REVIEW OF THE WESTERN AUSTRALIAN PILCHARD FISHERY 12 - 16 APRIL 1999

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EXECUTIVE SUMMARY

A workshop was held on Monday 12 April 1999 at which presentations were made by representatives of Fisheries WA, speakers from other state fisheries agencies and the Western Australian (WA) pilchard industry. These presentations covered the current approaches to assessment and management of the WA pilchard fishery, approaches followed in some other comparable Australian fisheries, and the perceptions and concerns of the pilchard fishing industry.

This workshop identified some of the key concerns in the assessment and management of the fishery. After its completion, the reviewer spent three days reading the available literature, holding discussions with various staff from Fisheries WA and reviewing the methods currently being applied. This report presents the conclusions reached by the reviewer at the end of the process, which were also presented to members of the WA pilchard fishing industry in Albany on Friday 16 April.

Overall, the approach taken by Fisheries WA to assess the pilchard stocks on the west and south coasts was found to be appropriate for the scale of the fishery, and consistent with approaches taken for similar fisheries by management agencies elsewhere in the world. Fisheries for small pelagic fish such as anchovy and sardine are characterised by high levels of variability, largely environmentally-induced, and this variability generates uncertainties and problems for management and for the fisheries. The problems being experienced by the WA pilchard fishery are therefore common in similar fisheries elsewhere.

Intensive studies have suggested that the west coast and south coast pilchard stocks are separate stocks and that the south coast stock is made up of three major aggregations (Albany, Bremer Bay and Esperance), linked by common recruitment. The south coast management approach is therefore to attempt to protect both the overall biomass and the biomass of each aggregation.

The conclusions on stock structure are supported by the available evidence. More importantly, the approach of attempting to maintain both overall spawner biomass and the distribution of that biomass at suitably high levels is the more precautionary approach, even if the hypothesis on stock structure turns out to be incorrect.

The use of the Daily Egg Production Method (DEPM) for estimating biomass has been an innovative and useful practice. The approach generates estimates that have a relatively low precision but are unbiased. It is recommended that these surveys are conducted regularly, and as frequently as economically feasible, in each zone.

Similarly, the use of otolith weights as indicators of the age of fish appears to be an accurate and cost-effective method of determining the age of WA pilchard. It is recommended that the existing key, which is approaching ten years old, is checked by a new study.

Management of the fishery could be strengthened by use of formal and transparent methods for determining the management measures each year. Developing clear and precise decision rules for setting the Total Allowable Catch (TAC) each year, selected

and tested through running simulation models of the fishery, is recommended as the best method of incorporating uncertainties and encompassing the range of objectives for the fishery in the management strategy.

An integral part of this process would be to identify suitable biological reference points, e.g. the minimum spawning biomass required to maintain acceptably high recruitment. The status of the resource can then be compared to this reference point in order to determine appropriate management responses. The true seriousness of the biological status of the Albany aggregation can only be determined in relation to such a reference point.

Some other specific concerns are addressed in the report.

<u>Summary of Major Recommendations</u>

Daily Egg Production Method (DEPM) Issues
The application of DEPM for biomass determination in the management of this fishery is commendable and should be continued. Consideration should be given to the following.

- Ensuring that surveys are undertaken in each fishery zone as frequently as possible, within the prevailing economic and logistic constraints, and according to a regular schedule.
- Allowing more time for each survey so as to ensure the area can be sampled completely and parameters estimated with sufficient precision to generate a useable estimate.
- It is important to include all of the spawning area in the survey and hence to obtain a good estimate of spawning area, as this directly affects the final biomass estimate.
- Appropriate stratification of the survey area is important so that greatest effort is put into the areas where the highest spawner biomasses occur.
- Input from an experienced statistician into the survey design and analysis of data could lead to further improvements in the approach.
- The biomass estimates of different surveys should be directly comparable, especially within each fishery zone. This means that the timing, design and implementation of surveys should, as far as possible, remain constant.

Otolith : Age Issues
It is recommended that the validity of the Fletcher (1995) key for the current pilchard populations is checked. Provisional checks could be conducted by modal progression analysis on otolith weight frequencies, but it would also be worthwhile to undertake aging by counting otolith rings, at least on a large enough sample to test statistically for difference from the Fletcher data.

Using Stock Assessment Results for TAC Recommendations
It is recommended that explicit and complete decision rules are developed, taking into account the best available knowledge of the resource and fishery, for setting the annual TAC or other appropriate management measure based on the most recent assessment of the status of the resource. This could be done, for example, by basing TACs on a biological reference point or points, such as using an $F_{0.1}$ fishing mortality rate.

Another approach, allowing for more explicit incorporation of socio-economic objectives and better consideration of uncertainties, is to develop a set of decision rules based on simulations using a model of the resource and fishery dynamics which includes uncertainties. The development of the decision rules can be undertaken with input from the fishing industry so as to reflect, as far as possible, their needs within the biological constraints imposed by the resource.

It is recommended, for optimal and sustainable utilisation of the resource, that appropriate biological reference points are estimated and applied in the management of the WA pilchard fisheries.

Stock Boundaries
The current approach of managing the resource with the objectives of maintaining overall and local abundances of the south coast pilchard at biologically desirable levels is the correct precautionary approach and it is recommended that this is maintained.

Juvenile Study
The proposed south coast juvenile study to attempt to locate the important nursery area or areas and to study the movements of juveniles in order to understand the full life cycle of the south coast stock and the recruitment mechanisms is supported. The use of commercial fishing vessels or other already available vessels for hydro-acoustic investigations of distribution could be considered.

Viral Mortalities
The attempts which have been made to obtain direct estimates of the numbers of pilchards dying are clearly useful, but are likely to be very imprecise and prone to errors. It is therefore also advisable to undertake direct biomass estimates for each affected zone as soon as possible after an event, so that the management strategy can be adjusted to the number or biomass of survivors.

There is a high level of uncertainty about the likely frequency and intensity of future outbreaks. The use of simulation approaches to test suitable management strategies under different scenarios of frequency and intensity of events, would be very useful.

The Seriousness of the Albany Situation
There are strong indications of substantial declines in the abundance of pilchard at Albany. In order to estimate how serious this decline is, the current status needs to be compared to appropriate biological reference points, such as the average biomass under unexploited conditions. On this basis, some prognosis for the future can be undertaken, incorporating uncertainties.

It is recommended that these estimations and calculations are done as soon as possible. An objective evaluation of the current economic status of the fishery would also be useful in a biological reference point, so that the biological prognoses can be expressed in social and economic terms as well. These would then form the basis for an objective decision on the future of the fishery.

Fish Rolling

Fish rolling is the problem of releasing of fish that are caught in a fishing vessel's nets, but which cannot be taken aboard.

It is recommended that the extent of rolling and its impact on the stock should be investigated These estimates could then be incorporated into the assessments, leading to improved accuracy in assessments, and facilitating the development of more appropriate management strategies.

In the longer-term it is important that technological means are found to allow unwanted fish to escape unharmed from fishing nets. The benefits of this would accrue mainly to the fishing industry, through higher biomasses and TACs in the future, and it is therefore in the interest of its members to cooperate with each other and with Fisheries WA to explore ways to achieve this objective.

1. INTRODUCTION

A workshop was held on Monday 12 April 1999, at which presentations were made by representatives of Fisheries WA, speakers from other state fisheries agencies and the Western Australian (WA) pilchard industry. A list of the participants in the workshop is included as Appendix A of this document.

The presentations covered the current approaches to assessment and management of the WA pilchard fishery - approaches followed in some other comparable Australian fisheries - and the perceptions and concerns of the pilchard fishing industry. This workshop identified some of the key concerns in the assessment and management of the fishery.

After the workshop, the reviewer spent three days reading the available literature, holding discussions with different staff from Fisheries WA and reviewing the methods currently being applied. This report presents the conclusions reached by the reviewer at the end of the process, which were also presented to members of the WA pilchard fishing industry in Albany on Friday 16 April.

2. FISH DISTRIBUTION AND THE LEEUWIN CURRENT

Small pelagic fish such as pilchard and anchovy typically undergo substantial variations in abundance and in distribution, and much of this variability is driven by changes in the environment (Caputi *et al.* 1996; Cochrane and Hutchings, 1995; Lenanton *et al.*, 1991).

Direct evidence of such an effect on WA pilchard has been presented by Caputi *et al.* (1996), who found a negative relationship between the strength of the Leeuwin Current, as indicated by the Fremantle sea level, and recruitment of two year old pilchard to the WA south coast fishery. They suggested that this relationship could be explained in terms of the eastward transport of eggs, away from the fishing grounds, by the current.

The Leeuwin Current is clearly a dominant oceanographic feature in the region and Lenanton *et al.* (1991) referred to its role in limiting production of pilchards in WA by restricting their habitat to inshore areas and bays. It is therefore likely that variations in the distance of the current from the coastline will affect the distribution of pilchard in the region. If the variations in distance of the current offshore follow any long-term cycles, this could also influence abundance through longer-term changes in the area of suitable habitat for pilchard.

Clearly, therefore, good and verified knowledge on the influence of the Leeuwin Current on distribution and abundance of pilchard could assist in the management of the resource, and it is for this reason that environmental research is carried out as an integral part of much fisheries research.

One such benefit could be in improved design of surveys, if the areas of distribution could be predicted beforehand from environmental indices. However, fisheries-environment interactions are normally complex and dynamic, and caution is required in making use of postulated or even identified fish-environment relationships and effects for management purposes.

In principle, only relationships or impacts that have been thoroughly tested and validated through normal scientific methods should be used to determine management actions or, for example, to determine survey areas. As the relationship between the Leeuwin Current and the distribution of pilchard on the west coast is not well understood at present, it would have been inadvisable to have attempted to design the 1998 Daily Egg Production Method (DEPM) survey based on the position and strength of the current at that time.

3. DAILY EGG PRODUCTION METHOD (DEPM) ISSUES

3.1 Method

Fisheries WA are to be congratulated on their progress in adapting and utilising the DEPM to estimate biomasses in the WA pilchard stocks and aggregations. There can be no doubt that the biomass estimates generated by application of the method have provided extremely important information for management of the resource.

I have looked at a number of papers and reports describing different DEPM surveys of WA pilchard and their results, and cannot find fault with the broad survey design and estimation methods as applied in recent years (for example that used on the south coast in 1997 [Gaughan, 1997]). The method is applied in a manner which is consistent with that tried and tested in California and South Africa.

The method is not without its problems, and these have been encountered in the WA surveys as well. Foremost amongst the problems is that the combination of all the uncertainties inherent in the different stages of the method means that the results tend to be imprecise, with wide to very wide confidence intervals.

In South Africa, where four week surveys (combined hydro-acoustic and DEPM) are undertaken each year and between 200 and 300 egg stations are sampled for eggs on each surveys, CVs (standard error as a fraction of the mean) typically range from 35% upwards (Armstrong *et al.*, 1988; Butterworth *et al.*, 1993). The greatest contributor to the variance is usually the estimate of the daily egg production P_0.

High variances and other problems have been encountered in the WA DEPM surveys and estimates have had wide confidence intervals (Gaughan, 1997 and 1998). The variance of the DEPM estimates could be decreased to some extent by increasing the number of plankton samples taken, but this obviously would require more time and involve greater expense.

Related to this problem, in the 1998 West Coast survey, eggs were taken on the outermost station of two transects, suggesting that the area in which spawning was taking place had not been fully sampled. If this was the case, it would mean that the spawning area, used directly for determination of spawning biomass, would have been under-estimated. This problem probably arose as a result of the need to try to complete the full survey in a limited amount of time.

Overall, optimising the collection and analysis of DEPM data could be facilitated by a combination of the following.

- Allowing more time for each survey so as to ensure the area can be sampled completely and parameters estimated with sufficient precision to generate a useable estimate.
- It is important to include all of the spawning area in the survey and hence obtain a good estimate of spawning area, as this directly affects the final biomass estimate.

- Appropriate stratification of the survey area is important so that greatest effort is put into the areas where the highest spawner biomasses occur. This will become easier and more effective with time, as patterns in distribution are learnt from on-going surveys.
- Fisheries WA has the services of a full-time statistician, Dr H. Cheng, who has already played a valuable role in assisting in analysis and interpretation of DEPM data and results. His advice in survey design and analysis of data could lead to further improvements in the approach.

3.2 Use of the Results for Management Advice

The DEPM results are the most important source of information for estimating absolute biomass of the WA pilchard (Hall and Gaughan, 1999). A start has been made in developing a time series of estimates and these are extremely important in monitoring stock biomass in each of the important zones.

Ideally, a DEPM estimate should be made in each zone each year and used in a stock assessment model (e.g. Hall and Gaughan, 1999) to obtain an integrated 'best estimate' of the biomass and age structure of the exploitable biomass each year. Given the financial and personnel constraints, annual surveys of each zone are probably impossible. However, it is important that surveys are undertaken in each zone as frequently as possible and according to a regular schedule.

It should be noted that the accuracy of the estimates from the stock assessment model will decay each year subsequent to the most recent DEPM estimate, meaning uncertainty about the true biomass will increase. Simulations, using the Hall and Gaughan model, should be able to assess the value, in terms of increased TAC for a given level of risk to the stock, for increasing frequency of surveys (see e.g. Butterworth *et al.* 1993 and Figure 1).

The biomass estimates of different surveys should be directly comparable, especially within each zone. This means that the timing, design and implementation of surveys should, as far as possible, remain constant. Where changes are made, for example as improvements, attempts should be made to determine the effect of the change on the accuracy (bias) and precision of the estimate.

At present, the way in which the biomass estimates are used to provide management advice is unclear (see Section 5 below) and, particularly when faced with high Coefficients of Variation (CVs) on the estimates, difficulties have been encountered in deciding on how to use them. This was particularly apparent after the 1997 Albany survey when two plankton samples had a major impact on the biomass estimate (Gaughan, 1997).

The dilemma faced by all parties in interpreting such results and deciding on appropriate management action is both common and understandable. The reason for the problem, again common in fisheries management in many parts of the world, is that there was and is no formal way in which to consider such uncertainties during the decision-making process.

It is suggested that Fisheries WA need to consider formal means of incorporating the uncertainty surrounding estimates used for decision making into the decision-making process. This can be done through the development of decision rules or management procedures, which are discussed under Section 5 below.

3.3 Hydro-acoustic Surveys

Hydro-acoustic surveys, accompanied by sampling (e.g. mid-water trawling) for species identification, are used in some areas to estimate the biomass of pelagic stocks. Given a suitable vessel (which should have low noise and vibration) and suitable echo-sounding and echo-integration equipment, this provides a useful tool for biomass estimation.

In general terms, with hydro-acoustics it should be possible to attain a more precise estimate of abundance than by DEPM, but an estimate that is likely to be biased, typically negatively biased (i.e. an under-estimate). This contrasts with DEPM estimates which should be unbiased, but with a low level of precision.

In South Africa the two methods are used simultaneously, and both are used in a model to estimate the value of key parameters and variables (see e.g. Butterworth *et al.* 1993).

There is little doubt that hydro-acoustic techniques could play a useful role in improving knowledge of the WA pilchard stocks, for example in determining the full range of distribution of adults (e.g. possibly assisting in determining where the missing adult age classes on the west coast are at present) and in identifying the distribution and movements of juveniles (see Section 6.1). If the necessary funds and other resources are available to undertake such studies, even as ‘one-off’ studies or semi-quantitative estimates, they should prove worthwhile.

4. OTOLITH : AGE ISSUES

Determining the age of fish by counting growth rings on hard parts, such as otoliths, is a widely applied method. It is, however, time consuming and not error-free, with particular potential for error in identifying annuli.

Careful and rigorous investigation of the relationship between otolith weight and age for the WA pilchard (Fletcher, 1991; 1995) demonstrated that pilchard can be reliably aged by weighing their otoliths. Fletcher (1995) therefore developed a key relating otolith weight to age class. This key was based on samples obtained from 1989 to 1991, and has been in use to age WA pilchard since then.

Concern was expressed by a member of the pilchard industry that there appeared to be a conflict in the trends exhibited by mean length and weight of pilchards in the Bremer Bay catches and the trend exhibited by mean otolith weight of fish taken in the catches from the same locality. The former variables showed a decrease from 1992 to 1996, before beginning to increase again, while the latter has increased consistently each year since 1993 (Gaughan, 1998, Fig. 10).

This conflict could indicate that the relationship between otolith mass and age has been different or inconsistent in recent years.

It has not been possible to examine the raw data in the time available. However, some possible explanations warrant consideration. The greatest change, as a percentage, occurs in mean weight, where the decrease from 1992 to 1996 was approximately 6 g, or more than 10 per cent of the 1992 mean mass of 42 g. The mean length decreased over the same period by approximately 7 mm or 4 per cent of the 1992 mean length of 162 mm, while mean otolith mass increased from 1993 to 1996 by 0.15 mg or approximately 10 per cent of the 1993 mass of 1.6 mg.

The first thing that should be checked is whether the differences between months are significantly different, or whether they could be simply reflecting sampling variance. If this is not the case, the data could indicate that the somatic growth rate decreased between 1992 and 1996, meaning that although the mean age of the fish in the catches, as indicated by otolith mass, was increasing (from just below 5 years in 1992 to the border of 5/6 in 1998), the mean length and mass of the fish was actually decreasing. In order to check this, it would be necessary to re-examine the growth rate of fish during that period.

The age composition of each aggregation has been considered in setting Total Allowable Catches, in as much as an increasing proportion of older animals in the annual catch at age curve was taken to indicate poor recruitment in the younger age classes leading to a decline in abundance. Where such a trend of poor recruitment and hence increasing mean age of the catch persisted for several years, it has been used as indicating the need to reduce the TAC as a precautionary measure (Gaughan *pers. comm.* and see, for example, recommendation for Bremer Bay in Gaughan, 1997).

Within the new South Coast model, age compositions do not have a substantial effect on determining estimated biomass, but will influence estimates of recruitment strength (Hall and Gaughan, 1999).

Overall, it is possible that changes in morphometric parameters, including otolith weight and their relationship to age have changed and, even discounting the concern over apparent data contradictions from Bremer Bay, it is recommended that the validity of the Fletcher (1995) key for the current pilchard populations is checked.

Provisional checks could be conducted by modal progression analysis on otolith weight frequencies, but it would probably also be worthwhile to undertake ageing by counting otolith rings, at least on a large enough sample to test statistically for difference from the Fletcher data.

5. FROM STOCK ASSESSMENT TO TAC RECOMMENDATIONS

Some concern was expressed by members of the fishing industry over the methods used to determine Total Allowable Catches (TACs) each year. One member suggested that every time a figure was presented, the selected option was "the lowest of the low", while another member referred to large fluctuations in TAC from year-to-year and called for fitting a trend line, or smoothing out the natural variability.

The decision rules used to determine the TAC based on the estimated status of the stock are not fully defined. Hall and Gaughan (1999) described them as "..the TAC within each area is such that the combined TAC over the three regions is less than 15 - 20 per cent of the total spawning biomass estimated for the stock, and that the TAC for each region must not exceed 15 - 20 per cent of the local spawning stock (except under exceptional circumstances)". The authors point out that:

- "exceptional circumstances" are not defined; and
- the decision rules that apply under exceptional circumstances are not specified.

In addition, as described in Section 4 of this document, the absence of recent biomass estimates in some cases has meant that less precise indices of abundance, such as the age composition of the aggregation, have been used to adjust TACs, again not in a clearly specified manner.

Other problems with these existing decision rules are:

- it is not clear when 15 per cent, 20 per cent or some intermediate value is selected as the allowed proportion;
- the way in which the biomass is estimated is not specified (e.g. when is it the 'lowest of the low'?); and
- they do not formally consider the uncertainty in estimates, in particular the precision of the egg production or model estimates.

5.1 Developing a Formal Management Strategy

If confidence in the management system is to be retained, it is important that decisions on the TAC are made in a manner which is transparent, replicable and justifiable in terms of the conservation and socio-economic objectives for the fishery. This requires explicit and complete decision rules which have been developed taking into account the best available knowledge of the resource and fishery.

One way in which to do this is to base TACs on a biological reference point and, for example, to set the TAC to equate to an $F_{0.1}$ fishing mortality rate on the best estimate of exploitable biomass (see e.g. Hilborn and Walters, 1992). Another approach, which allows for more explicit incorporation of socio-economic objectives and better consideration of uncertainties, is to develop a set of decision rules, based on simulations using a model of the resource and fishery dynamics which includes uncertainties.

The development of the decision rules can be undertaken with input from the fishing industry so as to reflect, as far as possible, their needs within the biological constraints imposed by the resource.

This approach has been adopted in management of the South African anchovy and pilchard fisheries where formal management procedures have been developed for monitoring the status of the stock and setting TACs each year (see e.g. Cochrane *et al.* 1998 and De Oliveira *et al.* 1998). The management procedure also specifies just what information is used in each TAC decision and how it is used.

As an example, a decision-rule could be to take a specific proportion of the mean Daily Egg Production Method (DEPM) biomass estimate, regardless of the uncertainty around that. It is known that in some years the DEPM over-estimates true biomass, sometimes considerably, while in other years it similarly under-estimates true biomass. By simulation, including all known sources of uncertainty, the proportion of the best-estimate DEPM biomass which could be taken each year, while maintaining the stock above a selected threshold (or maintaining a pre-defined 'risk' of the stock falling below a selected level), can be identified. Further, the impact on specified objectives (such as risk to the resource and attainable catches) of industry preferences (such as a possible minimum TAC or desires to introduce greater stability into the TACs) can be explored by simulation.

While the South African approach has not been problem-free (see Cochrane *et al.*, 1998*)*, it has resulted in improved communication between the management agency and the fishers; clarification of the objectives for the fisheries; and a long-term perspective of management of the fishery, rather than just an annual fight to arrive at a compromise TAC.

5.2 Defining Biological Reference Points

An integral part of developing decision rules for the WA pilchard fisheries will be determining specific and quantitative biological objectives. These are normally done through consideration of one or more biological reference points (Caddy and Mahon, 1997).

Biological reference points are commonly based on some proportion of the maximum, or average unexploited, biomass or abundance of the stock. For example, a common limit reference point would be to avoid, or minimise the risk of, falling below 20 per cent of the average unexploited biomass (e.g. Butterworth *et al.*, 1993). It is essential for optimal and sustainable utilisation of the resource that such reference points are estimated and applied in management of the WA pilchard fisheries.

Mace and Sissenwine (1993) suggested that for many stocks a suitable limit reference point would be to maintain at least 30 per cent of Spawner biomass Per Recruit (SPR). The applicability of this value for pilchard should be checked (the Mace and Sissenwine paper also examines factors affecting the replacement SPR for different species and characteristics), and an appropriate minimum spawner biomass for this particular stock determined and used as a biological reference point for managing the resource.

The use of a formal and explicit approach to setting the TACs for the WA pilchard fisheries each year, based on the best available knowledge of the status of the stocks in relation to target and/or limit reference points, is strongly recommended. It is suggested that the use of management procedures (decision rules developed through simulation tests) could be a useful approach.

6. STOCK BOUNDARIES

A lot of work has been done over the years on the probable stock structure and stock boundaries of Australian pilchard (see Dixon *et al.* 1993 and references therein). This work has included a comprehensive genetic investigation.

With reference to Western Australia, the general conclusions at this stage are that there is some degree of mixing throughout the distribution of pilchard in the State, but that sub-populations and stocks can still be recognised. The major sub-division is between the western coast of WA, i.e. Dunsborough and Fremantle, and the south coast of WA, i.e. Walpole to Esperance.

On the south coast, it seems likely that the major adult aggregations at Albany, Bremer Bay and Esperance are effectively isolated from each other but that recruitment to each of the three regions occurs from a common pool. Eastward movement of eggs and larvae under the influence of the Leeuwin Current is highly probable, possibly accounting for the high incidence of immature fish at Esperance.

Some form of return migration or movement of immature fish from east to west is also likely, leading to recruitment to the major adult aggregations. In addition to the above general scenario, there is the possibility, however, of some local retention of eggs and larvae in the King George Sound/Bremer Bay area.

I am not a geneticist and cannot comment on the methods or interpretation of results of Dixon *et al.* (1993). However, the several studies undertaken have been generally consistent in their conclusions and the results are plausible in terms of the structure of the coastline, the oceanographic features of the region, and the behaviour of pilchard populations in other regions of the world. I therefore cannot find fault with the existing working hypothesis. The management approach that has been taken under these circumstances, has been:

1. to treat the west coast stock separately from the south coast stock; and
2. to treat the three major aggregations on the south coast as separate stocks and to set separate Total Allowable Catches (TACs) for each of them.

The approach listed as point 2 has met with some criticism and the Albany fishing industry expressed concern that fishing at Bremer Bay is impacting on fishing at Albany. Under the hypothesis of separate adult aggregations but mixing during the egg, larval and juvenile stages, the size of the total adult spawning stock (i.e. the sum of the separate aggregations) could impact recruitment, and hence fishing in any one region could impact fishing in any other region, through subsequent recruitment.

However, the concern expressed appears to be more about direct impacts through fishing on a common adult pool. Under the current hypothesis, there should not be such direct impacts or any impact should be negligible. However, whether or not the current stock hypothesis is correct, the approach used by the Fisheries WA is the best approach, and the more precautionary approach, as it aims both to maintain an adequate total spawner biomass and to avoid local depletions.

Under the current hypothesis, it is likely if not probable that recruitment will vary from region-to-region, depending both on spawner biomass and oceanographic conditions. Hence, one region could enjoy relatively high recruitment one year or over a series of years, while another suffers poor recruitment.

Under such a scenario, the temptation may be to allow the biomass in the poor recruitment region to be depleted below limit reference levels in order to maintain the fishery. The danger with this approach is that it could lead to local depletions or even extinctions which, depending on the rate of external supply of recruits, may be difficult or impossible to undo.

Given external recruitment, with the fished stock consisting of seven age classes (ages 2 to 8), a serious local depletion across all age classes would require a minimum of seven years for recovery of both spawner biomass and age structure. Therefore, it is recommended that the current approach of managing the resource to maintain overall and local abundances at biologically desirable levels is maintained.

6.1 Is the intended juvenile study appropriate to begin addressing these issues?

At present, little is known about the distribution and dynamics of pilchard less than about two years in age, and hence little is known about the nature of the recruitment process. There is no doubt that this situation hampers effective management of the fishery.

Improved knowledge of the source, locality and movements of the juveniles would facilitate developing management strategies that made optimal use of the resource. Obvious questions that need to be addressed include:

1. The relative contributions of the different adult aggregations to overall recruitment, and hence desirable spawner biomass thresholds for each aggregation.
2. Variability in recruitment strength, both of the south coast zone as a whole and of the separate aggregations, and the factors that could affect that;
3. Whether the year-class strength of, for example, one year-olds can be estimated, providing advance notice of likely trends in biomass and hence TACs;
4. Whether substantial recruitment arises from further afield, e.g. the west coast stock or the south central 'stock', and whether this needs to be considered in a geographically-expanded management strategy?

Therefore, the proposed juvenile study to attempt to locate the important nursery area, or areas, and to study the movements of juveniles is supported. The logistics of the study will be difficult, but it is suggested that use of echo-sounding or sonar equipment, even in a 'semi-quantitative' mode, coupled with mid-water trawling may be useful.

Attention is drawn to the studies undertaken in South Africa to undertake pre-recruit surveys. These may provide information useful in the design and implementation of the local study. Details of these studies do not appear to have been published, but the Head of the Survey Division of Marine and Coastal Management, Ministry of Environmental Affairs and Tourism, in South Africa could be contacted for further information.

7. VIRUS

The recent virus-induced mortality events amongst the WA pilchard stocks are clearly cause for considerable concern. The impact of these mortalities on stocks which may already be at low levels relative to their unexploited biomass could be very serious. The approach being taken by Fisheries WA is probably all that can be done, i.e. to attempt to determine the impact of each mortality event on the stock or aggregations and also to attempt to isolate the cause of the outbreaks, in the hope that knowing the cause will enable appropriate action to be taken to prevent a repetition.

The direct estimates of numbers of pilchards dying are clearly useful but are likely to be very imprecise and are prone to errors. It is therefore also advisable to undertake direct biomass estimates for each affected zone as soon as possible after an event, so that the management strategy can be adjusted to the number or biomass of survivors.

In addition to the uncertainty, and associated management problems, about the impact of each event, further uncertainty and management difficulties are generated about the frequency of such events in the future. With only two events having been recorded, and these within approximately five years of each other, it is very difficult to forecast the frequency of events in the future.

For the purposes of developing a management strategy, probably the best approach would be to:

1. develop a strategy that would be able to cope with an event as severe as the more severe of the recent two events, occurring with a frequency of at least that of the recent two; and
2. include contingency plans in the strategy for use in the event of more serious or more frequent events (e.g. taking a much lower proportion of the biomass).

The use of simulation approaches, as described under Section 5, to test suitable management strategies under different scenarios of frequency and intensity of events, would be very useful.

8. ALBANY DECLINE

There can be little doubt that the status of the pilchard resource in Albany is cause for concern. The indicators that the biomass there is low in comparison to previous years include the following:

- DEPM biomass estimate for 1997 one of the lowest on record ($\pm$ 18,000 t; Fig. 1, Gaughan, 1998).
- The good recruitment of 1992 has now nearly passed through the fishery (Gaughan, 1998).
- Catch rates in 1998 were very low and only 67 per cent of the TAC was taken (Gaughan, personal comments).
- The viral mortalities in 1999 will have reduced the biomass even further.

Anecdotal accounts of ecosystem effects, including sea birds apparently having difficulty locating food and other small pelagics (scad) apparently increasing in abundance, may also indicate changes in the pilchard regime.

The signs are therefore bad. However, without knowing how the current status compares to a biological reference point (see Section 5.2), it is impossible to say how bad the situation is, or whether drastic management measures are required.

Figure 1 of Gaughan (1998) suggests that the biomass in 1997 was approximately 50 per cent of the peak biomass which was estimated in 1994. If this peak biomass was close to the mean unexploited biomass, then the situation would not be too serious. However, if the 1994 peak is itself much below the mean unexploited biomass, the current status could be cause for considerable concern.

The other factor that needs to be considered in a determining how serious are the current low biomasses is the economic status of the fishery, with a TAC for Albany of 1,500t for 1999. I was not shown any economic information to indicate the economic implications of recent trends, but clearly a careful economic analysis and forecast should be undertaken to inform any planning on the future of the industry.

9. MISCELLANEOUS

9.1 Differences in mean size of pilchard catch between Albany and Bremer Bay: should the TAC be set by numbers rather than tonnes?

This is a valid question, asked by a member of the Albany fishing industry. The yield which can be obtained from a stock in a sustainable manner varies according to the age composition of the catch in relation to the growth and mortality rates and the age at maturity of the stock.

The relationship between the sustainable yield, the age-at-capture and the biology of the stock is studied through looking at yield and spawner biomass-per recruit. This could be a consideration in determining decision-rules or a management procedure for the WA pilchard fishery and, as the fishery is managed under different zones, differences in the age-at-capture in each zone could be used as the basis for differences in the decision-rules for each zone.

For example, differences in age-at-capture, all other features being equal, would lead to different proportions of the exploitable biomass being taken for the same level of risk to the stock. However, in setting up different decision-rules for each zone, consideration would also need to be given to the implications for monitoring, control and surveillance (MCS) and any rules that resulted in unwieldy or impractical MCS systems should be avoided.

9.2 Are changes in species composition of the WA pelagic community likely to occur (e.g. a shift from pilchard to scad)?

I am not sufficiently familiar with the species assemblage in WA to provide a specific answer to this question. However, experiences elsewhere have been that small pelagic fish demonstrate considerable variability, both from year-to-year and on decadal time scales. Typically, stocks of small pelagic fish demonstrate decadal scale cycles, shifting from ‘regimes’ of high abundance to regimes of low abundance.

As different species within the same area could be following different cycles, the net effect is commonly that one or more species will be increasing while one or more others are decreasing. A likely driving force for this variability is changes in the physical characteristics of the environment, favouring some species but not others.

Such fluctuations have been observed in the small pelagic communities of California, Japan, Peru and South Africa, amongst others (Lluch-Cota *et al.*, 1997). Based on this wider experience, such fluctuations could also be anticipated in WA small pelagic fish. With the time series of data available, however, it is not possible to determine whether the trends being observed at present in the local pilchard are the consequences of random inter-annual variability or part of a longer-term cycle.

9.3 Use of CPUE as an abundance index

In addition to the information from DEPM surveys and interpretations of data on the age compostion of catches, catch per unit of effort (CPUE) is used as an index of stock abundance in determining TACs for WA pilchard (see e.g. Gaughan, 1998; Hall and Gaughan, 1999). A common assumption in using CPUE for this purpose is that it is linearly related to biomass (or abundance) :

$$CPUE = q*B$$

where q = catchability
B = biomass.

However, as recognised by Hall and Gaughan (1999), this relationship is not appropriate for small pelagic fisheries, because their shoaling behaviour tends to lead to easy location and capture, even when abundance is low, and their geographic range tends to decrease with decreasing abundance. Together, these features mean that catch rates can remain high, even though abundance is declining - a property known as hyperstability.

In order to address this problem, the model developed by Hall and Gaughan (1999) assumes that catchability is related to biomass such that:

$$CPUE = q*B^{1-a}$$

where q and a are estimated parameters.

This relationship is appropriate for shoaling small pelagic fish, and captures the hyperstability described above.

CPUE is at present not being used as an important index of abundance for the resource. However, if frequent and regular estimates of biomass by DEPM are not available and it is used as an index in the future, it is important for managers to know when abundance is declining and, as a result of hyperstability, an overall CPUE index may not show this.

Better information may be obtainable if not only CPUE is monitored, but also the distribution of fishing. This could indicate, for example, that the area in which the fleet is operating is shrinking, in response to declining abundance, even while CPUE remains high.

A further problem with use of CPUE with time is that it assumes that catchability, q, remains constant over time. In practice, on-going improvements in efficiency of the fishing operation for a given unit of effort mean that q increases continually. Therefore, for proper use of CPUE as an abundance index, it is necessary to monitor any changes in efficiency, and estimate their impact on q.

A common means of estimating the impact of efficiency changes is to make use of general linear modelling which, by use of a regression approach, can separate the impact of a number of variables, both continuous and boolean, on CPUE. Use of the technique requires a data set of catch and effort by vessel, along with details on any aspects of the fishing practice or strategy which are considered likely to have impacted on fishing efficiency, such as area fished; time of year fished; changes in gear type; and acquisition of technological aids such as echo sounders, GPS etc.

Discussion of this type of approach may be found in Kimura (1981) and Hilborn and Walters (1992).

9.4 Fish rolling

The problem of fish rolling, of releasing fish which cannot be taken aboard, with associated high rates of mortality, is an example of illegal and unreported catches - a widespread and serious problem.

The fish that die as a result of ‘rolling’ are just as much of a loss to the stock as if they had been taken on board and constitute a part of the effective fishing mortality. They will lead to a reduction in the biomass in subsequent years, and hence to a reduction in TACs. It is therefore in everyone's interests to attempt to reduce the incidence of rolling.

There are two issues which need to be addressed. The first of these is that it would be useful for assessment and management of the stock if the extent and impact of rolling could be investigated. It has been estimated that approximately 20 per cent of rolled fish die (Gaughan, *personal comments*.), and the next step in determining the impact on the stock will be to estimate the frequency of rolling.

These estimates could be incorporated into the assessments, leading to improved accuracy in assessments, and facilitating the development of more appropriate management strategies. For this purpose, the fishing industry should attempt to provide Fisheries WA with estimates of the amount of fish released through rolling every year. This could be done, for example, through the use of an anonymous questionnaire, or by asking the industry to conduct an internal survey and report back on estimated totals.

However, in the longer-term it is important that technological means are found to allow unwanted fish to escape unharmed from the net, prior to landing the required catch on the vessel, thereby nullifying the need for fish rolling. The benefits of this would accrue mainly to the industry, through higher biomasses and TACs in the future, and it is therefore in their interests to cooperate between themselves, and with Fisheries WA, to explore ways to do so.

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11. FIGURES

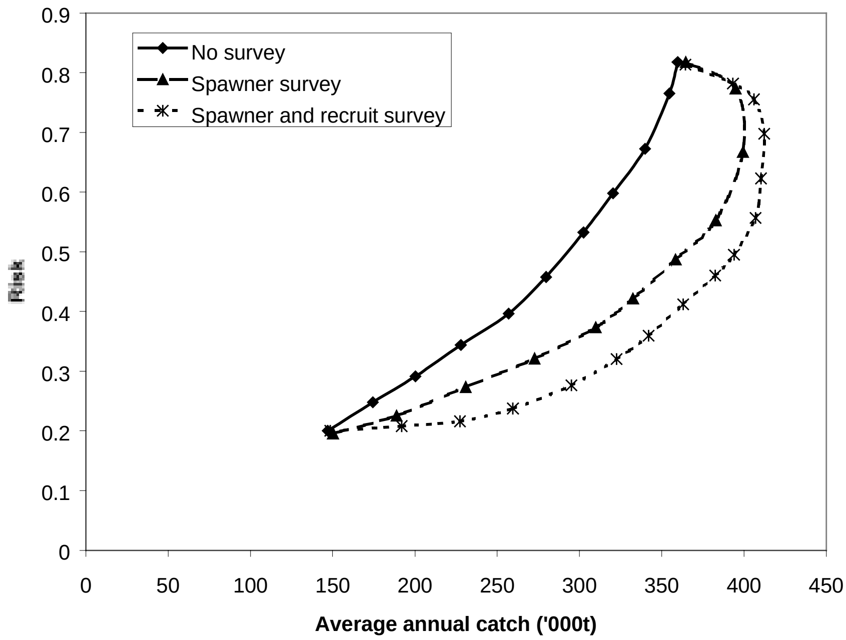

Figure 1 An example from a study on the South African anchovy fishery of using simulation to determine the effect of increasing knowledge (in the form of additional biomass surveys each year) on average annual catch for a given level of risk to the resource (from Butterworth *et al*. 1993). The figure indicates that each additional survey results in higher catch for the same level of risk.

APPENDIX 1 ATTENDEES FOR THE PILCHARD RESEARCH WORKSHOP

Location: Seminar Room, WA Marine Research Laboratories, West Coast Drive Waterman.

Chairman: Dr Rod Lenanton	(Supervising Scientist, Fisheries WA)
Dr Kevern Cochrane	(Independent Reviewer, FAO)
Dr Dan Gaughan	(Scientist, Fisheries WA)
Mr Norm Hall	(Supervising Scientist, Fisheries WA)
Mr Gary Jackson	(Scientist, Fisheries WA)
Dr Mike Moran	(Senior Scientist, Fisheries WA)
Dr Tim Ward	(Scientist, SA Research & Development Institute)
Mr Jonathan Staunton-Smith	(QLD Department of Primary Industries)
Dr Rick Fletcher	(Director, NSW Fisheries Research Institute)
Mr Tim Bray	(Program Officer, Fisheries WA)
Mr Martin Holtz	(WA Fishing Industry Council)
Mr Mervyn Drew	(Purse seine industry and MAC member)
Mr Peter Lombardo	(Purse seine industry and MAC member)
Mr Doug Rogers	(Purse seine industry and MAC member)