marine Fisheries (R4584).

During the workshop prototypes of the new versions of LFDA and CEDA were demonstrated. The new versions met with a positive and enthusiastic response from the participants. A list of 29 interested participants was compiled for future dissemination of the packages (see Appendix VII).

2.3.3 Feedback

The work on the case studies and the other studies in which CEDA and LFDA were used provided a considerable amount of feedback material on the use and performance of the software. Comments were received on all aspects of the software, including general requests for changes to the menu and data entry systems, to more specific technical requests for enhanced modelling capabilities, such as seasonal growth models and confidence limits on parameter estimates in LFDA. All of this information was compiled and assessed prior to the start of work on the revision of the software, and as much of it as possible was taken into account in the design and production of the new versions. The main new features incorporated in the new versions are described in section 3 (Results).

2.4 Revision of the Software and Manuals

The main work on the development of the new versions of the software took place over a five month period between January and May 1995. The two packages were developed concurrently, with emphasis being placed on common programming code, to give them a similar look and feel. The programming language used to develop the software was Borland Pascal version 7.0 and the user interface was written using Borland's Turbovision object library.

The development work was planned and carried out in four distinct and logical phases: Research, Design, Implementation, and Testing. These are detailed below.

2.4.1 Research

Before embarking on the development of new features, it was necessary to undertake a considerable amount of testing and simulation to determine their viability. This was particularly true for technical advances such as a seasonal growth model and estimation of confidence limits for parameters in LFDA. Most potential new features which had been requested by users proved feasible, however, some could not be implemented at this stage for technical reasons.

The most technically difficult of the proposed new features was perhaps the facility to determine confidence intervals for parameters estimated in LFDA. LFDA is a very powerful tool for estimating growth parameters from length distributions, but without some indication of the uncertainty associated with these estimates, it had become evident during the case studies that there was a tendency for inexperienced users to accept results which were in fact invalid for one reason or another. In order to remove some of the subjectivity in deciding whether a given set of parameter estimates was acceptable or not, it was decided to attempt to develop a workable method by which confidence intervals could be generated by the program. The technique to be used was a variation on the bootstrap method used in CEDA (see the CEDA manual for an explanation). Unfortunately this led to considerable computational problems. The re-sampling techniques which were developed appeared to work on certain datasets, but the amount of simulation time required to verify their effectiveness over a full range of datasets was prohibitive. With much regret, it was decided to drop this feature from the development programme, due to the considerable delays in the production of the software which would have resulted. It is intended that work on this problem will continue, and that the feature will be incorporated in a future version of the software.

Other new features which have been incorporated in the new versions are described in section 3 (Results).

2.4.2 Design

The design phase consisted of planning the internal data structures and workings of the software and of designing the user interface. The design of the data structure proved to be relatively straightforward because it was possible to work from previous versions of the software. Maximum possible use was made of Object-Oriented design in order to maximise the amount of code that could be reused. As a result the core code for LFDA, for example, was reduced to about one third of the previous version.

2.4.3 Implementation

The implementation phase is the realisation of the results of the design phase. As each component of the software was coded, the routines were verified by running test datasets and comparing the results with output generated in spreadsheets. Again, a certain amount of code from the previous versions was re-used. This had the advantage that it had already been well tested.

2.4.4 Testing

Whilst it is comprehensive, the testing carried out during the implementation phase is not exhaustive. It is vital to have the prototype versions of the software extensively tested by a number of users with a variety of datasets in order to identify and sort out any remaining problems.

The testing phase was undertaken initially by a team of in-house testers. For final testing three external referees where identified with extensive experience in stock assessment and particularly in the design and use of computer software in fisheries science.

All of the bugs and problems identified by the in-house testers and the external referees were corrected before the final versions of the software were verified by the senior programmer and approved for release.

2.4.5 Manuals

The substantial changes made to the software meant that the manuals needed to be extensively revised. This was particularly true of the tutorial sections, due partly to the changes to the menu structure in both packages and also to the introduction of the completely new seasonal growth model in LFDA.

The new data entry and menu systems are described and explained in the reference and operating guides, which have been completely re-written. Technical changes, such as new models and improved fitting procedures are documented and explained in the revised technical appendices.

The review of the manuals was started towards the end of the software implementation phase and completed following the receipt of comments from the three external referees. The revised manuals are included in this report in separate chapters.

3. Results

This section provides a summary of the most significant changes and developments in the new versions of CEDA and LFDA. Full details of the features available in the new versions are provided in the User Manuals, included in this report.

3.1 CEDA version 2

The majority of comments received from users concerning CEDA version 1 related to the program's failure with some datasets to fit a model and produce parameter estimates. Other areas which were clearly in need of improvement were the data entry system (including the facility to edit data files within the package) and the user interface (i.e. the menu system).

•Fitting Algorithm & Diagnostics

A number of cases where CEDA had failed to fit a model were investigated to pinpoint the source of the problem. The problem involved the procedure by which CEDA identified the best parameter estimates for a particular dataset. This procedure is explained fully in the CEDA manual and will not be described here. In brief, however, it was found that the datasets which caused the greatest problems generated very complex score function surfaces, within which CEDA had to locate the global minimum. If the search for the global minimum started in the vicinity of a local minimum then there was a high chance of CEDA finding incorrect parameter estimates, or failing to find estimates at all. Unfortunately, if this happened there was no way for the user to find out what the problem was, nor to do anything about it.

To remedy this it was decided to provide the user with a visual representation of the score function and the search for the global minimum on the screen. The progress of the minimisation, represented by a line, was superimposed on a contour plot of the fitting surface. If the search algorithm fails to identify the global minimum, the user can now use information presented on the screen firstly to see what is happening, and secondly to identify starting parameter estimates which are more likely to result in the global minimum being identified.

There were concerns that it was perhaps unreasonable to expect users in developing countries, where datasets are frequently less than ideal, to have sufficient experience to understand the fitting process and make decisions about starting estimates. The fitting of biomass dynamic models appeared to be particularly difficult for some datasets. It was therefore decided to modify the estimation procedure to increase the probability of CEDA locating the global minimum without the need for the user to specify starting values. This was done using a technique which runs three minimisations, each with different starting parameter values. CEDA then chooses the best parameter estimates from the three answers obtained in this way.

•Data Entry and Editing

Many users of version 1 wanted the data entry procedure to be simplified and to be able to edit data within CEDA. This feature had been deliberately left out of version 1 to prevent users inadvertently changing data for which they had already generated results and plots. In this case the data and results would not match up, causing confusion with potentially serious consequences. In order to include a revised data entry procedure and an editing facility in the new version, a strict security procedure was devised in which all results and stored runs must be erased before editing can proceed. An option has been included which allows the user to duplicate a dataset before editing so that work on different datasets can be saved.

•Timing of Catches

Version 1 allowed the user to specify whether catches were taken at the beginning or in the middle of each time period. This gave rise to some confusion and misinterpretation of results. In version 2 this option has been removed. All models are standardised to middle timing only, which is the most common approach used when fitting the type of models available in CEDA.

•On-Line Help

Despite the comprehensive nature of the manuals many users felt that a help system within the package would be beneficial. A context-sensitive on-line help system has been included in version 2 to provide more focused advice than can be given in the manual. This means that when the user presses the 'Help' button at any time, a window appears on the screen telling them about what they are doing.

•User Interface

Version 1 was programmed using MRAG's own user interface software. This was reasonably advanced when developed in 1990, but by 1994 computer users were becoming used to advanced menu driven program interfaces such as Microsoft Windows. Version 2 has a considerably more sophisticated interface system which provides users with the menus, windows and dialog boxes.

3.2 LFDA version 4

Most of the feedback about LFDA version 3 related to the lack of any models for estimating seasonal growth and requests for a function to provide confidence intervals for parameter estimates. Users felt that these deficiencies restricted the applicability of the software in tropical waters. Other areas that were highlighted for improvement, as with CEDA, were the user interface and the ability to edit data files. The only substantial feature which was asked for but has not been included in version 4 is the estimation of confidence intervals, for reasons explained in section 2.4.1.

•Seasonal Models

Two seasonal growth models were incorporated into LFDA version 4: Hoenig & Choudary (1982) and Pauly *et al* (1992). The procedures for estimating the parameters of these models are broadly similar to those for the Von Bertalanffy non-seasonal model in version 3.

•Data Entry and Editing

The data entry and editing facilities described for CEDA in section 3.1 were also incorporated in the new version of LFDA.

•On-Line Help

The on-line help facility described for CEDA in section 3.1 was also incorporated in the new version of LFDA.

•User Interface

The sophisticated user interface described for CEDA in section 3.1 was also incorporated in the new version of LFDA.

•Larger Grid Searches

The limit on the size of the grid within which LFDA searches for the best parameter estimates has been removed. Previously users were restricted to a 10 by 10 grid. The only restriction now on the size of the grid is the computer's available memory.

•**Diagnostics**

A facility to view the score function fitting surface and the progress of the fitting algorithm similar to that described for CEDA in section 3.1 was also incorporated in LFDA. Using this facility the user is able to easily spot when something has gone wrong or when a particularly difficult fitting surface has been generated.

•**Data Simulator**

A facility to simulate length frequencies for a population given specified growth parameters has been included in version 4.

4. Implications of the results for achieving the objectives

This section examines the implications of the results of this project for achieving its objectives, as they are stated in section 1.

4.1 In general

In general the results show that the project has been very successful in achieving its objectives. New versions of CEDA and LFDA have been produced which include extensive revisions of old features and an number of very powerful new options. The revision has been significantly driven by demand from developing countries, in the form of comments and requests for new features from stock assessment scientists who have been using the software in practical fisheries applications. The new packages have received good reviews from three highly experienced specialist stock assessment scientists, whose comments have been incorporated in the final versions.

4.2 In detail

Objective 1:Evaluation of the stock assessment software packages produced under ODA project R4517 to test:

Their applicability to the assessment of commercial fish stocks in tropical developing countries and;

their applicability for use by fisheries scientists working in tropical developing countries.

The three case studies, designed to address objective 1, achieved this objective in different ways.

Thailand

The Thailand case study aimed to develop the stock assessment capability of scientists working with the Thailand Department of Fisheries and Kasetsart University on a project to develop alternative management strategies for small pelagic fish, principally anchovy. There was some external input from MRAG to introduce the software and provide advice on the assessment method, but it was largely left up to the local scientists to do the work. Thus both of the applications specified in objective 1 were tested. The collaborative component of the work indicated that the Thai scientists understood both CEDA and LFDA and could apply the results to management of the anchovy fishery. In fact they had used the production models in CEDA previously, but had not had access to the sophisticated parameter estimation techniques which CEDA provides. They had also used an early version of Elefan, which is one of the models included in LFDA.

The problems experienced, which are described in detail in section 2.1, were caused primarily by data. Firstly the data required substantial pre-processing, the capability for which in Thailand was apparently poor, and secondly there were problems with data access. These two problems were not un-related; the storage of the most important data by one individual in an inappropriate format was the root cause of both of these constraints to proper stock assessment using CEDA and LFDA. Significant progress was made during the project in overcoming the data organisation problem, but this was ultimately defeated by the problem of data access. The data access problem arose between members of the project team in Thailand, and it was therefore impossible to predict at the start of the project.

Unfortunately this meant that the applicability of CEDA and LFDA to the assessment of a commercial fish stock in Thailand (anchovy), could not be tested within the time frame of the project.

Turks and Caicos Islands

The TCI case study achieved its objectives well. The scientists in the Fisheries Department had no problems using the software, although it must be said that the experience and capability of the scientists involved in the project was extremely high. CEDA proved not to be the most appropriate assessment tool for lobster, because the models did not fit the data well, but the scientists were very quickly able to ascertain from the work with CEDA what was the best way forward. The CEDA work underlined the importance of monitoring lobster post-larvae in order to develop an index of recruitment. Attempts are currently being made to set this up. It was also clear that daily catches would have to be entered onto computer, rather than just monthly totals. According to the TCI scientists it is expected that in the future CEDA will have a role in demonstrating to the TCI Government that the lobster fishery could be managed to provide much greater economic benefit to the islands.

Subsequent work in TCI by the same team of scientists showed that CEDA was extremely useful for assessing the local conch fishery (see section 2.2.9).

Zimbabwe

The Zimbabwe case study tested the applicability of LFDA for estimating the growth parameters of fish in African Lakes, but did not test its applicability for use by fisheries scientists working in tropical developing countries, because the work was done by MRAG. The results of the analysis showed that LFDA was very useful for estimating growth parameters from good datasets taken from this area, although there were clearly problems with poorer datasets, which are perhaps more common in developing countries. However, it is probably true to say that this is a limitation of most stock assessment models. Much of the emphasis during the development of CEDA and LFDA has been placed on making it easy for the user to identify when the fit is bad and when more information is needed. In this way misleading results are discarded rather than being used as the basis for management decisions.

It is hoped that the successful application of LFDA to data from the lakes in Zimbabwe will give confidence for a wider usage for such fisheries throughout the continent.

Objective 2:Preparation of revised versions of the software packages CEDA and LFDA, taking into account the results of the evaluation carried out under objective (1) above.

As stated in the introduction to this section, the project has been very successful in achieving the objective of developing and producing new versions of the software. In particular great emphasis was placed in the incorporation of changes and new features suggested by feedback from applications in the field. The manuals of the new versions, which provide a detailed explanation of the new features, are included in separate chapters of this report.

5. Priority tasks for follow up

Three priority tasks for follow up are considered: dissemination, user support and further revision of the software. These activities have budgetary implications of varying degrees, which are outside the scope of this project.

5.1 Dissemination

Clearly the most important activity to follow up this project is dissemination of the new software and manuals. However, there are a number of important considerations before this can proceed.

Some consideration must be given to the format in which the material should be disseminated. There are a number of formats which can be used. CEDA and LFDA were first distributed in professionally produced complimentary boxed sets of disks and manuals. This is an attractive format, but is expensive to produce. Once the initial production run of boxed sets had been exhausted, the manuals were either distributed as photocopies or on diskette, with instructions for printing. Distribution of the package entirely on diskette is clearly the cheapest method, but it relies on the recipients having the facilities necessary to print off the manuals. It may also be possible to make use of the electronic mail system, with the material being distributed as encoded files.

5.2 User support

The level of ongoing future support which should be given to users also needs to be considered. This can be sub-divided into three parts.

Firstly, users may encounter problems of a technical nature in installing and running the software on their computers. A tear out sheet was included at the back of each manual of the first release of the packages, asking users with problems to provide detailed specifications of their computers and the nature of the problem. These would then be answered with advice for solving the problem. Some of these problems may not have a simple solution. It may be, for instance, that the software cannot be run on the computer being used, either because it is of insufficiently high specification, or because other programs loaded, such as network drivers, mean that there is insufficient free memory. Enquiries regarding such problems can be answered with helpful suggestions on the basis of information provided, bearing in mind that the suggestion may simply be to run the programs on a different computer.

Secondly, despite extensive testing, there will be bugs in the programs which only manifest themselves with some datasets. Such problems will only come to light with widespread use of the software over a long period of time. The precise nature of the remedy required will depend on the problem, but under certain circumstances it may be necessary to issue an update disk, containing a new version of the software. For the most part, and again depending on the problem, it will only be necessary to send such a version of the software to the user who encountered the problem. However in some cases it may be necessary to distribute the new copy to all prior recipients of the packages.

Thirdly, some users may simply have problems analysing their data and need assistance with understanding what is going wrong. The manuals have been written in a comprehensive way in an attempt to anticipate any such problems. In addition the diagnostic capability of both packages has been significantly improved with the inclusion of the facility to view the minimisation routines. However, some users may not have the experience nor the technical skills necessary to self diagnose their problems. Experience with the previous versions indicates that requests for assistance will be received. Clearly it will not be the place of the ODA nor MRAG to analyse people's data for them, however it will be necessary to decide how specific requests for advice in using the software with particular datasets will be dealt with.

5.3 Further revision of the software

Finally there is the question of further revision of the software. One possible development which has already been identified is a facility to generate confidence intervals for parameter estimates in LFDA. Another future development which can be identified at this stage is the production of versions of CEDA and LFDA for Microsoft Windows (Microsoft Corporation 1985-1990). This could lead to significant enhancement of the package's capabilities, particularly with the superior memory availability associated with Windows.

CEDA version 2

The revised CEDA manual

The revised LFDA manual

Appendix I

Alternative Management Strategies for Small pelagic Fish

Appendix II

Test of the CEDA Program on the Catch and Effort Data Series, Turks and Caicos Islands

Appendix III

The Application of LFDA to Zimbabwe Lake Data

The Application of LFDA to Zimbabwe Lake Data

Final Report

Contents

1. Background and data set

In order to test the applicability of the LFDA suite of methods to African localities, two sets of data were obtained from Zimbabwe. Both came from man-made lakes and it was considered that, given the importance of the man-made lakes to the fisheries of Africa, a valid application of LFDA would give confidence for a wider usage for such fisheries throughout the continent.

The length frequency data obtained came from two different man-made lakes:

(i)Fourteen months consecutive data for the kapenta, *Limnothrissa miodon* from lift net catches of the Sanyati Basin, Lake Kariba.

(ii)Variable monthly samples from experimental poisoning of bay communities at seven locations around Lake McIlwaine.

Both lift net and poisoning methods are relatively non-selective and should, therefore, provide suitable samples for length frequency analysis. The kapenta is a small clupeid which is essentially an annual species and supports a major 18,000 mt per annum fishery in Lake Kariba. Their wide significance is that they also support major fisheries in Lake Tanganyika, where they are endemic, and also in the man-made Lake Cabora-Bassa, downstream of Lake Kariba on the Zambesi system.

The rotenoned samples from Lake McIlwaine comprise a wide variety of species, including tilapias, which form the main commercial catch from the lake. The significance of the fishery is its proximity to the major demand centre of Harare. The tilapias as a group, however, feature in most significant lake fisheries in Africa. Both data sets were provided courtesy of Dr Brian Marshall, University of Zimbabwe and neither have previously been analyzed.

A summary of the samples collected from Lake McIlwaine is provided in Table 1.

2. Methodology

LFDA was used to estimate growth parameters and total mortality (**Z**) from the length data described in section 1. Certain samples from Lake McIlwaine were discarded as they did not comprise a sufficient time series to make testing of the data worthwhile. For example, data were only collected at Myriophyllum Creek on two occasions, both during 1974. Additionally, certain time series had sample events where only a few individuals were caught and sampled, for example, *Labeo altivelis* at Research Bay. An attempt to fit the data for this location and species using LFDA was made, but the fit proved to be unsatisfactory. For these reasons, only species that were found on a large number of sample dates and in reasonable numbers, i.e. the more common species, *T. macrochir, T. rendalli* and *H. darlingi* were analyzed in detail.

The length distributions of *Limnothrissa* in the Sanyati Basin indicated some seasonality in growth. An attempt was made to fit the non-seasonal growth models in LFDA, but the results were unsatisfactory. As an alternative approach the data were divided into two 'seasons' and fitted separately. This produced much better results. This emphasised the advantage in having a factor to describe seasonal oscillations in the program which will be incorporated into the revised LFDA.

2.1 Summary of the findings during the application of LFDA

Lake McIlwaine

Tilapia macrochir

Pelican Harbour:SLCA - Boundary values only
Projmat - L∞ appears reasonable, but did not include individuals at over 300mm.
Elefan - L∞ appears better, as above, without the larger individuals.
Z values appear similar between these two methods, but L∞ and K are relatively different.

Research Bay:SLCA - Fits made, but not very accurate. L∞ is very high.
Projmat - Fit better, but not perfect. L∞ similar to Elefan and better when compared with results.
Elefan - Fit reasonable. L∞ as above.
Z values vary widely.

Crocodile Creek:SLCA - Boundary values only
Projmat - Reasonable fit with data, L∞ appears large, but does include the few larger individuals found.
Elefan - Reasonable fit, L∞ covers the majority of individuals found.
Z values are similar between the two methods.

Lewin's Harbour:SLCA - Fit moderate, L∞ reasonable
Projmat - Fit better, L∞ reasonable
Elefan - Good fit, L∞ also most consistent with the data
Z values comparable, but there are variations

Tilapia rendalli

Pelican Harbour:SLCA - Boundary values only
Projmat - Reasonable fit, L∞ appears high but large individuals are present.
Elefan - Fit not as good as Projmat, L∞ appears slightly low.
Z values appear similar between these two methods.

Research Bay:SLCA - Boundary values only
Projmat - Fit reasonable. L∞ quite high when compared with data.
Elefan - Fit better. L∞ more comparable to data.
Z values show some variation in Powell-Wetherall and Age-Slice.

Crocodile Creek:SLCA - Reasonable fit, L∞ appears low,
Projmat - Reasonable fit with data, L∞ appears slightly large, but does include the few larger individuals found.
Elefan - Reasonable fit, L∞ low compared to data. K value comparable to Projmat
Z values vary. No Powell-Wetherall estimates could be made due to the extreme bi-modality of the graphs.

Lewin's Harbour:SLCA - Boundary values only
Projmat - Fit reasonable, L∞ slightly large. Many 'multiple maxima' found
Elefan - Good fit, L∞ also more consistent with the data
Z values comparable for these two methods. Bi-modality again found on attempting the Powell-Wetherall method

Haplochromis darlingi

Pelican Harbour:SLCA - Fit not brilliant. L∞ appears high

Projmat - Reasonable fit, L_∞ better.
Elefan - Fit reasonable, L_∞ comparable to data.
Z values vary between methods.

Research Bay:SLCA - Boundary values only
Projmat - Fit OK. L_∞ high when compared with data.
Elefan - Fit better. L_∞ more comparable to data, if slightly low.
Z values comparable in methods apart from Age-Slice.

Crocodile Creek:SLCA - Fit not brilliant, L_∞ appears consistent.
Projmat - Reasonable fit with data, L_∞ appears large.
Elefan - Good fit, L_∞ consistent.
Z values comparable for Projmat and Elefan.

Lewin's Harbour:SLCA - Boundary values only
Projmat - Fit not very good, L_∞ large.
Elefan - Fit reasonable, L_∞ reasonable
Z values vary.

Sanyati Basin

Season 1:SLCA - Boundary values only
Projmat - Sensible result, good fit and L_∞ appears consistent
Elefan - As for Projmat

Season 2:SLCA - Boundary values only
Projmat - Sensible result, good fit and L_∞ appears consistent
Elefan - As for Projmat

3. Results

The parameters obtained from LFDA for the Lake McIlwaine datasets are shown in Tables 2 to 4. The results of the analysis of *Limnothrissa* length data for the two 'seasons' in the Sanyati Basin are shown in Table 5.

4. Discussion

In general the "Amoeba" method of finding the maximum peak was only useful (on this data) if the range of K and L_∞ values had been narrowed down manually using the score function table. This is stated in the manual, but it's importance when using 'real' data becomes apparent.

SLCA frequently located the highest score function towards the edge of the range selected. When the range was modified to take account of this, another 'boundary value' was given, and the process was repeated until the values of K and L_∞ were unrealistic. Of the 14 data sets 9 gave no result using SLCA, due to this phenomenon. Fits on the Sanyati Basin data, which gave good results using Projmat and Elefan, gave no result with SLCA.

With certain data sets maximum/minimum score values were identified within a specified range of K and L_∞, but when the range was focused in on this location, the optimum score moved to a new pair of parameter values, which were not within the original range. For example, if a peak was originally found at K=0.5, with 0.1 intervals in the range, the peak could be between approximately 0.45 and 0.55. However, on focusing the range, the peak may have been found at K=0.65, which would have corresponded to 0.6 in the original search. Projmat appeared to show this phenomenon on testing certain data. The problem was usually overcome by visually comparing the growth curves of different parameter sets with the original length distributions.

5. Conclusion

Both Projmat and Elefan performed well on good data. SLCA was less successful and was unable to find reasonable parameter estimates for many of the datasets tested. It is clear that even at these latitudes, a program which takes into account seasonal changes in growth rate would be advantageous.

Appendix IV

Report of the IUCN Workshop, Karachi, May 1993

Appendix V

Poster presented at the 46th Annual Meeting of the Gulf and Caribbean Fisheries Institute, February 1994

Appendix VI

Schedule and List of Participants - Training Course at Udon Thani Fisheries Research and Development Centre, Thailand. March 1995

Appendix VII

List of Participants at the FFA/SPC Workshop, Noumea June/July 1995 who requested copies of the new versions of CEDA and LFDA