MODELLING, A METHOD OF SETTING RESEARCH PRIORITIES, NOT JUST THE TOOL FOR THE FINAL ANALYSIS OF WESTERN AUSTRALIAN PILCHARDS

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Introduction

A typical dilemma is that the early stages of a research project on commercially fished species often coincide with the time when managers require information with which to regulate fishing. In many cases, the reason that the research was started was because it was obvious that there was a problem. Under such circumstances it has usually been impossible to provide definitive answers on the size of the stock and, therefore, whether measures are required to prevent recruitment failure or further stock declines. This type of situation should not, however, mean that no advice can be given. Instead, even when there is little information apart from catch and effort data, the use of computer modelling can be of great assistance in utilising what is known about the stock.

Realistic population models can be constructed to fit a time series of catch and effort data with only meagre data to provide either a broad range of estimates for key population parameters or, at least, narrow the range of possible stock sizes that are consistent with the data (Walters 1989). This approach has been used to develop a spatial model of the developing fishery for pilchards (*Sardinops sagax neopilchardus*) off Albany in south western Australia (Fletcher 1992).

The Albany purse seine fishery began in 1980 and quickly developed into a fleet of over 30 boats, with a catch in 1988 of 8500 t (Fletcher 1991a), the majority coming from the one location, King George Sound (Figure 1). In 1989, there was a sharp decline in the catch to just 5300 t, despite an increase in effort compared with previous years. This was followed by only a partial recovery during 1990 which lead to a situation where some action to reduce effort appeared necessary. Consequently, a management advisory committee, comprising fishermen, processors, Fisheries Department managers and research staff, was formed to determine what actions (if any) were required. The major question was whether the recent declines in catch were symptomatic of recruitment overfishing, evidence of local depletion because of the concentrated fishing effort, or merely short term variations in the abundance (or availability) of pilchards in this area. Underlying much of the concern was the knowledge that elsewhere in the world, pelagic fish, and specifically pilchards, have a poor record of management, with their stocks collapsing under intensive exploitation (MacCall 1979; Radovich 1982).

Pilchard research in Western Australia had, in 1990, been in progress for less than two years. Consequently, a precise understanding of the state of the pilchard stock was unavailable, the only data being preliminary information on their biology (Fletcher 1990; 1991b) and monthly catch and effort figures since 1982. From these data, a model was constructed (Fletcher 1992) which took into account the likely spatial distribution of the stock along the coast (especially in relation to the distribution of fishing effort), together with historical changes in the level of fishing effort, catches and catch rates. It was expected that this model would provide some realistic boundaries for the size of the Albany pilchard stock. Moreover, it was hoped that it could be used to generate predictions to both ascertain the impact of possible management options and enable independent testing of the structure of the model which would enhance the understanding of the stock itself.

Methods

Model Operation

The method and operation of the model are fully described elsewhere (Fletcher 1992). Briefly, the model was both age and spatially structured with 8 year classes and fishing only in the centrally located zone of a region that extended some 150 km either side of Albany (Figure 1). Adult fish were moved towards and away from this central region on a seasonal basis such that they tended to congregate near Albany during the winter spawning season, the time when catch rates have historically been the highest (Fletcher 1991a). Recruitment of juveniles to the stock was either fixed at constant levels, irrespective of how low the adult stock level had become, or was subsequently allowed to vary as a function of the total stock size. Catchability (q) was assumed to be a function of the local stock size in the one "fished" zone, increasing at lower abundances due to the schooling behaviour of this species (MacCall 1976). The model used the historical levels of effort for the fleet, with the litres of diesel fuel used per month as the preferred index. The local abundance of adult pilchards for the Albany zone was replenished each month by immigration from surrounding areas and reduced by fishing effort and emigration. The abundance in all zones was reduced each month by natural mortality but the recruitment of juveniles was assumed to occur only once each year.

Model Outcome -Initial Results

The range in the level of recruitment that corresponded to the pattern of catches was from 6 to 9×10^8 individuals per year. Within this range three representative levels (6, 7.5 and 9) were chosen and a non-linear estimation routine provided three different scenarios of recruitment and migration rates which each closely fitted the data.

The trends in simulated catch and CPUE each month closely matched that of the actual catches (e.g. Figure 2). Thus the largest catches, and the best catch rates, occurred during winter with much lower values in summer. Similarly, the total yearly catches for all three scenarios were similar to the actual values (Figure 3) with an initial value in 1982 of 1200 t, rising to a maximum greater than 8000 t in 1988 and subsequently declining after 1989 to approximately 6000 t. It was impractical to try and distinguish which of these scenarios was more likely to be closest to the real situation merely from evaluating the fit between predicted and actual catch and effort data. This situation does not, however, signify that the uses of the model have been exhausted. Instead, the underlying structure of the model allowed a number of predictions which did vary among the scenarios and could be tested with relative ease using independent quantitative and qualitative research.

Predictions:Directing Future Research

Age Structure: As expected, the simulated catch-at-age data (Figure 4) suggested that the higher the total mortality rate (Z), the lower the overall stock size. Whilst the rate of natural mortality (M) was not known precisely, the values found for pilchards in other locations are within the fairly small range of 0.35 to 0.5 (Fletcher 1990). Therefore, the calculation of Z would again help constrain the potential range of stock size values. Moreover, because the model predicts that if the stock size is at the lower end of the range, Z should be increasing annually, as between 1989 and 1990 in Figure 4, such a pattern is amenable for testing even if M is unknown. This pattern occurred even when the assumed value for M used in the model was altered. Collecting the required catch-at-age data has formed part of the routine monitoring of the Albany fishery since 1989 (Fletcher, submitted).

Adult Distribution: Probably the most crucial part of the model, with respect to its being a realistic representation of pilchard behaviour, was the variation in the spatial distribution of the pilchards both in seasonal terms and how this differed among the various recruitment scenarios. Thus, for the lowest stock size, the model predicted that to achieve the high catch rates observed during July, the majority of the stock must be located off the King George Sound region, whilst there could be a much more even distribution at this time if the stock was larger (Figure 5). In December, while all three scenarios indicated that there should be a dearth of pilchards in the KGS region, the greatest decline would be seen if the largest recruitment level was correct (Figure 5). The differences in patterns among these scenarios reflect the variations in the assumed rates of aggregation used by the model with the rate being greatest in the smallest recruitment scenario.

With the actual fishery only operating in the one central zone, no information on the spatial distribution of adult pilchards could be obtained directly. Consequently, the collection of pilchard eggs by plankton tows has been used to provide indirect data on the spatial distribution of adults. Plankton tows are completed throughout this south coast region in both July and December (e.g. Fletcher *et al.* 1992) with the average abundance of eggs in each of the blocks assumed to give a close representation of the abundance of the adults.

Future Catches: The final prediction is the simulation of future catches for the fishery beyond 1990 (Figure 6). If any of the three constant recruitment scenarios was correct, which would suggest that recruits are probably not just derived from adults in the Albany region, the catches would be likely to stabilise at about 6000 t (assuming 1990 effort levels). If, however, there had been a significant reduction in recruitment, further declines in catches would be likely (Figure 6).

Use of the Model for Management

The above predictions, and the accompanying program of research, whilst useful in the longer term evaluation of stock size, did not help to resolve the immediate problem in 1990 of what management measures should be introduced for 1991. The situation was complicated by the presence of three groups of licence holders within the Albany pilchard fishery who had different levels of access related to their histories in the fishery. In 1990 there were 17 "A-Class" licences, which were fully transferable and allowed to fish in King George Sound (KGS) all year; these boats had been operating in the fishery since at least 1985. They generally wanted some or all the other groups removed, especially from KGS. The 8 "B-Class" licences, which, at the time, were not transferable and only allowed in KGS between March and September (when 85% of the catch was taken), had been operating since 1986 and did not wish to be either removed totally or even lose all access to KGS. Finally, there were the 7 "C-class" licences who had never been allowed to fish in KGS and had generally only been operating since 1988 or later. Nonetheless, they wanted to continue having access to the fishery. It should be noted that the boats not fishing in KGS operated from either Two Peoples Bay or Torbay, both of which are still within 40km of Albany (Figure 1).

A plethora of options were put forward by the licence holders from all three groups in an attempt to support their positions. Submissions were also made by the W.A. Fishing Industry Council and finally there was an options paper presented by the Fisheries Department. These alternatives ranged from no modifications, to a variety of combinations for excluding different groups of licence holders (totally, temporally and regionally). Finally there was an option of introducing output controls in the form of catch quotas.

The severity of the management measures ultimately had to be a function of the state of the stock. If there had not been a long term decline in recruitment and the declines in catch were only a local or short term problem, then as stated above, the catch could have stabilized without intervention. Reductions in effort under this 'optimistic' scenario could, therefore, be restricted to reducing the problems of crowding that occurred in KGS when all boats were fishing and helping to relieve what would have been basically a local depletion problem. If, by contrast, there had been a significant and persistent decline in recruitment due to the reduction in the size of the spawning stock, the catch would continue to decline in 1991 and large reductions in effort would be necessary to redress the situation. This being the 'worst case' or 'stock-recruitment scenario'.

To alleviate the stock-recruitment scenario, a reduction of effort of *at least* 50% of the 1990 level would be required to see a stabilisation in the spawning stock at 10000 t and the catch at about 3000 t per year, while the CPUE should rise by 30% to 18kg/l (Figure 7). Smaller reductions in effort, such as would occur if just the C-Class or even both the B- and C-Class licence holders were removed (20 - 35% reduction in effort) would not halt these declines (Figure 8). Moreover, the model indicates that merely divesting effort out of the central area (such as if the B class vessels were merely forced to fish outside of KGS all year round) would be a very poor option. Whilst it should initially raise the catch and catch rates of all groups, the fish would have a reduced spatial refuge from exploitation, and this would have ultimately resulted in the total collapse of the stock and consequently the catch (Figure 8). Thus, a number of minimalist options could be eliminated.

To convince most fishermen of the need to reduce their effort by 50% during 1991, given the uncertainties in the assessment and the inherent natural fluctuations in abundance of small pelagic fish such as pilchards, was an unrealistic task because of the clear hardships that such an action would invoke. According to the model, deferring drastic action until after 1991 appeared to only reduce the long term catch and CPUE by less than 10% (Figure 7). Consequently, it was decided that the management arrangements for 1991 would see the rationalisation of the fleet by removing the "C-Class" fishermen (who were given licences to fish at Bremer Bay, Figure 1), and impose an individually transferable quota (ITQ) system, based on a total allowable catch (TAC) of 5500 t with two zones, KGS and the Albany 'Development' zone (B-class fishermen allowed to catch only 80 t of an average 220 t allocation in KGS). This, therefore, represents a 15-20% reduction in effort which may have only been sufficient to solve the problems of too many boats trying to fish in a small area. Nonetheless, the fishermen were warned that if the catch in 1991 declined again, the TAC would immediately be reduced to 3000 t (or less) in 1992.

Discussion

Constructing the model was useful for a number of reasons. First, it constrained the possible stock size for the Albany region dramatically, demonstrating that it was unlikely the virgin Albany stock could have been larger than 40000 t and that the 1990 stock may have been as low as 8000 t. This information finally put to an end the often speculative figures for the catch of this area, many of which had been well in excess of 10000 t (e.g. Robins 1985). Significantly, even the fishermen no longer talk in terms of there being "millions of tonnes out there", with these descriptions having, now at least, been reduced to "thousands"!

The second benefit of the model was its impact on the research program. Even the actual process of building the model was useful, requiring a number of definite inputs thereby highlighting which areas of biology were understood sufficiently for use without additional study. Furthermore, by altering the values of some parameters, such as size-at-age and natural mortality, it could be ascertained that these had only a minor impact on the essential outputs of the model, so that any imprecision in their estimation could be ignored, at least in the short term.

Of more importance were the predictions that were generated by the different recruitment scenarios. It was through these that it would, hopefully, be possible to tighten up estimates of stock size by eliminating some of the original combinations. This was the stimulus for the expansion of the plankton sampling research programme to investigate the distribution of pilchard eggs along the whole south coast. Following its inception, this plankton research has not only helped to understand more about the spatial distribution of pilchards, but it has provided information on stock separation and even estimates of biomass using the egg production method (Fletcher *et al.* 1992).

Finally, the model gave some help in determining what management strategies could be introduced. By providing some impression of what level of intervention would be required, depending upon the state of the stock, it highlighted the *potential* seriousness of the situation. Furthermore, it reduced the likelihood of erroneous measures being implemented because their impact could at least be subjected to some assessment beforehand.

The structure of the model has not remained static since 1990, but it is being refined as more data are acquired. Thus, variations in year-class strength, determined from the catch-at-age sampling, are now being incorporated. In the future, results from the plankton tows will be used to revise the pattern of seasonal migrations to reflect the actual patterns and, from logbook data, assess the possibility that there are seasonal variations in catchability in addition to the variations in local abundance.

In summary, building the model has been a useful exercise both for monitoring and research of the pilchard fishery despite the relatively small amount of data at the beginning. Moreover, it is certain that the knowledge of the stock has increased far more quickly than if modelling of the fishery had not been commenced early on. This experience, which is likely to be of benefit to other fisheries assessments, shows clearly the advantages of not waiting until research has been completed before attempting to model.

Acknowledgements

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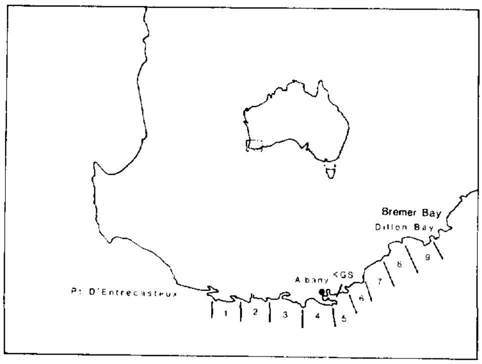

Figure 1. A map of the south coast of Western Australia indicating the presumed extent of the pilchard stock for the Albany region. KGS refers to King George Sound.

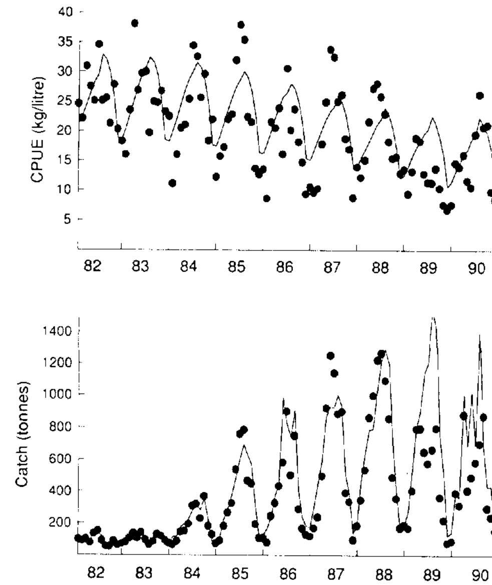

Figure 2. The actual (•) and predicted (–) monthly catch (tonnes) and catch per unit effort (kg/litre of diesel) for one of the recruitment scenarios (7.5 x 10^8 individuals per year) for the period 1982-1990.

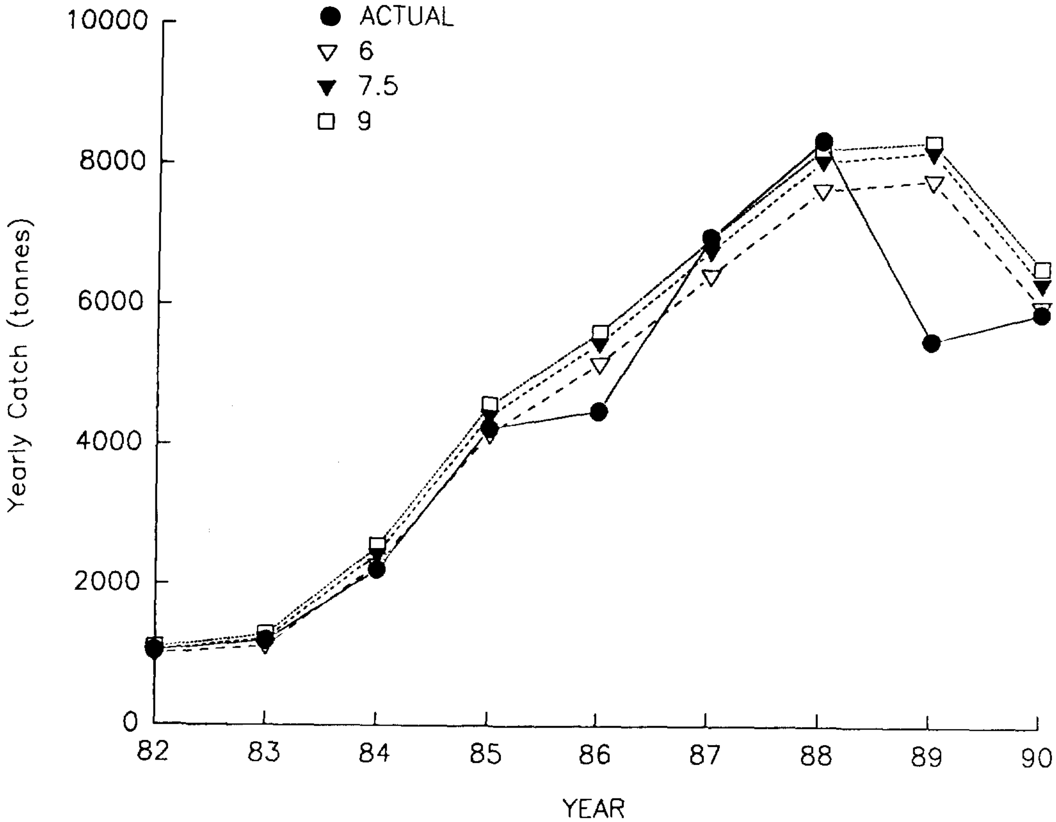

Figure 3. The predicted total yearly catch for the three constant recruitment scenarios (6, 7.5 and 9 x 10^8 individuals per year) and the actual yearly catch by the Albany fleet.

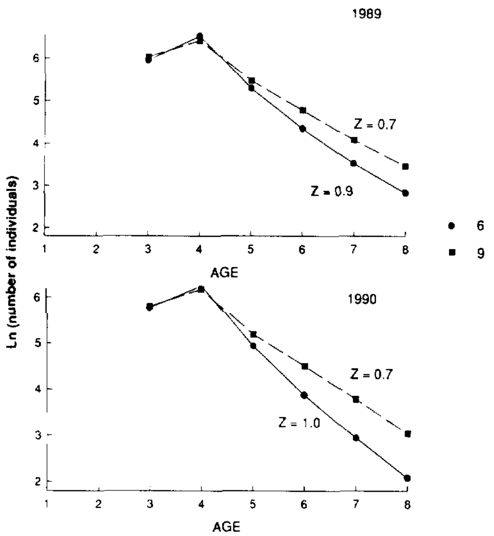

Figure 4. The simulated age-structure of the catch (as numbers of individuals) for two of the recruitment scenarios (6 and 9 x 10^8 individuals per year) in 1989 and 1990, with calculated Z values.

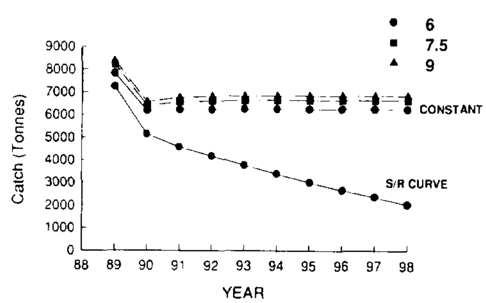

Figure 6. The simulated catches for the three constant recruitment and one stock recruitment scenario over an 8 year period after 1990, assuming that the level and distribution of effort were maintained at the 1990 levels.

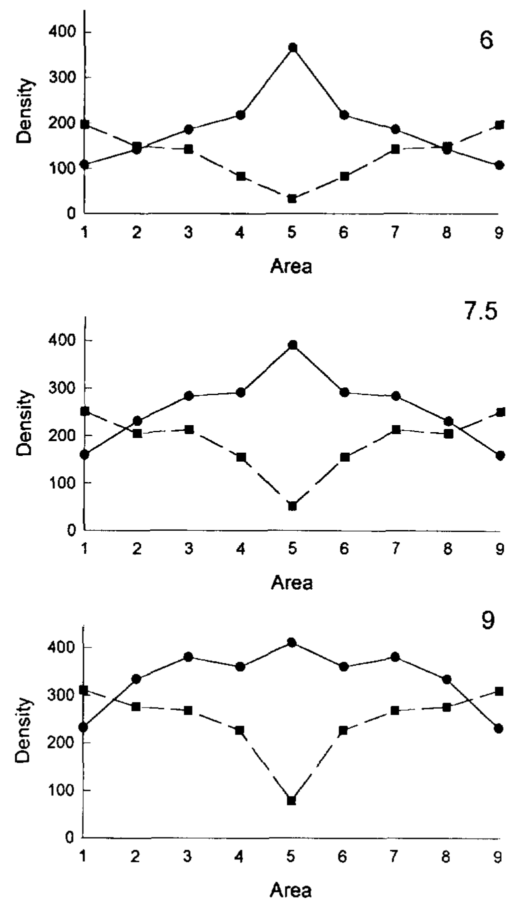

Figure 5. The presumed distribution of pilchard biomass in the nine areas shown in Figure 1, in July (•) and December (■) for the three simulated levels of recruitment (6, 7.5 and 9 x 10^8 individuals per year). The fished area, representing King George Sound, is area 5. Density is expressed as numbers of individuals (x 100000) per area.

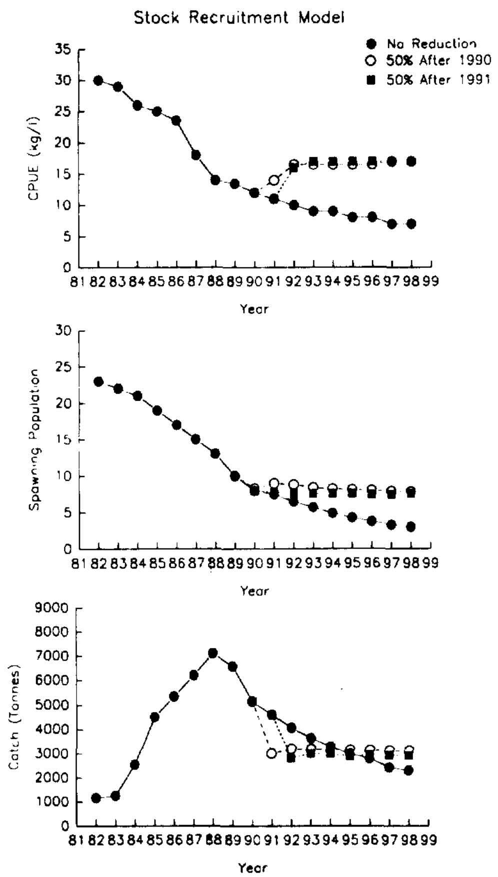

Figure 7. The simulated catches, CPUE and spawning stock levels for the stock-recruitment scenario over an 8 year period after 1990, assuming (1) that the level and distribution of effort were maintained at the 1990 levels, (2) annual effort was reduced by 50% in 1991 and (3) annual effort was reduced by 50% in 1992.

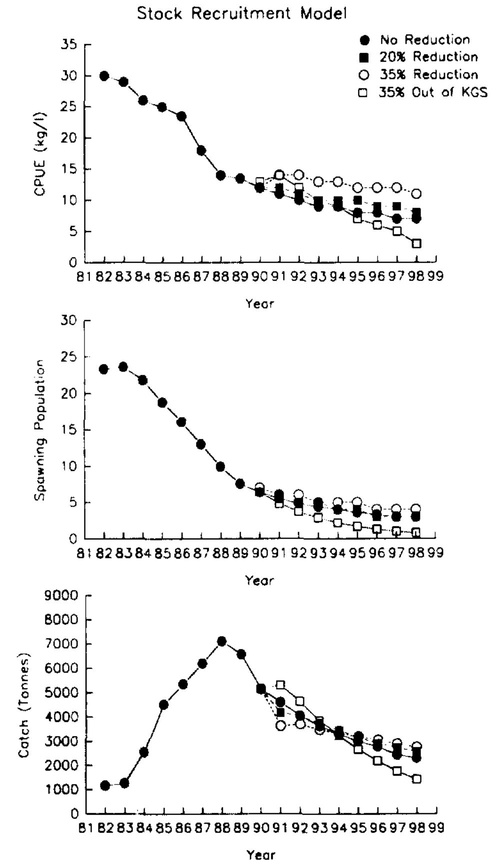

Figure 8. The simulated catches, CPUE and spawning stock levels for the stock-recruitment scenario over an 8 year period after 1990, assuming (1) that the level and distribution of effort were not reduced from the 1990 levels, (2) annual effort was reduced by 20% in 1991, (3) annual effort was reduced by 35% in 1991 and (4) 35% of the annual effort was redistributed out of area 5 after 1990.