Analysis of the Turks and Caicos Islands Lobster Fishery Using the CEDA Package

P. A. H. MEDLEY, C. H. NINNES and S. RAVEN
Fisheries Department
Turks and Caicos Islands
British West Indies

ABSTRACT

Catch and Effort Data Analysis (CEDA 1.0) is a PC based system provided by the UK Overseas Development Administration for the analysis of catch, effort and abundance index data, giving estimates of current and unexploited stock size and catchability. This system is used to analyse lobster catch and effort data over the period 1957 - 1992. The data series has a number of problems, including significant gaps in the time series. CEDA appears to be effective in obtaining an estimate of the population size at the beginning of each season. Analysis of changes over years is more difficult and requires care in interpretation. The results of the analysis and performance of the package are discussed. CPUE; computer package; depletion model; estimation; stock model.

INTRODUCTION

The CEDA Package

The Catch and Effort Data Analysis (CEDA, 1992) package was produced to allow fisheries scientists access to some of the latest techniques in the analysis of catch and effort data. The package offers numerical techniques which take advantage of the greater availability of computers. The population dynamics models which the package fits offer two significant advantages. First, they do not assume the population is at equilibrium. Second, they allow different error models which can significantly improve the fitting procedure and the accuracy of the estimates and their confidence intervals.

The Models

All the models in CEDA are based on the concept of depletion. As a result they require two types of data. First, the catches which cause the depletion. The catch data series needs to be complete. Ideally the catch series should go back to the start of the fishery, but if early catches are unavailable the user can estimate how much exploitation took place before the start of the fishery. Second, the models require an index of abundance, which should be proportional to the population size. The abundance index need not be complete over the series, although enough indices still have to be available to obtain meaningful parameter estimates.

Six population models are available in CEDA to be fitted to the data. Five of these models were used in the analysis of the TCI's lobster fishery data. The sixth requires a recruitment index time series, which was not available for this analysis, although further analysis may provide such an index. The first two models work with numbers of fish only, and to use them with catch weight, the average weight of fish is required. They assume either no recruitment or constant recruitment (Allen, 1966). In both cases the user must supply two parameters. First, the proportion of the unexploited population size present at the start of the time series must be given. This allows the user to account for fishing occurring before the start of the data set. It is also necessary to supply an estimate of natural mortality in both cases. The program then estimates the initial unexploited population size and catchability parameter. The assumptions for the no recruitment model would rarely be satisfied. In general, populations are not fixed and are subject to decreases only through natural and fishing mortality. However in some cases it may hypothesized that such a model would provide a good approximation to observations. The constant recruitment model assumes equilibrium before exploitation so that numbers dying due to natural mortality equals the number of immigrants. This means that recruitment can be derived from the initial unexploited population size, which is estimated, and natural mortality which must be provided by the user from an alternative source.

The remaining three models allow the user to fit non- equilibrium production models, namely Schaefer (1954), Fox (1970) and Pella and Thompson (1969). These models relate the production of the fishery to the stock biomass. They use catch weight data, so, if catch is recorded in numbers, average weight data are required. An additional parameter in all cases allows a delay to be built into the model, so that current biomass can depend on the stock size in periods other than the immediate past. The Pella and Thompson model also requires a second parameter to be provided by the user which allows great flexibility in the shape of the surplus yield curve, but is difficult to provide a priori since it cannot be directly related to any biological function.

For all models CEDA allows the user to make projections from a successful fit, where the user supplies future scenarios. This may be useful in exploring results expected from implementing particular management plans.

The CEDA Software Interface and Support

CEDA (version 1.0) provides no data entry itself, but has a flexible method whereby data can be read in as columns from text files or from the database dBase DBF files. For this version it is therefore necessary to be familiar with a text editor such as MSDOS edit or have a package which can export data in DBF format. Once read in, data are stored in the package's own format, which makes it easy to access during the analysis. Data editing is not supported from within the package.

Instructions are given in the form of menus and user defined parameters are requested through dialog boxes when needed. Fits can be logged, so a particular result can be called up at any future time. This is particularly useful since the fitting procedure can take several hours on slower computers. The package is particularly good in the production of diagnostic graphs for the models. This is very easy and can allow rapid assessment of a model and avoid pitfalls in the analysis.

CEDA allows limited printer support. All text, including estimates and data can be printed on any printer. Graphs can only be output on Epson compatible printers or HP Laserjets. Graphs also cannot be directly exported into other packages, such as word-processors, so it is difficult to generate graphs for a report without the support of other software. If results are needed in a report the user is probably better off exporting the results as text to a spreadsheet and regenerating the graphs from there.

The Turks and Caicos Islands Lobster Fishery

The export of lobster from the Turks and Caicos Islands has a long history. Brown (1938) reports an operational canning plant on South Caicos that was established in the early 1930s. Frozen lobster tails were first exported from a plant established in 1947 and which continued in operation (with a number of different owners) until 1969. There were two periods of expansion in the processing sector. In 1966 two plants were built on South Caicos (South Caicos Pride and the plant that was to become the South Caicos Co-operative). In the 1970's further expansion occurred on both South Caicos and Providenciales so that two plants were operational in 1974 on Providenciales (Stevens, 1975) and two additional plants were built in 1971 (Atlantic Gold) and 1979 (Caicos Fisheries) on South Caicos.

Until the late 1950s lobsters were caught after fishermen first 'sighted' them using a glass bottomed bucket and then either impaled them with a grange or caught them in a 'bully' net. Fishermen operated from small dinghies which were either rowed to nearby fishing grounds or were carried on-board larger sloops to more distant grounds. Lobsters were collected by motor vessels and brought back to the processing plant.

In the late 1950s two events occurred which were to shape the future of the industry. In 1956, 20 American divers fished the resource using SCUBA and Hawaiian slings from motorized vessels. In 1957 eight dug-out canoes powered with 15-18 hp outboard engines were introduced to the fishery. These vessels were fished by Jamaican fishermen using hand hauled lobster pots. Although neither venture lasted into the 1960's lobster catching methods had been transformed with the introduction of free-diving and traps.

During the late 1960s and early 1970s, free diving for lobster gradually replaced less efficient harvesting methods, although fishing was still predominately conducted from small non-motorized dinghies. In 1965 the first fiberglass skiff was introduced, powered by an outboard engine and capable of high speeds. These craft, operated by free-diving fishermen, significantly increased the exploited fishing area. The Hawaiian sling used by the American divers was replaced with the "tosse" (a wire noose operated on a short pole) at the insistence of processing plants to improve product quality. However, in the mid 1970s the use of a hook to impale lobsters became more common and is now used exclusively.

The Catch and Effort Data Series

The catch and effort time series extends back to 1957. These data contain a great deal of historical information about the fishery. Catches in weight or numbers of lobster are complete going back to 1957. Effort in the form of boat days or man days is available for the seasons 1966-1969, 1974-1983 and 1986-1993. These are used to generate abundance indices in the form of catch per unit effort (CPUE) for these periods. In some cases total effort is not available, so effort is associated with a proportion of the total catch. CEDA allows for all these shortfalls in the complete data set. Additional data recently uncovered will extend the periods for which effort data is available for analysis. These data will also provide a more accurate estimate of total catch.

In many of the years, catch records are held as daily and monthly catches made by individual fishermen. This allows an in depth analysis of the changes occurring within the year as well as over years. Both data types can be analysed using the recruitment models, although production models will not be suitable for within year analysis.

Year Time Series

The analysis of the catch and effort combined into years would appear to be a good start point for the analyses of these data. If successful, it would be possible to obtain an estimate of optimum effort and sustainable yield for this fishery. A model assuming no recruitment would clearly be unreasonable for the length of time series considered, so the analysis starts with the constant recruitment model.

Constant Recruitment Model

The model requires input of two parameters, natural mortality and previous level of exploitation before the current catch series. Because the level of exploitation before the catch time series was small, the parameter estimates are insensitive to any reasonable choice in the proportion of unexploited stock size present at the start of the series. In contrast, parameter estimates were very sensitive to choice of natural mortality, and this parameter requires careful handling.

In line with many other fish stocks, natural mortality estimates published in the literature vary widely. For instance, Munro (1974) gives values for *Panulirus argus* varying from 0.14 to 0.52 yr^{-1}, depending on the degree of exploitation. Similarly, Evans (1987) quotes estimates varying from 0.19 to 0.4 yr^{-1} depending on the location and sex of the lobster. It was found the model's fit improved with lower natural mortality, and was best for a natural mortality of 0.08 yr^{-1}, considerably lower than any of the published estimates.

As well as pre-defined parameters, the user is required to specify the error model. This defines the distribution of residuals. The choice of error model is fundamental to the fitting process and can radically alter the results. Generally, variance in catch rate or CPUE increases with increasing mean catch rate or CPUE. This is expected even when there are no complicating processes such as differences in skills and gear within the fishing fleet. Hence using least squares methods which assume a constant variance can lead to poor estimates. CEDA offers two other error models. The log-normal is an extremely skewed distribution where most residuals are small, but some can be expected to be found far away from the mean. The alternative gamma is more flexible, but can show similar dispersion to the log-normal (and also has a stronger theoretical justification). Both distributions have similar advantages over least-squares. First, they exclude the possibility of negative catches and second, they assume increasing variance with increasing mean CPUE. The price paid for improved error models is increasing the time and work taken to fit the model and difficulties in interpretation. It should also be noted that where the variance of data is known or can be estimated, CEDA will accept statistical weights for data observations which may get around many of the the problems associated with changes in variance. For this study no statistical weights were available.

To demonstrate how the choice between error models is made, Figures 1 and 2 show diagnostic output from CEDA for the least- squares and error models. While the package cannot help with interpretation, it is very easy to display and examine these graphs. In this case there is evidence that the least-squares error model poorly describes the residuals, whereas the gamma model does better, but patterns are still evident in the residuals. Such patterns probably point to inadequacies in the population model rather than problems in choice of error.

As well as diagnostic graphs, CEDA makes it relatively easy to look at the affect of outliers. The package allows the user to remove particular data points from the fitting process. Figure 3 gives the results of the fit without the four points 1966-1969, and can be compared directly with Figure 2. R2, the goodness of fit statistic, indicates only a slightly better fit without 1966- 1969 CPUE indices.

As the manual makes clear, justification for removal of points must be provided by the user. The first four effort points, 1966-1969, were generated by the Fisheries Officer at that time estimating the numbers of fishermen active during a week rather than counting individual daily activity. This may have led to an estimate of CPUE higher than it should be, justifying the re-fitting of the time series without these data points. However, recently uncovered data collected in the same format used 1974-1992 confirmed these high catch rates, suggesting there is little justification for their removal.

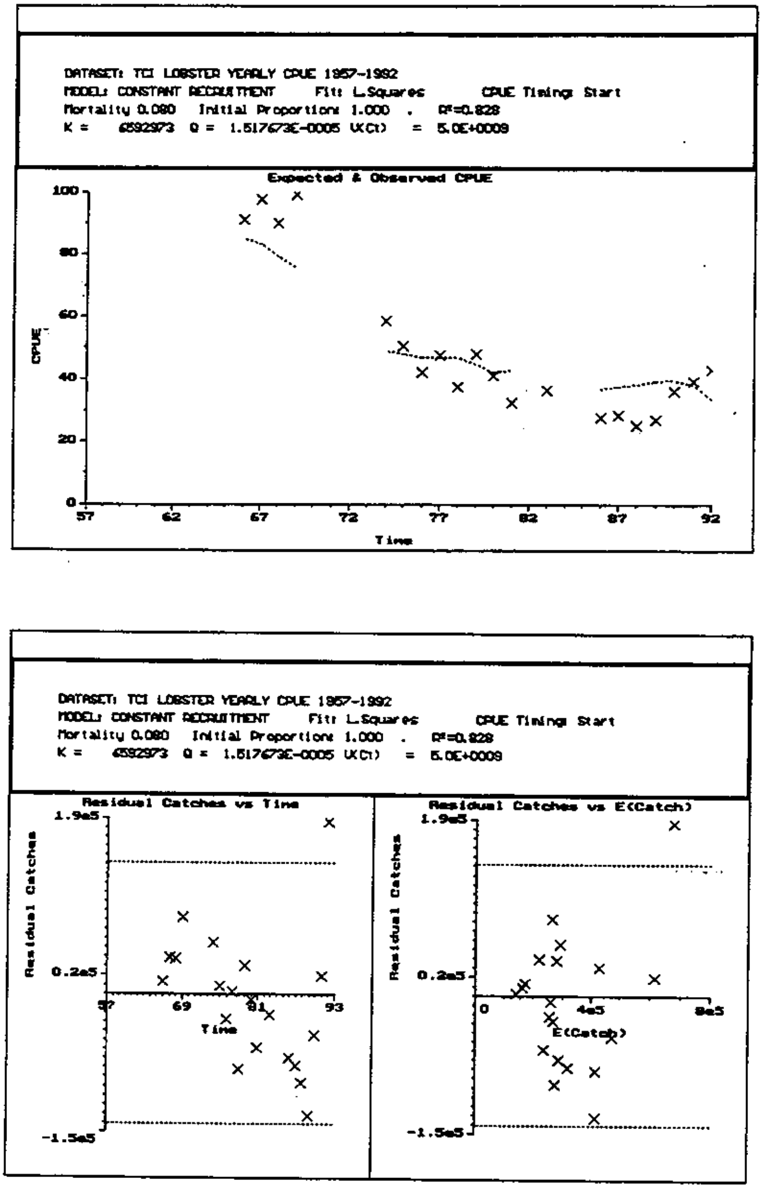

Figure 1. CEDA diagnostic output for the constant recruitment population model with a least-squares fit. The graphs imply a poor fit, with patterns discemable in the residuals v time and an unexplainable outlier for the 1992 point.

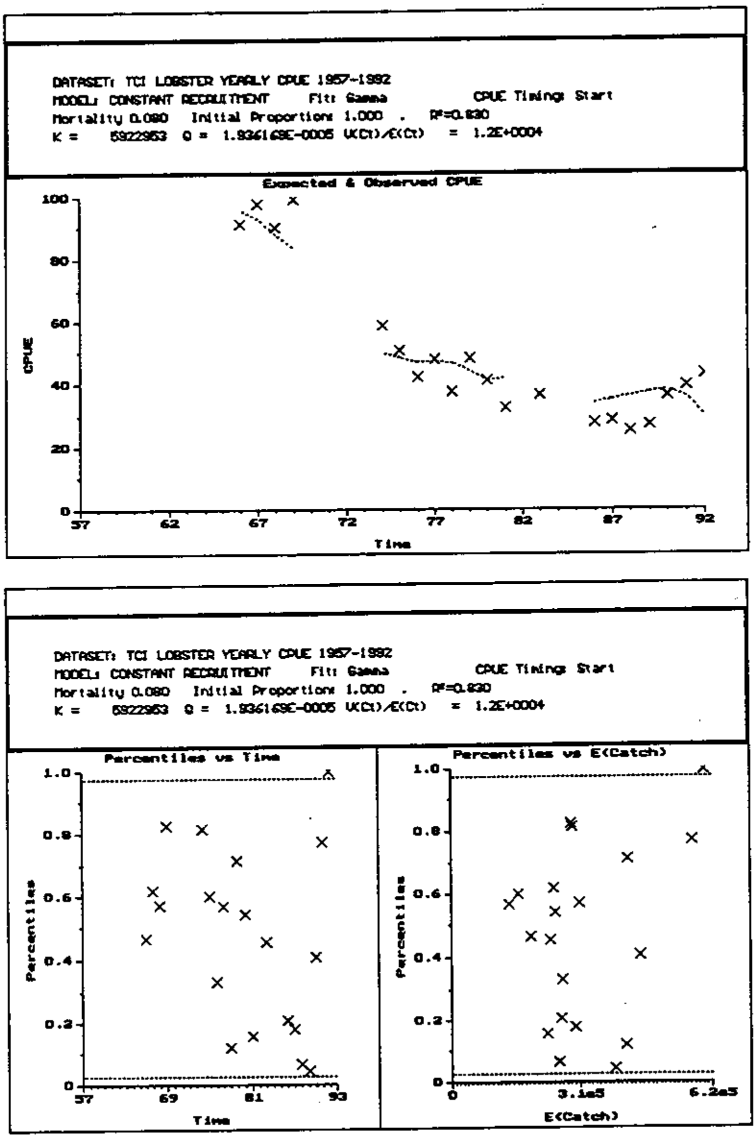

Figure 2. CEDA diagnostic output for the constant recruitment population model with a gamma fit. The graphs suggest an improvement on the least-squares fit. A pattern is still present in the graph of residuals v time, but less distinct, and in particular the model explains the four 1966-1969 points much better. However the model is still unable to explain the outlier for the 1992 point.

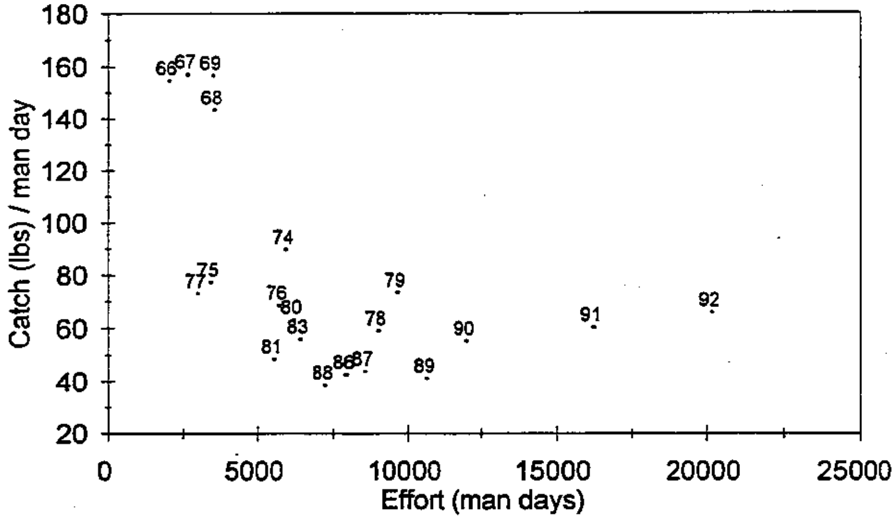

Figure 3. Observed and expected CPUE for the yearly lobster data series using the CEDA constant recruitment model (M = 0.08). The model does not fit the data well, failing to explain the increasing CPUE since 1989.

A further problem evident from Figure 2 is the outlier for the last year, 1992. The model predicts a fall in CPUE from 1990 onwards, but this has not been the case. The poor recent performance of the model strongly indicates it is inadequate as a description of the lobster population. In particular the model predicts a decline in catches and CPUE since 1990 which has not occurred. The poor predictive power of the model severely undermines its value for stock assessment.

Overall, the results seem highly sensitive to choice of error model and natural mortality. It would appear foolish to base any management decision such as quotas or limited entry on these parameters. The poor performance of the population model indicates an alternative approach is required.

Production Models

Three production models are available. They are all based on theoretical descriptions of biomass growth and mortality. In general the models assume that reproduction and growth is constant for each animal, but that mortality increases with population size. This leads to a carrying capacity that is assumed to be the unexploited population size (for a recent review see Hilborn and Walters, 1992). The most recent advantage which has revitalized their use are new fitting methods, used in the CEDA package, which do not require the assumption that the population is at equilibrium.

CEDA requires two input parameters for the Schaefer and Fox models, and three parameters for the Pella and Thompson model. The first two parameters in all cases are the proportion of the unexploited population present at the start of the data series and the delay between the stock size and production. The Pella and Thompson model requires an additional parameter to indicate the shape of the production curve.

Results from fitting these models to the data set are disappointing. In most cases, the fit was so poor that the routines failed to provide sensible results. If this occurs CEDA simply gives an error message reporting failure of the fit. Plotting CPUE against effort (Figure 3) gives some indication as to why these models are unable to explain the observations. Both 1966-1969 and 1991-1992 CPUE were higher than expected. Since there is no reason to doubt these figures, it would appear production models cannot explain these data.

Olsen (1985) fitted the Schaefer model assuming equilibrium to derive an estimate of maximum sustainable yield using catch and effort data for the seasons 1970-71 and 1974-1985. His data was derived from sampling daily records and from the work of earlier researchers. Despite differences in annual catch and effort data between his data and our totals derived from daily records Olsen's analysis does suggest a reasonable catch which management could target. It is not possible to fit Olsen's data with CEDA without using unreasonable parameter values that have no biological meaning. The program therefore indicates the model is inappropriate. Subsequent observations, particularly for the years 1991 and 1992, also suggest that the package was correct in rejecting the model. These outlying years cannot be explained by the Schaefer model. Perhaps the most significant, but implicit, result from the CEDA analysis is that MSY, derived from a production model, is an inappropriate target for this fishery. While Olsen's MSY may provide an *ad hoc* target catch in the short term, a better model is needed to indicate appropriate management procedures to ensure long term sustainability.

Daily Catch and Effort Time Series

At first glance a model assuming no recruitment, immigration or emigration would not be widely applicable to fisheries data. However much depends on the time scale used. Approximately two thirds of the fishing effort at the start of the season centers around a comparatively small area near the main fishing town in South Caicos. Initial catches of lobster in August are generally very high. Usually the catch rate declines rapidly in the first two weeks and have settled down by September to an average observed throughout the rest of the season. As this area is depleted fishermen spread out operating in their favoured locations for the remainder of the season. Lobster size tends to be smaller than for the rest of the year suggesting that many of them are new recruits to the fishery.

It is, therefore, not unreasonable to fit a model which assumes recruitment and movement are not significant during these first four weeks. Daily catch records can be used to estimate the number of lobster in this area at the beginning of the season. CEDA provides such a simple Leslie-DeLury model as well as the slightly more complex constant recruitment model discussed previously. Both these models may be reasonable descriptions of the first two weeks of the season.

No Recruitment and Constant Recruitment Model

For the 'No Recruitment' model, the population starts with a fixed number of fish which is not added to by recruitment or immigration. Fishing removes animals from this population, which subsequently declines, as indicated by the abundance index. By comparing the index with the catch it is possible to estimate the initial population size. This is exactly the same as the constant recruitment model, except no recruitment is entering the population during the process.

For both models the user is required to enter natural mortality. On a daily basis we would expect natural mortality to be close to zero, however the same estimate could not only represent deaths, but also the emigration rate from the population. If this is the case, a model with a considerably higher value than natural mortality may be possible. For the 'Constant Recruitment' model, because the time series starts on the first day of the season, it seems reasonable to assume the population is at its unexploited size.

Both models gave a reasonable fit to each of the four years, 1978-1980 and 1983, for which data were available (Figures 4-7). In all cases a high natural mortality ($M=0.05$ day), constant recruitment and a gamma error model gave the best fit. The diagnostic graphs indicated no major departure from the assumptions with the exception of the unexplained patterns evident in the time series towards the end of August (see Figures 4-6).

For 1979, the CPUE index did not decline at the start of the season. This suggests that the season effectively opened earlier than the official start of the season. High levels of illegal fishing may have been taking place during the closed season (C. Hall, pers. comm.). The initial proportion parameter takes care of this anomaly by allowing the user to set the level of previous exploitation, the best fit in this case obtained when the initial population size was assumed to be 50% its real value. As for natural mortality, CEDA does not attempt to estimate this parameter. The lack of contrast in the data will result in poor parameter estimates, as indicated by the wide confidence intervals (Table 1) and a large dependence on the natural mortality parameter.

Such simple models can be particularly useful in the analysis of catch and effort data. By shortening the time period, the population processes may be simplified. However, the better fit of the constant recruitment model with high natural mortality suggests a population with significant immigration and emigration, and may explain why the models do not fit the time series well towards the end of August. Alternatively, these patterns may be due more to

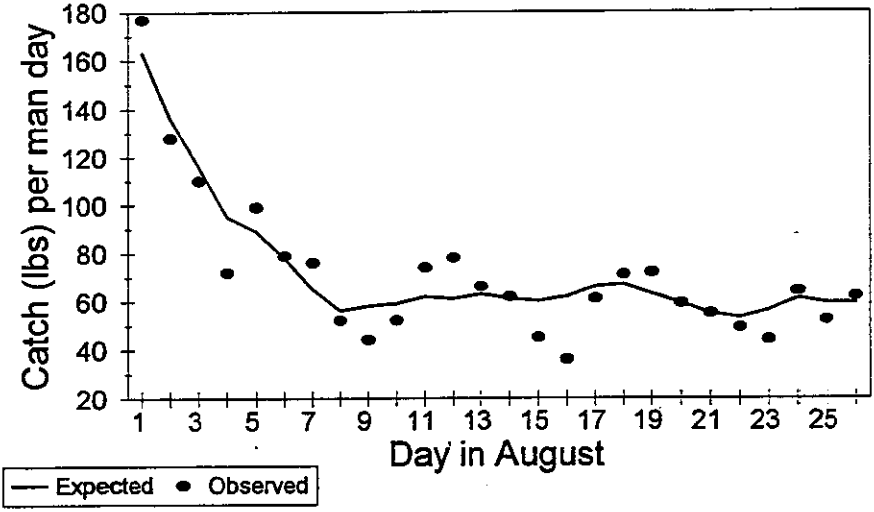

Figure 4. Observed and expected CPUE for August 1978 using the CEDA constant recuitment model (M = 0.05). The model fails to explain later fluctuations in the observed values.

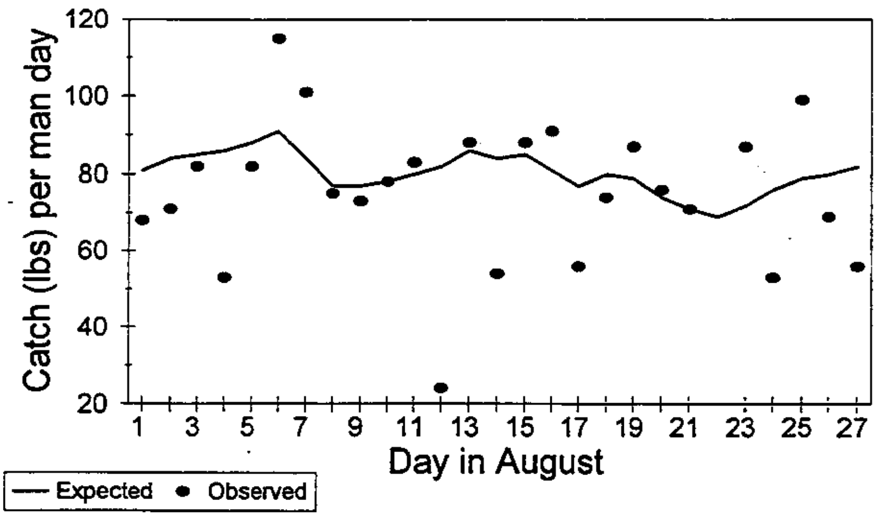

Figure 5. Observed and expected CPUE for August 1979 using the CEDA constant recuitment model (M = 0.05; Initial proportion = 0.5). There was no decline in CPUE, explained by fishing before 1st August.

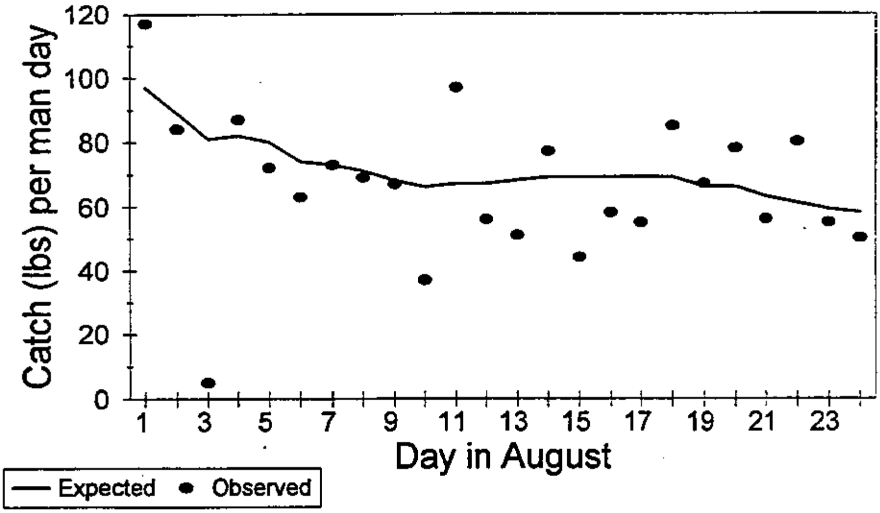

Figure 6. Observed and expected CPUE for August 1980 using the CEDA constant recuitment model (M = 0.05). The model does not account for the increasing variation in the observed values.

Table 1. Estimates of initial population size (K) and catchability (q) with 95% confidence intervals for the start of the lobster fishing season in the years 1978-1980 and 1983. It is too early to tell yet whether the K parameters are correlated with total catch for the year.

Year		Estimate	2.5% CI	97.5% CI	Total Catch (lbs)
1978	K	55568	52125	60275	653052
	q	$2.928\ 10^{-3}$	$2.442\ 10^{-3}$	$3.335\ 10^{-3}$	
1979	K	102288	80640	221150	708319
	q	$1.586\ 10^{-3}$	$5.433\ 10^{-4}$	$2.251\ 10^{-3}$	
1980	K	64782	45931	170982	678991
	q	$1.501\ 10^{-3}$	$4.700\ 10^{-4}$	$2.251\ 10^{-3}$	
1983	K	94268	87793	102615	806973
	q	$2.594\ 10^{-3}$	$2.238\ 10^{-3}$	$3.017\ 10^{-3}$	

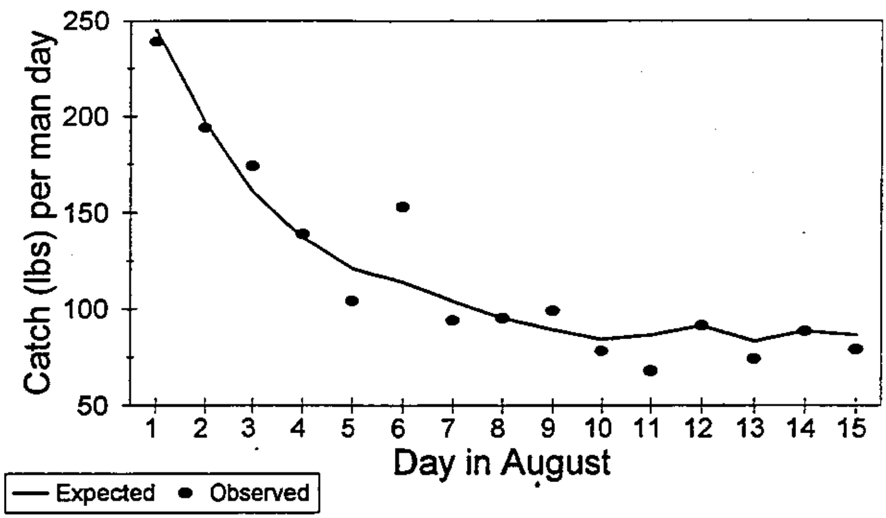

Figure 7. Observed and expected CPUE for August 1983 using the CEDA constant recuitment model (M = 0.05). The model fits the data well, although data is available only to 15th August.

fishermen exploiting new areas different from fishing grounds to those visited at the beginning of August.

The results are of interest in that they give estimates of recruitment and catchability. The catchabilty parameter converts fishing effort into fishing mortality, and is directly convertible from daily to yearly data. These estimates allow comparisons across years which is particularly important where it is felt fishing power has changed. Together with license and anecdotal information on changing practices in the lobster fishery, it should be possible to correct past CPUE data to more accurately reflect abundance.

For the constant recruitment model, the recruitment estimate depends entirely upon the natural mortality and the estimate of the initial population size. Because the user provides the natural mortality estimate, the initial population size alone indicates the effective change in recruitment year by year. It would seem reasonable, in the absence of post-larvae abundance data, to use this initial population size as a recruitment index, particularly since many of the animals landed are around the minimum size limit. Once all the initial population size estimates for each year have been obtained, it will be seen whether the results can be used in this manner.

A final use for the initial population size parameter is to indicate how good the remainder of the season will be from just the first two weeks. It has been noticed that the August catches are correlated with the total catch for the year. This parameter may provide a better predictor for total catch than the August catch rate alone.

DISCUSSION

Overall, CEDA proved to be a useful tool, allowing a rapid analysis of the data. Although the package offers few models, they are widely applicable and should probably form the start point for many stock assessments involving catch and effort data. The structure of the interface encourages correct procedures in modelling data and should detect whether failure has occurred. Rigorous application of these methods should minimize the chance of incorrect assessment, or at least make the user increasingly aware of the chance of failure in model prediction.

None of the models fitted the yearly lobster catch and effort data for the Turks and Caicos Islands, and in particular the production models failed to explain the data time series. This could be due to their inability to explain recruitment to the Caicos Bank which may show no simple relation to stock size. A constant recruitment model appears to provide a better fit, but is unable to explain the last two years catches. This suggests the model has little predictive power and a recruitment index may be necessary in predicting catches and setting future management controls.

The analysis of daily catches at the start of the season showed some promise in estimating recruitment and catchability for different years. The problem will be using these generalized models for a particular case where we are trying to include a number of sources of data. For instance, it is likely we would want to keep catchability constant over a number of years where fishing gear and activities are known not to have changed. CEDA will not allow the user to fit a number of time series, allowing catchability to remain constant, but initial population size to vary. However models with a special form may not be widely applicable and be inappropriate in a general package. Expansion of the available models would require careful thought and perhaps a precursor would be a survey of the types of catch and effort data collected by many fisheries.

Many users would probably welcome estimation of additional parameters, particularly natural mortality. The disadvantage is that natural mortality is usually heavily correlated with other parameters, and it is rarely possible to get good estimates of both fishing and natural mortality from the same data set. Although estimates are likely to be poor or unavailable in many cases, in principle future versions of the package could attempt to estimate it as an option, as long as diagnostic tools exist to help identify any problems.

The manual and the package both encourage and help in the statistical fitting procedures. However, the package still requires a good background knowledge of statistical modelling and fisheries stock assessment. The package could be greatly enhanced by further guidance in fitting procedures perhaps incorporating context-sensitive help and guidance during fitting. Such additional on-line help would be particularly valuable if a wider range of more complex models were incorporated.

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