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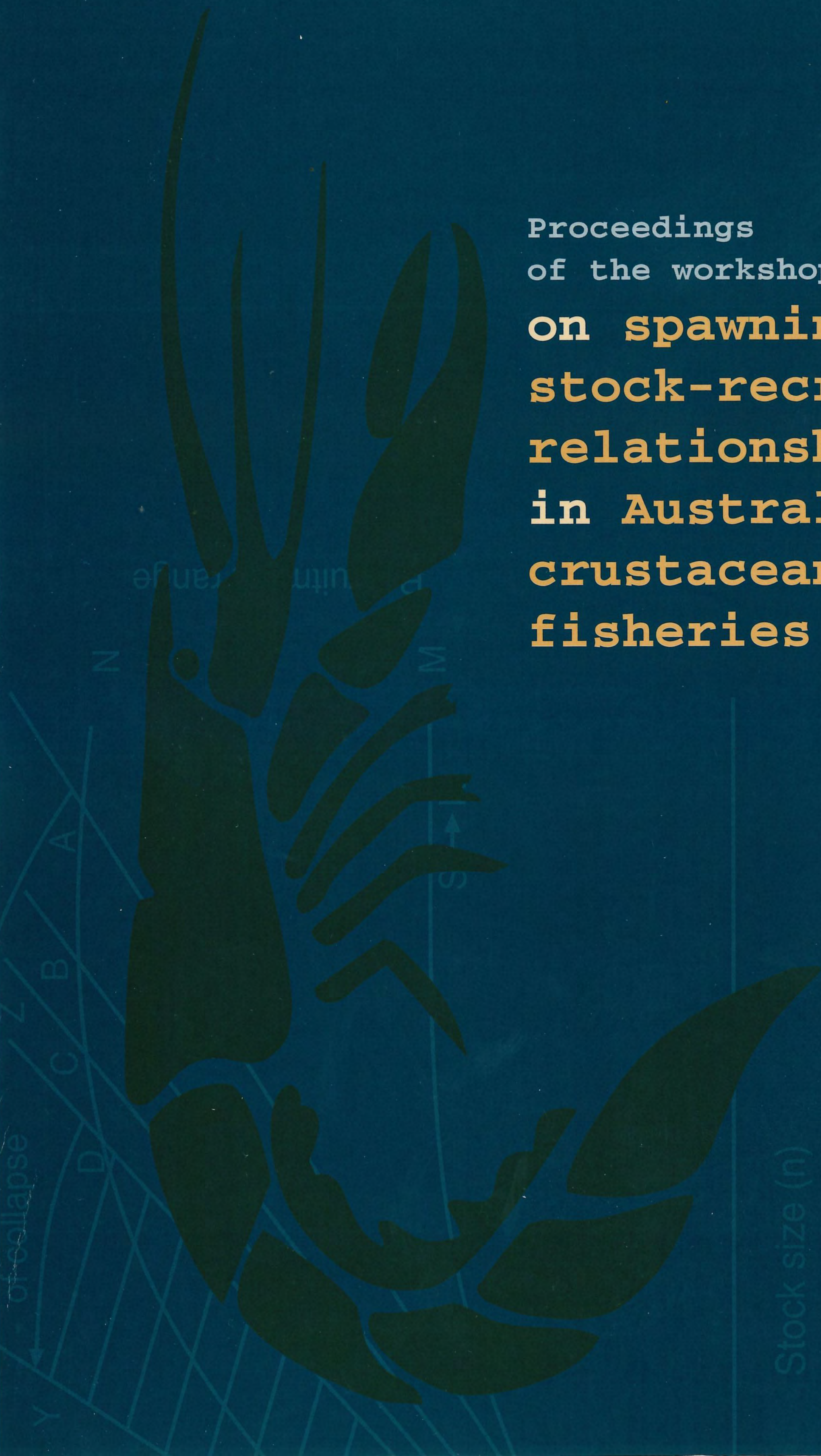
Bribie Island, Queensland

1-3 June 1994

Proceedings of the workshop on spawning stock-recruitment relationships (SRRs) in Australian crustacean fisheries



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QUEENSLAND
DEPARTMENT OF PRIMARY INDUSTRIES

Proceedings of the Workshop on Spawning Stock - Recruitment Relationships (SRRs) in Australian Crustacean Fisheries

Joondoburri Conference Centre 1-3 June, 1994

Sponsored by Fisheries Research and Development Corporation (FRDC) and Department of Industry, Science and Technology (DIST)

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FOREWORD

The relationship between spawning stock size and the size of the subsequent recruitment is fundamental to fisheries science. Without a working knowledge of the relationship it is not possible to know how heavily a spawning stock can be fished before recruitment levels begin to decline. Although important to fisheries research and management, there are very few robust, published examples of stock - recruitment relationships (SRRs), particularly in crustacean fisheries. The aim of this workshop was to consider recent advances and trends in the research and application of SRRs in Australian crustacean fisheries. The workshop's organising committee put forward four general areas to be considered. These were 1) case studies of SRRs, 2) biological considerations for defining the spawning stock and recruitment indices, 3) mathematical and statistical limitations and biases in SRRs and 4) recruitment overfishing and management.

The workshop was held at the Joondoburri Conference Centre, Bribie Island, Queensland from June 1 - 3, 1994. It was funded by grants from the Fisheries Research and Development Corporation (FRDC) and the Department of Industry, Science and Technology (DIST) and attended by 53 fishery researchers, biologists, managers, biometricians and academics. This publication contains a copy of the 24 papers and abstracts that were presented, in addition to questions and answers, discussion, and ideas for future research relevant to SRRs. The majority of participants were from Australia. Researchers from Mexico and the United States of America also attended. Dr. Serge Garcia (Director, Fisheries Resources and Environment Division, FAO, Rome) who planned to attend but had to withdraw late in the workshop's preparation, also contributed by way of forwarding a paper which was presented by Dr. David Die.

Discussion sessions were held at the completion of each day and based upon the day's presentations. Key issues discussed included 1) assessing target and reference points for fisheries management, 2) the relationship between life history type and susceptibility to recruitment overfishing, 3) evidence of recruitment decline in crustacean fisheries, 4) determining appropriate environmental data to be incorporated with SRRs and 5) the value of catch per unit of effort (CPUE) data as estimates of spawning stock size.

A significant component of the text is a transcript of the questions and discussions. At times it was difficult to interpret, comprehend or hear clearly everything that was spoken. We have attempted to transcribe all conversation as accurately as possible.

At the time of this document's preparation, five papers that had been presented at the workshop were selected by the organising committee to be submitted to the *Australian Journal of Marine and Freshwater Research* for independent refereeing and publication. Further details of these papers may be available in the journal if required.

A.J. Courtney
Queensland Department of Primary Industries
Southern Fisheries Centre

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ABSTRACTS

Day 1. Case Studies of Spawning Stock - Recruitment Relationships in Crustacean Fisheries. (Chaired by Dr. David Die)

Stock-Recruitment Relationship and Precautionary Approach to Management of Tropical Shrimp Fisheries

S.M. Garcia

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Abstract

Exerting precaution implies acting in advance, taking into account the current uncertainty and potential consequences of being wrong. In a fisheries management context, caution would have to be exercised beforehand to provide against negative impacts of the fishery (and other competing activities) on the fishery resource and the fishing community itself, to ensure fisheries sustainability. Recruitment failure is certainly one of the negative impacts to be addressed in a precautionary fishery management context.

This paper examines the possibility and potential implications of using precautionary assessment and management approaches to deal with the uncertainty regarding the exact shape of the stock-recruitment relationship in tropical shrimp fisheries. After a brief review of the stock-recruitment problem and related reference points in these fisheries, and of the precautionary approach in general, it proposes a non-parametric approach to the SRR as a basis for the determination of safe and risky fishing mortality levels. It illustrates a management strategy based on the seasonal escapement of spawning biomass. In conclusion, it offers a discussion on the robustness of the non-parametric method and on validation of the conclusions using additional information.

Questions and discussion following Dr. Serge Garcia's paper, which was presented by Dr. David Die.

Dredge: The model that you presented is basically mono-specific. Do you believe it is feasible to extend it to management of multi-species fisheries?

Die: In terms of applying thresholds of fishing and target points, the model could be applied to multi-species fisheries. However, in terms of the seasonal constraints that he has put in to achieve escapement, it would be very different for a multi-species fishery because there may be several spawning times for each species.

Somers: With regard to reference points, this is something that many people in this area neglect. They get to stock recruitment relationships and forget it's supposed to provide guidance for managers in terms of sustainable yields. There was no reference point that gives FMSY, nor was there a reference point that reveals when there is a spawning stock problem. It's always going to depend on fishing mortality. Managers require an estimate of the fishing mortality that's going to maximise the benefits from the resource over the long term. There has to be some reference point that people should be aiming at, rather than just leaving it at a SRR.

Die: I agree in that there is no reference here to the impacts on yield from these types of reference points. I can't tell you what Dr. Garcia means when you try to aim at certain levels within the stock-recruitment, in terms of yield. Aiming at safe spawning stock levels may be very good but what does he mean in terms of yield to the fishery?

Glaister: Reference points and percentiles, whether they are 10%, 15% or 20%, have in-built costs that can be quite considerable to the industry. Reference points for escapement in Salmon haven't been all that successful. Why pick a particular figure or number? Managers want a target that they feel confident about, particularly if the fishery has to be closed down and causes hardship. If a target is put forward then they need to be able to support it for good reasons. Are those figures based on anything solid?

Die: Dr. Garcia suggests that the range of percentiles that he has chosen would represent fisheries that are operating around the world at a more or less sustainable levels.

Staples: There is a danger here in mixing *limit* reference points with *target* reference points and using the two interchangeably.

Die: Dr. Garcia makes that distinction. His goal is to operate with the spawning stock at medium level (S_{med}). That's his target. Then he defines escapement which is what should not be exceeded. He argues that recruitment failure in shrimps would be the biggest issue because each year it is the recruits that sustain the fishery.

Hilborn: Dr. Garcia is really proposing two strategies. One is a constant "F" (constant fishing mortality strategy) and the other is a feedback strategy. What is required is to determine the likely probability of a decline in yield and stock, if a particular strategy is adopted. I consider limit reference points as a sign of an unwillingness to examine the data and determine how likely it is that the fishery will get into trouble as stock levels get lower.

In a series of recent E-mail conversations from the ICES working group on risk analysis, they were discussing the probability of a major decline occurring under different strategies. There are two general hypotheses. Hypothesis A is constant recruitment. You need to determine what happens to yield, population size, stock size, etc., under a range of strategies assuming constant recruitment. Hypothesis B assumes declining recruitment and again you need to examine the effects from the various strategies. The most difficult task is to determine the relevant probabilities. When the relevant probabilities for the two hypotheses become available you approach the managers with them. This provides them with an idea of how often the fishery will need to be shut down. The problem is how you get those probabilities and the easy way out is to just use reference points and not go below 20%, or whatever.

John's point is that it may be a very conservative strategy, or it may not. In New Zealand the Ministry of Agriculture and Fisheries (MAF) has put forward a 20% reference point. Chris Francis has put up a proposal that the stock should not drop below 20% of it's virgin biomass, more than 10% of the time. The problem is that the fourth most economically valuable fishery, snapper, is at 5% of virgin and growing and appears to be as healthy as ever. All the evidence is that snapper is quite safe in New Zealand and yet if that reference point was adhered to, the fishery would be down. The same thing is true of the lobster fishery. Thus, the two competing hypotheses, that recruitment will drop, or that recruitment won't drop, should be put forward. Then review the evidence on a case by case basis. For example, there maybe 27 fishery examples, five of which show evidence for a SRR and in 22 in which there no evidence. You would use that statistic as your probabilities of the two models. The one difference that you must be careful about is not to use a 0.05 level of probability. Don't assume that there is no SRR because you can't prove it at the 0.05 level. You need to use 0.50 level. It is more likely than not that recruitment drops as spawning stock drops.

Caputi: In regard to Dr. Garcia's approach, when should the stock and recruitment points be attained? If they are attained when the fishery is just starting, they tend to have very high values of spawning and recruitment. When they are attained late in the fishery's development, low estimates of spawning stock and recruitment are attained. Thus, completely different answers are attained for the same fishery.

Die: Dr. Garcia makes no reference to that. It would be expected that, given the intensity at which most fisheries are fished, recruitment is consistently lower in the later years of the a fishery's history.

Hilborn: The values obtained from the different periods can often overlap.

Warburton: One of the advantages of the percentile approach is that you pay more attention to the extreme events - one tail of the distribution more than the other. This would help determine the level in recruitment variation which is due to stock and which is due to the climatic or environmental errors. That may relate back to that point about historical changes.

Hilborn: One of the classic problems in stock-recruitment is that if catch per effort is used as a measure of stock abundance, there is an enormous amount of variability in the x-axis. However, that is measurement error as opposed to real variability. Does Dr. Garcia discuss that issue?

Die: No.

Penn: Reference points have potential danger if they are not conservative enough. There are a number of fisheries that have a long history which had reasonably high catches in the earlier stages but currently operate at lower levels. They've stabilised at the lower production levels. In such circumstances by using the current data, the current, low-production of the fishery is maintained. The management strategy keeps the breeding stock at levels which have occurred in recent years. Sub-optimal levels of breeding stock are imposed by management and the question of what is an optimal spawning stock is not addressed. Thus, it really depends on when you get the data as to whether you should use Dr. Garcia's approach.

Somers: The attractiveness of this approach is that it is a essentially a "recipe". Such approaches are appealing to managers but they encourage us not to think carefully and that is a big danger. The other aspect is that the set of rules that is put up about opening and closing dates, and monitoring fisheries is very complex. It would be very difficult to do a cost-benefit analysis in relation to these requirements.

Die: With regard to the recipe analogy, although Dr. Garcia puts one forward, he is open to how those targets are derived and what percentile you choose. He notes that there are many choices, in terms of deriving limit or reference points. He is not necessarily saying that one is better than the other. I agree that recipes are very appealing, but they may be dangerous too. In terms of the complexity of his proposal regarding season, he goes into it at a lot more detail in the paper than what I've gone into in the presentation. You would have to read that part in the paper. He does acknowledge that it is complex and states that this may be very difficult to apply in practice because there are many fisheries where you don't have such tight controls. The costs of the different strategies in terms of yield are not really addressed.

Arreguín-Sánchez: There is another perspective to the problem, particularly in regard to the knowledge and the dynamics of shrimp fisheries in many developing countries. For example, in the Gulf of Mexico the management of the fishery was developed under the assumption that there is no SRR and that recruitment overfishing is not important. On the Pacific coast of Mexico overfishing occurs and in some regions yields are 10% of the what they were 20 years ago. Reference points could be useful in such cases for management.

Watson: Do you think it would work for cases where recruitment is more complex, where the recruitment pattern wasn't a simple, single pulse? Do you think you might have conflicts between opening and closing the fishery to manage recruitment overfishing versus growth overfishing?

Die: Yes. The recruitment pattern (single or multiple) influences the decision about whether you establish the escapement on the main cohort or on several cohorts. You may have to make some prediction about what the following cohort is going to provide, in terms of spawning stock escapement, before you close the fishery. Growth overfishing would obviously complicate things again and this probably relates to Mike Dredge's comments regarding multiple species. If you have several cohorts of the same species it would be equivalent to having several species with different spawning and recruitment patterns, although with a single species you would have only one growth pattern.

Gracia: Dr. Garcia's proposal could work. With regard to recruitment overfishing in the white shrimp (*P. setiferus*) fishery in the Gulf of Mexico, you could fit this model because it allows you to set a low and a high level of SRR. It enables you to prevent something that could occur, which, in the case of white shrimp in the Gulf of Mexico, has occurred. The problem will be the values and that depends on the species you are talking about.

Wang: The problem with this approach is that we don't have clear SRRs for most fisheries. Also, although this is a precautionary approach there is no bottom line for the level of risk. To answer the question raised by Ian Somers, it is interesting to have a recipe telling you what is the true level of fishing effort. Perhaps it has to be in the form of FMSY. That depends on one of the specifications of the relationship between stock and recruitment. You need to specify mathematically what the relationship is. When you have considerable noise, you have an unclear relationship. To go beyond that we have to make some assumptions, especially when you want to deal with a complex problem like stock size. How do you define stock size?

Die: We'll go into more detail over the next few days on those sorts of issues, in terms of elaborating indices for spawning stock and recruitment. That's one of the roles of this meeting - to give some guidance to all of us.

White Shrimp (*Penaeus setiferus*) Recruitment Overfishing

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Abstract

White shrimp *Penaeus setiferus* is one of the major species exploited in the Gulf of Mexico. Maximum annual catches of 1200-1800 (tail meat) metric tonnes were reached in 1970-1980. In the following years, there was a marked decline which took the fishery to less than one-fifth of its maximum production levels. The decline was firstly associated with decreasing fishing power of the fleet, and later to the establishment of a new artisanal coastal drift net fishery. The artisanal fishery has the following characteristics: (1) it acts selectively on spawners older than 8 months of age; (2) fishing effort increases during spawning periods when white shrimp school and are more vulnerable to drift nets and; (3) high profitability and explosive growth. This has resulted in unusually high fishing pressure. Previous evidence of an SRR in white shrimp suggested that a recruitment failure had taken place. The relationship between spawning and recruitment indices, based on the main cohorts of the two annual generations makes it possible to establish a SRR for white shrimp. The relationship in both generations exhibits a negative tendency, and is close to the critical spawner biomass levels. The environmental influence on recruitment, although important for annual variations, is unlikely to be responsible of this decline. Yield decline may be attributable to recruitment overfishing. Management measures, such as closed areas, closed nursery areas and closed seasons have been used to protect the spawning stock and aid in the fishery's recovery.

Questions and discussion following Dr. Gracia's presentation.

Staples: You assume that your two annual cohorts are independent. What evidence do you have that that spawning from the first cohort, and the subsequent recruits from that spawning, can be measured separately from the spawning from the following cohort? How do you determine which spawning the recruits are associated with and how do you handle the problem of overlapping generations?

Gracia: Cohorts are not clearly or definitely separated. One cohort can contribute to the other. White shrimp mature at about eight months of age and it is likely that some individuals spawned from the second generation contribute to the first cohort's major spawning. Thus, it is unlikely that there are discrete cohorts. Biologically, this may be an advantageous reproductive strategy, as it increases the reproductive capacity of the population. They can spawn throughout the year and this it is an opportunistic strategy. It may be why penaeids can recover from the very high fishing effort.

Staples: Did you assume that one generation would contribute to the second generation a year later when you did your SRR?

Gracia: Yes.

Wang: How did you estimate monthly recruit indices?

Gracia: It was based on commercial catch using commercial sampling in processing plants. This provided information on prawn size and sex composition. Weights were converted to numbers per month and growth formulas for each gender were considered. Estimates were obtained for the different genders. Numbers for each age group and gender were obtained and this was the basis for the VPA analysis.

Wang: Did you take account of the continuous recruitment during that period? If you apply VPA to monthly data, you would assume that all of the recruits come in at the beginning of the month rather than throughout the month.

Gracia: Yes, recruitment was assumed to be "knife-edged". To estimate the relationships several approaches and combinations were considered. One was to make biological years. Each biological year began in June and finished in May but there were no significant SRR results when the data was treated on a yearly basis so I made an analysis based upon monthly cohorts. The main cohorts provided the most information. Recruitment was assumed to be knife-edged and occur at four months of age. This was based on results from the estuaries on the eastern side of the lagoons and also from biological observations.

Update on Stock Recruitment Relationships for the Tiger Prawn (*Penaeus esculentus*) Stocks in Western Australia

Update on Stock Recruitment Relationships for the Tiger Prawn (*Penaeus esculentus*) Stocks in Western Australia

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Abstract

Hancock (1973) noted an absence of information on the stock-recruitment relationships (SRR) for crustacean fisheries. A number of years later Gulland (1984) noted at a 1981 prawn workshop that the SRR had received 'remarkably little attention' even though a number of papers at the workshop expressed concern that recruitment overfishing was occurring in some fisheries (Gulland and Rothschild 1984). These papers were later reviewed by Garcia (1983), who concluded that none of the available data provided good evidence of a penaeid SRR. It was with this background of uncertainty about the influence of spawning stock on recruitment that the declining catches in the tiger prawn stocks in the two major desert embayments of the central Western Australian coastline, Exmouth Gulf and Shark Bay, were being examined during the 1980s.

These fisheries commenced in the early 1960s and catches expanded as the fisheries developed and were relatively consistent during the period 1970-1979. During the 1980s catches of tiger prawns (*P. esculentus*) decreased markedly in both major fisheries. Average annual production of tiger prawns from the Shark Bay stock was about 300 tonnes (50% reduction) and the tiger prawn catch from Exmouth Gulf although more variable historically, declined from an average of about 600 tonnes to less than 100 tonnes, but has since improved. Catches of other penaeids in Shark Bay (*Penaeus latisulcatus*) and Exmouth Gulf (*P. latisulcatus, Metapenaeus endeavouri*) have, in contrast, been maintained.

Penn *et al.* (in press) examined the SRR of tiger prawns in these two fisheries and concluded that recruitment overfishing was the cause of the decline, i.e., the decline in spawning stock due to high levels of fishing effort had caused a reduction in the abundance of recruits. This report provides a brief summary of that study and an update of the more recent years' data.

To assess the cause of the decreased tiger prawn catch from Shark Bay, the tiger prawn spawning stock-recruitment relationship (SRR) (Fig 1.) has been examined. For this purpose, annual indices of spawning stock and recruitment levels have been developed, by combining biological information with the detailed and standardised fishery data base maintained since the fishery began (Slack-Smith 1969, Hall and Penn 1979, Penn *et al.* 1988). The complementary assessment of the effect of fishing effort

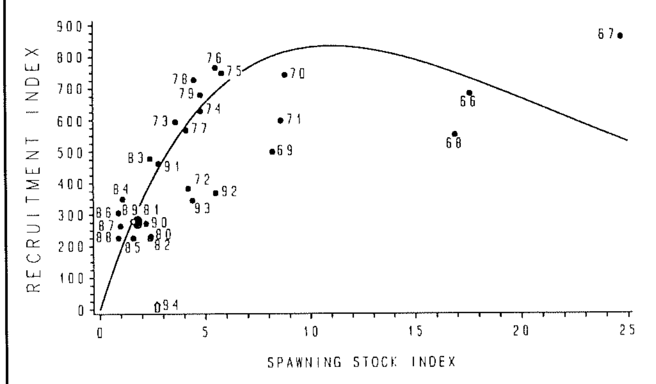

Figure 1. The SRR for the Shark Bay tiger prawn fishery with the year of recruitment indicated.

on the annual survival of recruits to the spawning stock (RSR) (Fig. 2) and the interaction between the SRR and RSR (Fig. 3) suggests that fishing pressure has been primarily responsible for the 1980 decline in tiger prawn catch (Penn 1988).

In the Exmouth Gulf fishery, a previous assessment of the state of tiger prawn stock (Penn and Caputi 1986) indicated that the dramatic (1981, 82) decline in tiger prawn catches also resulted from escalating fishing pressure. An updated assessment of this fishery, undertaken in 1989 (Fig. 4 and 5 - from Penn *et al.* in press) incorporating more of the data since the collapse of the tiger prawn stock in 1982-83, consolidated the previous assessment. This evaluation showed that the severe management controls imposed in Exmouth Gulf since 1982 which were designed to improve spawning stock levels, have been accompanied by an increase in recruitment and hence catch. This response of the Exmouth Gulf tiger prawn stock to the management induced variations in spawning stock levels, has been in contrast to the situation in Shark Bay over the same period.

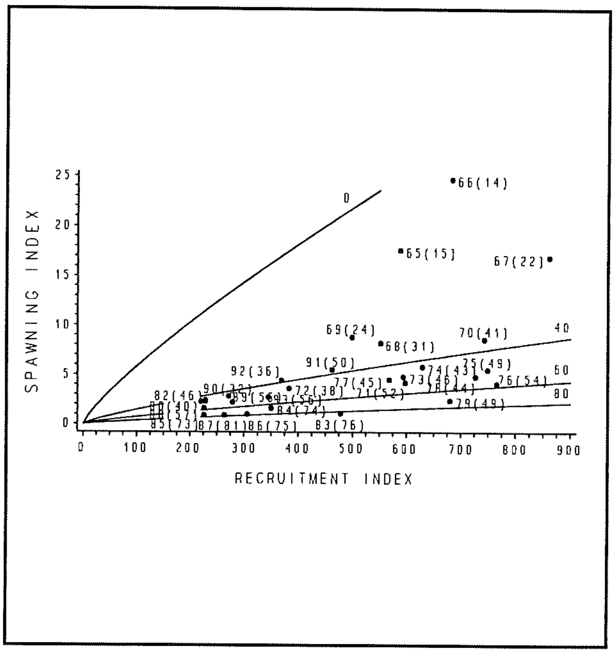

Figure 2. The RSR for the Shark Bay tiger prawn with the effort lines of 0, 40, 60, 80 thousand hours of effective effort on recruits. The year and effective effort in thousands of hours are shown.

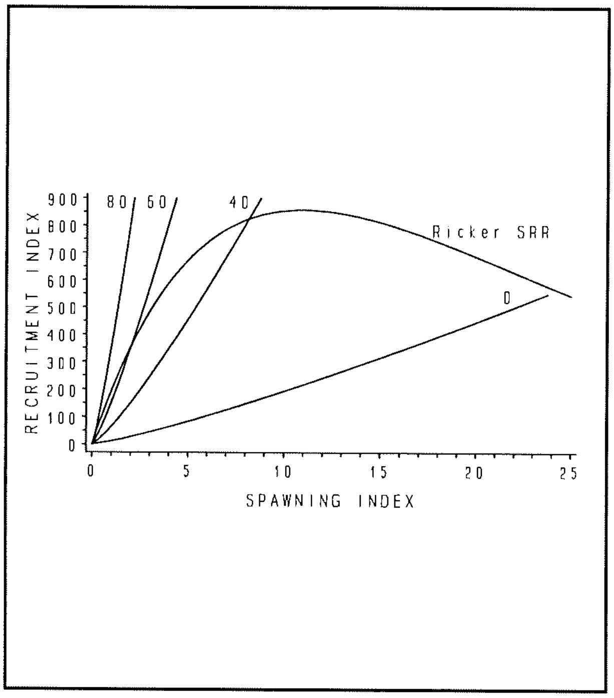

Figure 3. The interaction between the SRR and the RSR, with effort lines of 0, 40, 60 and 80 thousand hours of effective effort, for the Shark Bay tiger prawn. The lines show the theoretical trajectory for high and low fishing pressure.

In Shark Bay, tiger prawns have always been the minor species in the catch and the lack of a clear geographical separation of the tiger and king prawn stocks has only permitted minor management action to improve tiger prawn breeding stock levels. As a result, spawning stock levels during the 1980s have not increased to any marked extent and catches remained at about 300 tonnes annually. In 1990 a vessel buy-back system was introduced which reduced the number of vessels from 35 to 27. There has also been a progressive delay in commencement of fishing in the prawn recruitment areas from early March until mid-April because of the increased market demand for larger prawns. These two factors have resulted in a marked decrease in fishing effort from 70-80,000 hours of effective fishing effort on tiger prawn recruits to about 40,000 hours (Fig. 2). This has resulted in a general increase in spawning stock and recruitment in the last 4 years.

These different management strategies for the two fisheries, can together be regarded as a fortuitous example of actively adaptive management for replicated systems as advocated by Walters (1986). That is, the Shark Bay tiger prawn stock has acted as a "control" to the management induced increases in spawning stock levels in the Exmouth Gulf stock, thus adding considerable support to the view that the variable spawning stock abundance due to changing effort levels has been the dominant factor controlling recruitment during the 1980s.

The responses of the tiger prawn stocks to exploitation, compared with the other major species (*P latisulcatus*) in these two multispecies fisheries have also provided an opportunity to identify some general features which are likely to have contributed to the tiger prawns relatively "unusual" susceptibility to fishing pressure. Differences between the species, including: the level of aggregation at time of spawning, vulnerability to trawl gear, the multispecies - effective effort interaction, and latitudinal effects on spawning season duration, have been suggested as factors which may help identify other penaeid stocks which are potentially at risk from recruitment overfishing.

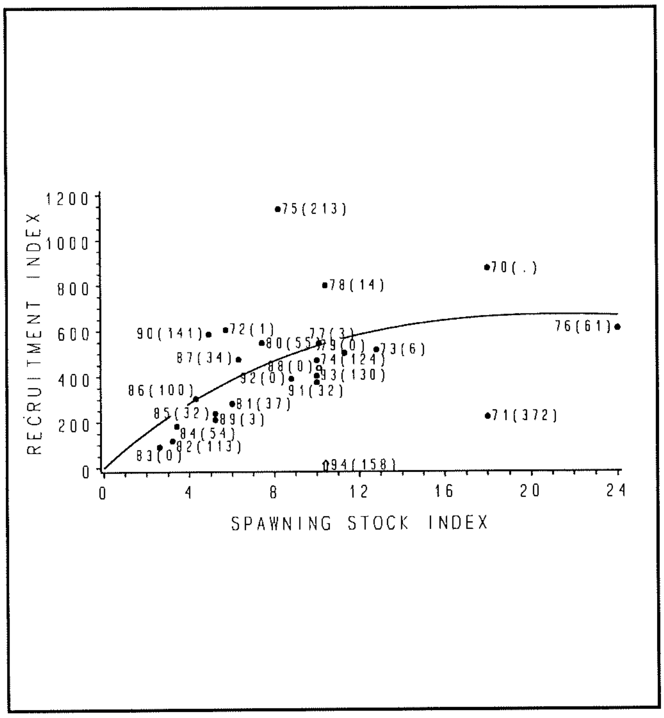

Figure 4. The relationship between spring spawning stock and autumn recruitment for the Exmouth Gulf tiger prawn stock. Data points are shown for the year of recruitment and the January and February rainfall (mm) in brackets.

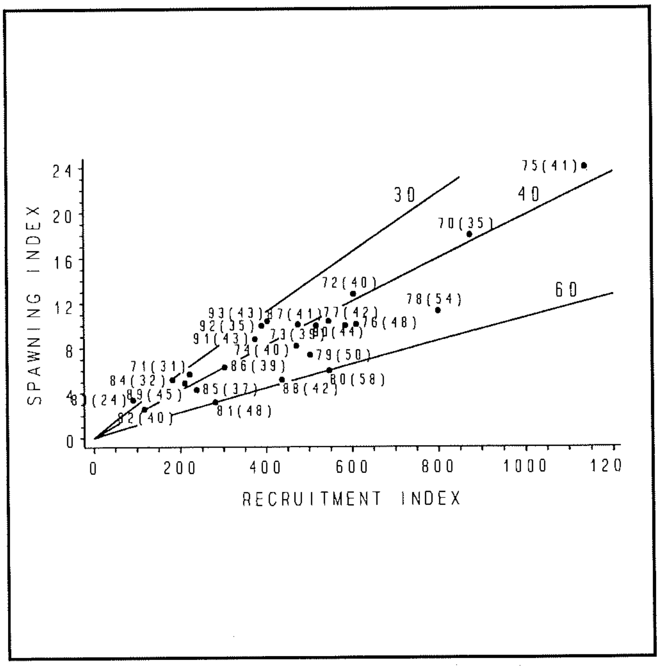

Figure 5. The RSR for the Exmouth Gulf tiger prawn fishery with the effort lines of 30, 40, 60 thousand hours of effective effort. The year and effective effort in thousands of hours are shown.

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Questions and discussion following Dr. Penn's presentation.

Loneragan: Most of the data you presented on the SRRs are based upon commercial catch data. I understand that you've also collected fishery-independent data. How do you use that data and are you still collecting it?

Penn: I'd prefer to discuss that issue later after I've given the second paper about the management process and the independent survey work. I can comment however, that introducing detailed management controls has been a hazard in doing SRR research on our fisheries. In essence, when you change the management plans you end up ruining the commercial fishery data base or at least make it much more difficult to deal with. I'll come back to this topic later.

Staples: Back in 1981 you made a brave, global prediction that highly aggregating stocks would suffer recruitment overfishing. The fact that you think it's been upheld, based on the Western Australian experience, especially for Banana prawns at the southern end of their range, is still arguable. If you look at white shrimp fisheries throughout Asia and the tropics, they seem to have been very constant and sustainable over many years. Thus, I'm not sure that your prediction has been right for the white shrimps, but I'll give you some points for the tiger and king prawns.

Penn: I was running out of time during the presentation so I didn't cover that issue in detail. When we first analysed the Exmouth situation we set out a number of factors which we thought contributed to the recruitment problem. These refined the hypothesis from the 1981 paper.

The first factor involved seemed to be the multispecies nature of our fisheries, where the economics allows vessels to fish the less abundant species to extremely low levels. Another factor is catchability - my previous hypothesis. I've done some further field work on this to show that tiger prawns are much more catchable than king or endeavour prawns. The aggregation factor is also critical. In this regard, the W.A. stocks are in a rather unique situation, occurring within embayments where the greatest aggregation occurs at the time of spawning. In these fisheries, fishing can greatly reduce the spawning stock levels. However, in most prawn fisheries the aggregation is the other way around. The prawns become more dispersed as they move offshore to spawn, so the geography of the coast is probably another critical factor in controlling the effect of fishing on the spawning stock.

To answer your question, I've added a few more aspects to the recruitment overfishing hypothesis in the light of experience since 1981. Clearly stocks that disperse widely, going from nurseries to spawning areas, are not going to be easily fished down to critical levels and any white shrimp stocks in this category are pretty safe. The position of the species within its geographic range is also important. The Exmouth banana prawn stock was clearly at the edge of its range and probably susceptible to any major environmental variation. However, the combination of the environment and the effect of fishing in this situation was probably critical. Banana prawns still occur in Exmouth Gulf, but have not been in commercially significant quantities for the past 25 years. The South Australian fishery problem with king prawns is also a classic case of this end-of-the-range problem.

The issue which now concerns me most is the technology changes, like GPS, which are now significantly affecting the efficiency of trawl fisheries. This is allowing fishers to target aggregations which they previously didn't know about, and shift the pressure on the stocks to much higher levels than previously experienced. How these developments will affect SRRs for prawns is an open question.

In summary I agree with you that spawner recruit problems with penaeid prawns are likely to be relatively special situations and there are many stocks where it doesn't apply.

Stock-Recruitment-Environment Relationship for the Western Rock Lobster, *Panulirus cygnus*, fishery in Western Australia[1]

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([1] Some of the text and figures have been reproduced from Caputi *et al.* (1995a and b) Crustaceana)

Abstract

Previous studies have shown that environmental factors, the Leeuwin Current and westerly winds, have a significant effect on levels of puerulus settlement at coastal locations in the western rock lobster (*Panulirus cygnus* George 1962) fishery. However, these environmental factors don't explain an average decrease of 50% in the puerulus settlement at the Abrolhos Is. (on the edge of the continental shelf, 60 km off-shore from the north coastal region) from the 1970s compared with that observed in the last 10 years. During the past 20 years, there has been an increase in fishing effort resulting in a marked decline in the spawning stock, particularly in the north coastal region. The stock - recruitment - environment relationships for three sites covering the main regions of the fishery show that environment effects explain the main fluctuations in puerulus settlement in the coastal sites Dongara and Alkimos, with the spawning stock not being significant. However, the reduction in spawning stock appears to be the main factor explaining the decline in Abrolhos Is. settlement during the last 10 years. The complementary relationship of recruitment to spawning stock shows that fishing effort two years prior to spawning, i.e., on the recruits to the fishery, is significant in explaining the decline in coastal spawning stock.

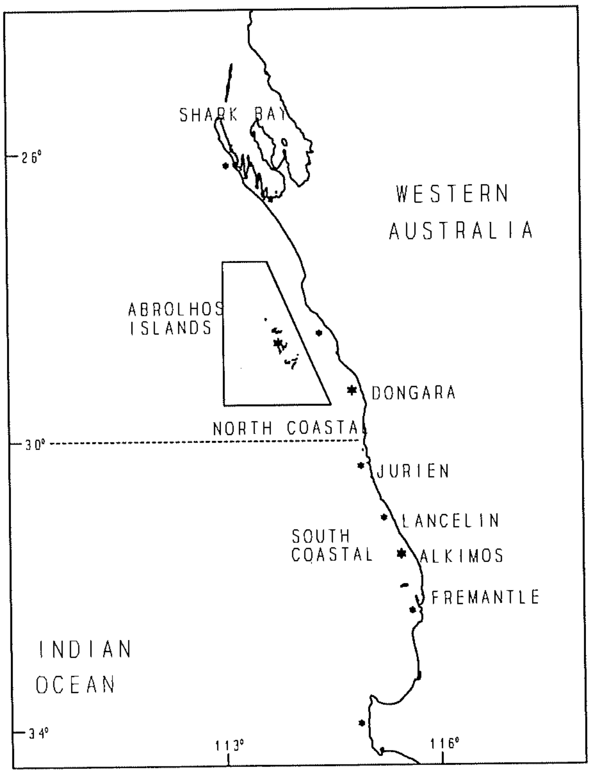

Figure 1. The locations within the western rock lobster fishery at which the indices of puerulus settlement are obtained and where the management regions occur (from Caputi *et al.* 1995a Crustaceana).

Introduction

Morgan *et al.* (1982) examined the relationship between spawning stock and puerulus settlement (an index of recruitment) at Dongara (Fig. 1) for the western rock lobster (*Panulirus cygnus* George 1962) fishery. They concluded that a Ricker stock-recruitment relationship (SRR) fitted the 11 puerulus year-classes (1969/70 - 1979/80). This relationship showed a strong compensatory density-dependent mortality with an inverse relationship between puerulus settlement and spawning stock. Subsequent analyses of the variation in puerulus settlement have shown that environmental factors strongly affect coastal puerulus settlement.

Pearce and Phillips (1988) showed that the puerulus settlement at Dongara was affected by the strength of the Leeuwin Current that flows south along the edge of the continental shelf. The strength of the current is reduced during El Nino years. Caputi and Brown (1993) noted that the variation in puerulus settlement at coastal sites could also be explained by the strength of westerly winds during storm events that occur during winter-spring, prior to and during the main period of settlement. The index of these storm events is rainfall from a number of coastal locations (Caputi *et al.* 1994b).

The multiple correlation of 0.75 between puerulus settlement at Dongara and the Leeuwin Current strength and rainfall (Oct.-Nov.) is similar to that obtained for the two rainfall periods (0.76) and significantly greater than for sea level alone (0.66) (Table 1). Thus, a combination of these two environmental factors may provide an alternative explanation of the large variation in puerulus settlement (Fig. 2a). A similar result was obtained for Alkimos settlement (Fig. 2b).

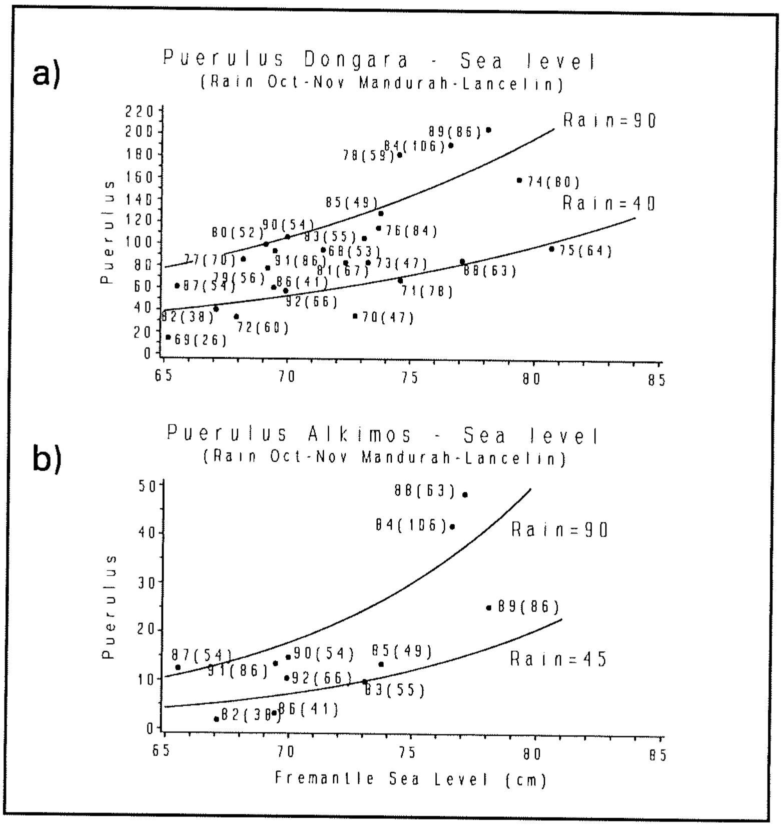

Figure 2. Relationship between the puerulus settlement of the western rock lobster fishery and the strength of Leeuwin Current (measured by the Freemantle sea level) and the westerly winds (measured by rainfall in southern locations) for a) Dongara and b) Alkimos, with rainfall (mm) in brackets (reproduced from Caputi *et al.* 1995b Crustaceana).

Neither the Leeuwin Current nor the westerly winds explain an average decrease of about 50% in puerulus settlement at the Abrolhos Is. (on the edge of the continental shelf, 60 km off-shore from the north coastal region - Fig. 1) from the 1970s compared with the settlement in the last 9 years. However in the past 20 years there has been an increase in nominal fishing effort and an increase in the efficiency of vessels, particularly, in the deep water (36+ m) (Brown *et al.*, in press) where the breeding stock is located. This has resulted in a marked decline in the spawning stock, particularly in the north coastal region (Fig. 3).

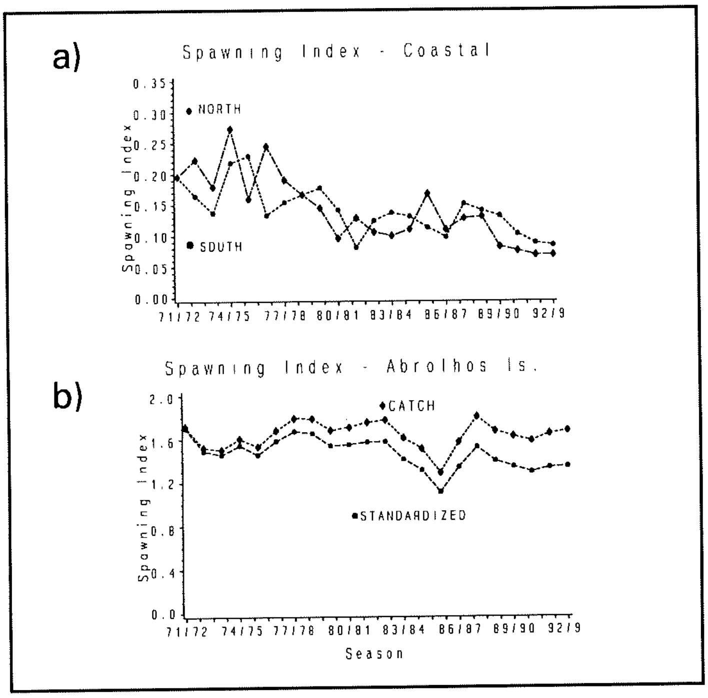

Figure 3. Time series for the spawning indices of the western rock lobster fishery for a) the north and south coastal regions, and b) the Abrolhos Is. (reproduced from Caputi *et al.* 1995b Crustaceana).

Table 1. Correlation between log transformed puerulus settlement at Dongara, Alkimos and Abrolhos Is. with the Fremantle sea level (FSL), rainfall during July-September and October-November for the north and south, and the combined spawning index (SI).

	Puerulus Dongara	Puerulus Alkimos	Puerulus Abrolhos
Recruitment-Environmental relationships:			
	(n=25)	(n=11)	(n=17)
FSL	0.66 ***	0.73 *	0.35 NS
Rain-south (Jul-Sep)	0.41 *	0.40 NS	
Rain-south (Oct-Nov)	0.65 ***	0.72 *	
Rain-south (Jul-Sep & Oct-Nov)	0.76 ***		
FSL & Rain-south (Oct-Nov)	0.75 ***	0.82 *	
FSL & Rain-south (Jul-Sep,Oct-Nov)	0.79 ***		
Rain-north (Jul-Sep)			0.13 NS
Rain-north (Oct-Nov)			-0.50 *
FSL & Rain-north (Oct-Nov)			0.61 *
Stock-recruitment-environment relationships:			
	(n=21)	(n=11)	(n=17)
SI	0.02 NS	0.20 NS	0.52 *
SI, FSL & rain-south (Oct-Nov)	0.75 ***		
SI & Rain-south (Oct-Nov)		0.77	
SI & Rain-north (Oct-Nov)			0.71 *

The decline in puerulus settlement at the Abrolhos between recent years and the 1970s may be caused by two factors - environmental variation or spawning stock levels. That is, the environmental conditions may have changed between these periods causing an adverse effect at the Abrolhos but not for the coastal locations. Alternatively, with the Abrolhos being situated off-shore and closer to regions where the pool of larvae occurs, there may be a more direct relationship between the spawning stock and puerulus settlement with the environment contributing less to the variation in puerulus settlement. Thus, the decline in spawning stock may be felt more directly at the Abrolhos.

The stock - recruitment - environment relationships for three sites covering the main regions of the fishery show that environment effects explain the main fluctuations in puerulus settlement in the coastal sites, Dongara and Alkimos, with the spawning stock not being significant (Fig. 4a and b). However, the reduction in spawning stock appears to be the main factor explaining the decline in Abrolhos Is. settlement during the last 9 years (Fig. 4c).

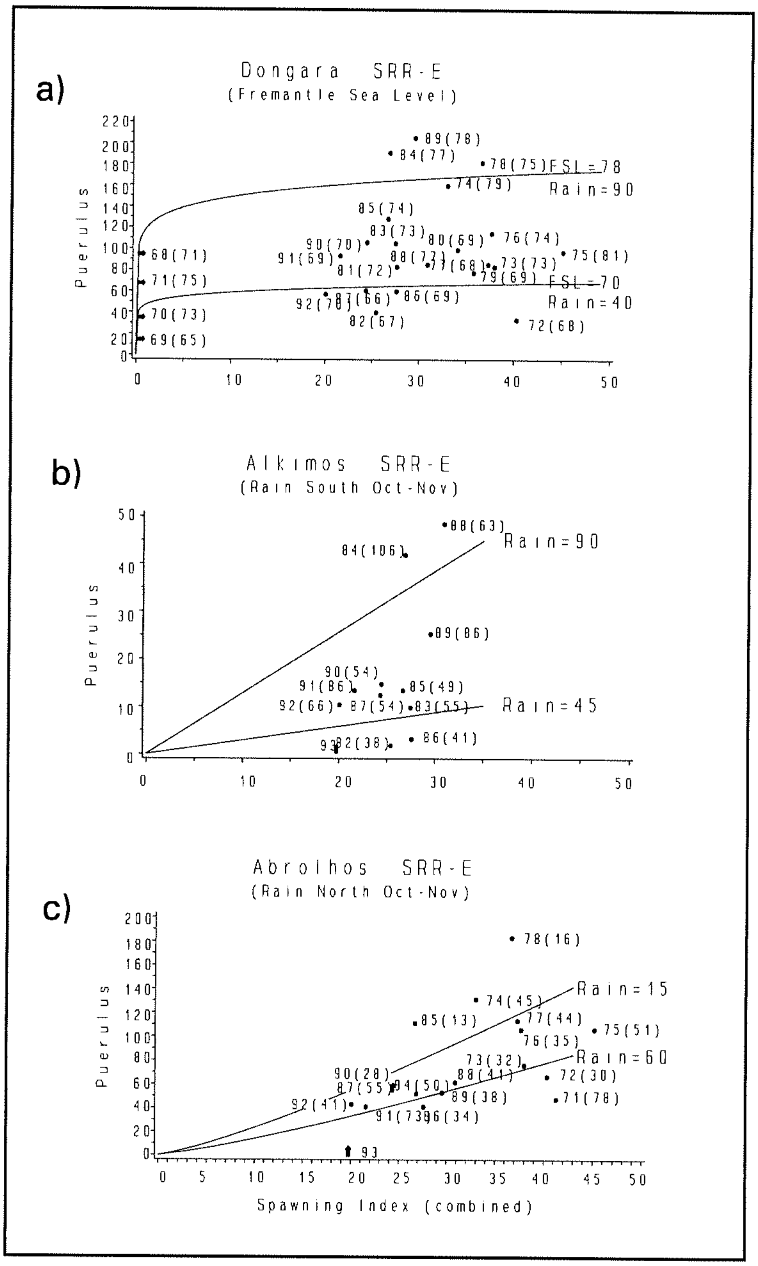

Figure 4. The stock-recruitment relationship with environmental effects incorporated for a) Dongara, b) Alkimos and c) Abrolhos Is. of the western rock lobster fishery. The year of puerulus settlement is shown with the environmental effect, sea level or rainfall, in brackets. The vertical arrows indicate the spawning index giving rise to the 1993 settlement and the horizontal arrows indicate years of puerulus settlement when no spawning indices are available (reproduced from Caputi *et al.* 1995b Crustaceana).

If the decline in recruitment (puerulus settlement) at the Abrolhos Is. is due to spawning stock reductions, then spawning stocks from other parts of the fishery, e.g., the coastal breeding stock, must provide an important contribution to Abrolhos settlement since the Abrolhos spawning stock has shown little decline over the last 20 years. For the coastal fishery, there has been a significant reduction in egg production because of the increase in fishing effort on rock lobsters that have to survive 1-2 years of fishing before reaching maturity (>90 mm carapace length). There has also been a large increase in catch in the region north of the Abrolhos Is., called Big Bank since 1986/87 (Chubb *et al.* 1994) from 50 t to over 300 t in the last two seasons. The impact of this change on the breeding stock in this area has not been taken into account in the spawning index used and is currently being assessed.

The question of whether larvae, hatched from all areas, contribute equally to the settlement at each location needs to be further explored. It is highly unlikely that only local spawning stocks contribute to the puerulus settlement in a given area because of the long oceanic larval life. The use of a combined spawning stock (determined as the geometric mean of the spawning index of the Abrolhos and north and south coastal regions) to assess the impact of the spawning stock on the puerulus settlement assumes that larvae hatched along the whole coast of the fishery contribute, on average, equally to the settlement in all areas. Work on larval studies and computer modelling of water currents affecting larval movement, growth and survival may be useful to test these assumptions. This work may provide information on the weighting to be given to the three regions in determining the combined spawning index.

The assessment of the SRR is not only of scientific importance but is also fundamental to proper management. For a SRR as described for Dongara, management would be concerned about the low level of breeding stock and the consequences of a further decline below that which has provided a reasonable level of settlement to date. Management response to this scenario would most likely be to maintain the breeding stock at levels which have historically provided good settlement. However, when the breeding stock level may be affecting the puerulus settlement, as in the Abrolhos, then there is a need to increase the level of breeding stock. The current level of spawning stock has been estimated to be about 15-20% of the spawning stock in the 1940s when the fishery was developing (Brown *et al.*, in press). This level of reduction has been described as the level where recruit overfishing may be observed (Beddington and Cook 1983). Current management is aimed at increasing the breeding stock to the level it was in the early 1980s at about 25% of the original spawning stock.

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Questions and discussion following by Dr. Caputi's presentation.

Hilborn: What's the evidence that puerulus is a reasonable measure of recruitment, particularly since there's so much life history from the puerulus to recruitment to the fishery?

Caputi: There is a reasonable relationship between puerulus and the catch three or four years later. The correlation between puerulus and catch is of the order of 0.8 or 0.9.

Hilborn: With the density dependent relationship in there?

Caputi: There is a level of density dependence. For the Abrolhos where the density of the juveniles is quite high, halving the number of puerulus results in a drop in catch of approximately 10%. For the south coastal fishery halving the number of puerulus results in a drop of approximately 20%. Thus, the level of density dependence seems to fit in terms of the relative abundance of the lobsters in those areas. This catch relationship has been used for predicting catches for well over 10 years and it seems to fit reasonably well.

Hilborn: In terms of the management, does that mean that any benefit that you get by increasing the spawning stock will actually be quite small?

Caputi: In terms of impact on the catch, yes. However, given that we are now in historically low spawning stock levels, we don't want that trend of lower spawning stock to continue and that's the concern. With increasing fishing power over time (e.g., fishers are now using GPS quite extensively) the spawning stock is going to continue to decline. Thus, whilst there is an immediate concern at the Abrolhos about the puerulus settlement, there are also concerns that they will be translated into the coastal fishery as well, if left unchecked.

Somers: In one of the inshore areas and also the Abrolhos, you spoke of an adjustment factor of fishing effort of 1-2% a year and that accounted directly for your decline in your spawning index. If you'd chosen 3% it would have been a 3% decline and that, in itself, is a worry. The decline you are measuring is almost an artefact of the adjustment factor.

Caputi: In the south coastal fishery the correction factor is of the order of 2% per year and the average rate of decline is about 2.5% per year. For the north coastal fishery with the same correction factor, a 6% decline in breeding stock per year occurs. Therefore, even if we do nothing, we've still got a decline of at least 4% a year. I accept your point and we've done some fishing power studies to determine the impact of GPS and colour echo sounders. Whilst they don't produce those figures explicitly, we do know that there is an impact from using them. The exact value of the correction factor I don't know precisely, but we do know there is a given impact. I put it to you we'd be more concerned if we didn't put in a correction factor at all and were optimistic, than if we do put in a correction factor and were too pessimistic. It is better to use a correction factor which is too high than pretend that the actual catch rates themselves are good indices of abundance, even though those catch rates are artificially high with the advent of GPS and colour echo sounder. I am aware of the concerns you've raised and we don't want to be putting in declines that aren't there. It would even be a bigger mistake not to put in anything at all.

Somers: The strategy would be to look for another measure as well.

Caputi:. Chris Chubb will be talking about that tomorrow.

Glaister: How do you calculate the fishing power?

Caputi: We've looked at boats with and without GPS. Catch rates from the two groups have been compared while fishing in the same block and same month. We've looked at three or four years data. There's two parts of the fishery: a migratory part and a sedentary part where the animals don't move. In deepwater, in the sedentary part of the fishery, there is a consistent difference in the catch rates of boats with, and without GPS and colour echo sounders. There is an effect there, but quantifying it is difficult.

Warburton: Presumably the difference between the Abrolhos results and coastal results has to do with the way the puerulus is swimming out of the Leeuwin Current. Do you have any fine scale hydrographic data that might explain movements of water and therefore larvae in the vicinity of the Abrolhos?

Caputi: Water movements are likely to influence the larval phase and therefore need to be looked at closely. We need to determine which spawning areas may be responsible for which recruitment areas. Very little is known about that. There was some CSIRO work in the 1970s on that, but it needs to be augmented.

Koslow: It concerned me that you have a huge coast line there and yet you have only a few collectors in discrete locations. How variable is that data and how much coherence is there along the coastline?

Caputi: There is general agreement in the level of settlement in most years in the coastal collectors. We average approximately 1 in 10 years where the settlement in one area doesn't seem to be reflected in some of the other areas. In general, 9 out of 10 years show agreement. Most of those coastal locations are influenced by some quite wide oceanographic phenomenon like the Leeuwin Current. Thus, when the Leeuwin Current is above average strength the settlement along the coast is generally above average. During periods of the recent El Nino, the general settlement along the coast is below average. Therefore, there is general coherence but in 1 out of 10 years there may be good settlement at Dongara and poor settlement at some of the other locations further south or vice-versa. The Abrolhos appears to behave differently at present.

Rothlisberg: It gets back to this issue about the larval phase, the puerulus stage and the fact that you sub-divided that coast into three regions. You said at one point that the Abrolhos was an important spawning stock, yet you have absolutely no appreciation of the puerulus that settle. How many of those come from Abrolhos spawners as opposed to north and south coast spawners? Could some of these divisions or subdivisions of your coastline have been very artificial?

Caputi: They are there because of management reasons. They have been combined into a general spawning index. I agree it is a question that requires attention. Using the Abrolhos situation (and I'll talk about this a little bit on Friday) you could hypothesise that all the settlement at the Abrolhos is coming from Abrolhos spawning stock. Given the long larval life that's highly unlikely. The second hypothesis is based upon a broad assumption, that virtually all the spawning stock on the whole coast is contributing to the recruitment on the whole coast and everything is mixing. That is highly unlikely as well. The truth is somewhere in the middle. For example, a more likely hypotheses is that the spawning stock in the northern region is more important for the settlement of the Abrolhos Islands than the spawning in the southern region. That is the next phase of progressing in this direction.

Rothlisberg: With regard to the group of collectors, for years the Dongara collector has done virtually all your predicting for you and the coherence between its activities and the whole fishery's seems to be fairly cohesive, is it not?

Caputi: Yes, in terms of the settlement it is cohesive because the environment is the major factor in explaining the settlement. Thus, in terms of the coastal settlement it is unlikely that the level of spawning stock is the limiting factor. If it was driven by the spawning stock, and there were differences in the spawning stock decreases along the coast, we would see some differences. Given that it's an environmentally driven settlement at this stage along the coast, it's understandable why there should be some coherence. It's an area that does need to be looked at in more detail, and is the next phase of this study.

Loneragan: With regard to density dependence in the inshore nursery habitat, they have 2-3 years inshore. That's an area which is subject to increasing change along the coast, particularly in population centres. Is that an area that you're exploring and if you are, how are you doing it?

Caputi: I don't think there's been that much change in the inshore areas, particularly in the locations we've been looking at (Dongara, Abrolhos, and Alkimos). There hasn't been that much change in terms of coastal development affecting recruitment. Density dependence is occurring and it differs between areas.

Rothlisberg: You said you used a rainfall proxy for your wind data or your wind strength. Could you elaborate on that?

Caputi: Looking at wind data directly, I looked at the various meteorological stations along the coast. They only had data at 3pm and 9am in some of those locations. They weren't providing good averages. Usually the winter storms which approach the coast are associated with rainfall, so in years when winter storms are quite strong they're usually associated with above average rainfall. Thus, there's a good relationship between the strength of those fronts crossing the coast and the level of rainfall occurring over the same period. Wind data is the more direct variable to use but the data was insufficient. Allen Pearce was also concerned that the wind data obtained along the coast may have been biased by the coast itself, and that it didn't represent what was happening offshore.

Rothlisberg: Initially, it was hypothesised that settlement was negatively correlated with the Leeuwin Current. Now we find it's positively correlated. Have there been any later developments about what the mechanisms might be? Why does a stronger current encourage settlement?

Caputi: There's no definite mechanism that's been put forward that's been generally accepted. When the influence of the Leeuwin Current was first found in the 1970s the hypothesis was that the stronger the current the harder it would be for puerulus to swim across it and settle on the coast. However, the correlation that was developed in the early 1980s by Pearce and Phillips has stood the test of time over the last 10 years. There is general agreement that the stronger the Leeuwin Current the better the settlement is. One thought on the mechanism that's been put forward in the Ph.D. project done by B. Morinavich is that the warmer water associated with the Leeuwin Current results in higher survival and faster growth of the larval stages, thus, reducing mortality. Also, when settlement is good, the peak in settlement occurs a month or two earlier. When the Leeuwin Current is weak, settlement over the year is weak, and peaks about November. When the settlement is very good the peak occurs in September, indicating that the growth theory may be correct, but there's no definitive statement on it.

Rothlisberg: Is there no measurable effect of enhanced onshore transport of water in that current system?

Caputi: That's another hypothesis that was put up in Pearce and Phillips' paper. They suggested that when the Leeuwin Current was stronger there are eddies formed. The eddies are stronger under those circumstances and those eddies form a retention mechanism for larvae. That's the water transport mechanism that could be operating. Neither of those two hypothesis have been proven.

Hilborn: If you take the SR data for the coastal regions, it shows only an environmental effect, but not a spawning stock effect. That suggests that there is a very strong density dependent mechanism operating on the larval stage. That's not an uncommon result but it is interesting to suggest that the larvae can be facing an environmental bottleneck comparable to habitat limitation. What could be providing such a strong regulatory mechanism for the larvae?

Caputi: Good question - no answer.

Rothlisberg: Why do you say density dependent?

Hilborn: What is implied is that the spawning stock may increase two-three fold but on average the same number of animals recruit back into the fished population. In effect, when few eggs are shed (ie., the spawning stock is small) on average the same number of puerulus survive as when many eggs are shed. There's a very strong density dependent mechanism and all the environment is doing is pushing it up and down.

Caputi: Is it possible that the environment is causing such variation in the level of recruitment that you can't detect the impact of that decline in spawning stock?

Hilborn: The most reasonable null hypothesis is that all the survival is more or less random, depending on environments. What you would expect to see is a straight line - the bigger spawning stocks the more recruitment, with a lot of scatter. The data you showed is *not* that. It's not possible that there's a straight line going through the data you presented. It goes through the origin. As long as the data are credible it's saying that there's a very strong density dependent mechanism out there. I've posed this question to some crab biologists who work in my department and they just say it couldn't be. They say that recruitment is constant because it's determined by the environment but there's no density dependence. They haven't got their arithmetic right. It seems to be true but nobody seems to have a mechanism for it.

Staples: Could the puerulus collectors have a carrying capacity?

Hilborn: Including the "natural" habitat collectors as well? The recruitment to the fishery itself is reasonably constant too. Therefore, not only are the collectors saturated, but the real habitat is too.

Penn: The other common proposition is food limitation. It is a particularly barren stretch of coast.

Caputi: Some information on the larval stages suggests that there are concentrations of stage-one larvae occurring just offshore from the Abrolhos and that they aren't equally spread all through that area. Thus, there could be pockets of high abundance of those stage-one larvae.

Hilborn: So competition could be taking place?

Caputi: Yes, there could be some competition effect. There's only work in the 1970's and that hasn't been followed up in the last 10-20 years.

Penn: Nobody's going to put in the money for that type of work because it costs so much.

Hilborn: What's the density of the puerulus larvae if you take the number of puerulus settling over the whole coast, then go back out to the area they're occupying?

Caputi: You could do that working back from the catch to the puerulus.

Rothlisberg: It's very low - 1 per 10's of 1000's of cubic metres.

Caputi: The late stage larval density is very low. The surveys of the puerulus indicate usually less than 1 or 2 per tow. Most times it's zero for puerulus.

Rothlisberg: The puerulus are more pneustonic (surface dwellers), are they not? They're up on top not spread out.

Penn: Only at certain times. The only big catches occur during heavy turbulence, normally none are caught.

Caputi: There's been two occasions when they caught approximately 20 per tow and these were associated with storm events. Usually it's been the last tow before they've headed back to shore. Most samples catch only 0-1 per tow.

Rothlisberg: I recall that of all the catches from the stratified sampling, phyllosoma were rarely moving up and down and through the water column. Puerulus are collected in the pneuston phase and not at depth.

Caputi: I thought it was the other way round - that puerulus were caught down below and in fact the few times they have caught large numbers under these storm events it was near the surface.

Trends in monthly Recruitment/Spawning Stock ratio (R/SSr): the Brown Shrimp *Penaeus aztecus* from the North West Gulf of Mexico

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Abstract

This study examines patterns and time trajectories of monthly Recruitment/Spawning Stock ratios (R/SSr) in a shrimp fishery. The case study presented is the offshore brown shrimp, *Penaeus aztecus* fishery from the North West coast of the Gulf of Mexico. Nine years of monthly catch-at-age data constitute the fishery data base. Rainfall, temperature and fishing effort constitute the environmental variables. An age-structured abundance (CPUE) matrix was constructed, rows being the months/year sequence, and columns representing age as the independent variable. Principal component analysis was applied to the data. The first two components each explained almost 40% of the variance. The first component was mainly explained by adults, while the second component by recruits. Decomposition of the eigenvalues of these two components allowed indices of adults and recruits to be obtained, which can be used to represent stock abundance.

Monthly indices were drawn in a graph of R vs. SS, using an average delay of three months, each point representing a R/SS ratio. Some clear patterns of the R/SSr were observed. A Base Population Level (BPL) was identified, and defined as the minimum average recruitment level required for population maintenance (corresponding to the average abundance of adults). From this BPL recruitment will increase, while adult stock could increase or decrease, depending on the current level of fishing mortality. If the BPL is not exceeded, the R/SSr will always converge to the BPL after each annual cycle. The general trajectory of the R/SSr is defined by the mortality rate and can be described as a "V shaped figure of eight" when two peaks of recruitment are present within the year. The crossing point of the V-shape corresponds to the BPL. The form defined by the trajectories may be flattened or rounded, depending on the seasonality of the recruitment, and may vary between years depending on environmental fluctuations. Analogies between the trajectories of the R/SS ratios and Ricker's model are put forward and the results are discussed in relation to sequential fisheries and environmental stress affecting nursery areas.

Introduction

Stock - Recruitment Relationships (SRRs) are not only important for estimating catches, potential yields and fishing strategies, but they also contribute towards the quality of management, especially for controlling access to the fishery and avoiding potential over-exploitation. Shrimp fishery SRRs have been a complex subject in fisheries science. The main reason for this is that they assume most of the variation in recruitment is explained by the spawning stock. However, in shrimp populations recruitment success depends more on environmental fluctuations and quality of the nursery areas, than the size of the spawning stock.

Ricker's type model (Ricker 1954) has been used to describe SRRs. However, the variability in recruitment explained by the spawning biomass is low. This does not mean the relationship between spawning stock and recruitment does not exist, as a certain minimum spawning stock size must always exist for a population to be maintained. With this in mind, environmental variables (i.e. rainfall, river discharge) have been incorporated into a Ricker-type model in order to model SRRs. In most cases, recruitment fluctuations are explained mainly by environmental variables, and the contribution from the spawning stock, although important, remains hidden. This also means that the processes underlying SRRs are not satisfactorily understood and require further research attention. The problem has been discussed by García (1983).

Another important consideration is that the longevity of many penaeid shrimps averages about one year. This means that there is only one linkage between two successive cohorts through the SRRs. Spawners from a given cohort in any year will not contribute to the egg production in the following year.

This study examines trends and time trajectories in the monthly Recruitment/Spawning Stock ratios (R/SSr) in order to delineate some of the processes underlying the relationship between spawning stock and recruitment. The approach presented is not a SRR (sensu Ricker), but it has some similarities to a SRR. The brown shrimp (*Penaeus aztecus*) fishery from the North West Gulf of Mexico is used as the case study.

Methods and materials

The brown shrimp is one of the three penaeid prawns of economic importance in the Gulf of Mexico. It represents 95% of the catches of the Mexican vessels operating off the coasts of Tamaulipas and northern Veracruz on the North West Gulf of Mexico (Fig. 1). In recent years, annual yield has been close to 8,000 t (metric tonnes), and potential yield has been estimated around 10,000 t (Arreguín-Sánchez and Chávez 1985). Studies on the population dynamics and stock assessment have been undertaken (Chávez 1973, Castro 1982, Castro *et al.* 1986, Castro 1987, Castro and Arreguín-Sánchez 1991). The fishery data from one study in particular (Castro 1987), which provides monthly catch-at-age data, fishing effort (number of fishing trips per month) and fishing mortality (using VPA for the period of 1974 to 1982) is also used herein.

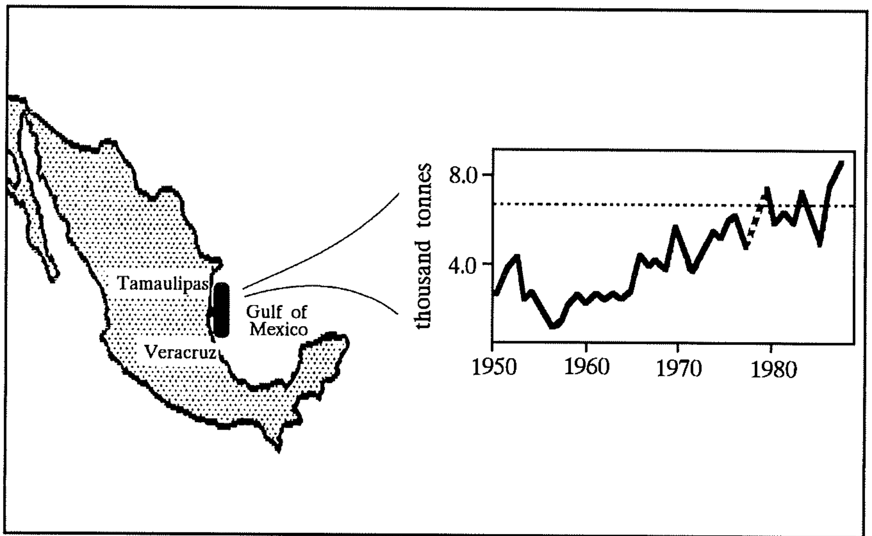

Figure 1. Fishing ground and historical tendency of annual yields for the brown shrimp, *Penaeus aztecus* fishery of the North West Gulf of Mexico.

The most important environmental variables influencing recruitment and survival of the early life history stages in coastal waters are air temperature (°C) and rainfall (mm) and have been considered in the analysis.

For the offshore fishery, age at recruitment ranged from two to six months. The most common age was three to four months. Age at recruitment varies according to season and also depends on the time juveniles migrate from inshore waters to the continental shelf. In the context of the age-structured data matrix, differences between juveniles and spawning stock were expected, but patterns between years were likely to be similar. Thus, a Principal Component Analysis (PCA) was applied to the age-structured time-series data. Age (in months) was treated an an independent variable. In order to avoid variability induced by differences in the amount of fishing each month, abundance of prawns in each age-class at time *t,* was expressed as the number of shrimps per fishing trip. The time sequence of the R/SSr was then analysed to identify specific patterns.

Results

The PCA was applied to the monthly age(CPUE)-structured matrix from Castro (1987). The first component explained 39.9% of the variance. The weighted components indicated that adults were the main contributors (age at first maturity = six months, Castro 1982). In contrast, the second component explained 38.3% of the variance and was determined by a contribution of recruits (aged three to six months). The third component explained 14.8% of the variance. The main contributors were prawns in the four to five month age-class (note opposite signs in equations below).

The lineal equations corresponding to the components above are as follows:
(C_{1-7} = age classes ranging from one to seven months)

$C_1 = -0.15a_6 + 0.97a_7$
$C_2 = -0.84a_3 + 0.32a_4 + 0.39a_5 + 0.18a_6$
$C_3 = 0.86a_4 - 0.47a_5$

Seven-month-old prawns were the most common age-class in adult stocks and were the main contributor to the first component C_1. Six-month-old prawns contribute partially to C_1, but with low magnitude and opposite sign (negative). This is because six-months is the age at first maturity and even when prawns in this age class were more abundant than those in the seven-month-old age class, they appeared in some months as recruits, as shown in the second component.

The main contribution to the second component C_2, is from recruits. The three-month-old prawns exhibit an opposite sign (negative) to the four-six month ages classes, and have a higher magnitude for their weighted contribution. This probably occurs because the three-month-old prawns are the most abundant of the recruits for the period analysed. Age classes of four and five months are the more frequent ages and appear as recruits in the offshore fishery (although they are not necessarily the most abundant age class for recruits). This is clearly shown by the third component C_3, through the weighted contribution and signs.

The PCA permitted separation of adult and recruitment components which together explain almost 80% of the total variance within the monthly age structure. This means that monthly indices could be obtained to analyse the population dynamics.

Indices for adults and recruits

Each principal component can be analysed by selection of the mean source of variance.

Let $$C_{a,t} = q_{a,t} E_t \bar{N}$$

where *C* is the catch in numbers

a,t are indices of age and time; both in months

q is the catchability coefficient

E is the fishing effort (numbers per trip)

$\bar{N}$ is the mean population size.

The stock index (adults or recruits) was computed as follows:

$$SI_t = \sum_{a=\tau}^{n} W_a \left[\frac{U_{a,t} - \overline{U}_a}{\sigma_a^2} \right]$$

where SI_t = stock index at time t
W_a = component a of the principal component vector (weighted component)
$\bar{U}_a$ = mean relative abundance (cpue) of age a, being $U_{a,t} = C_{a,t}/E_t = q_{a,t}\,\bar{N}$
$\acute{o}^2_a$ = variance of Ua
τ = index of recruitment or age at first maturity, depending on the component analysed.
a and *t* = same as above.

This stock index could be interpreted as the relative population (recruits or adult stocks) change weighted by both, the variance of the abundance of each age, and the relative weight of each age within each component.

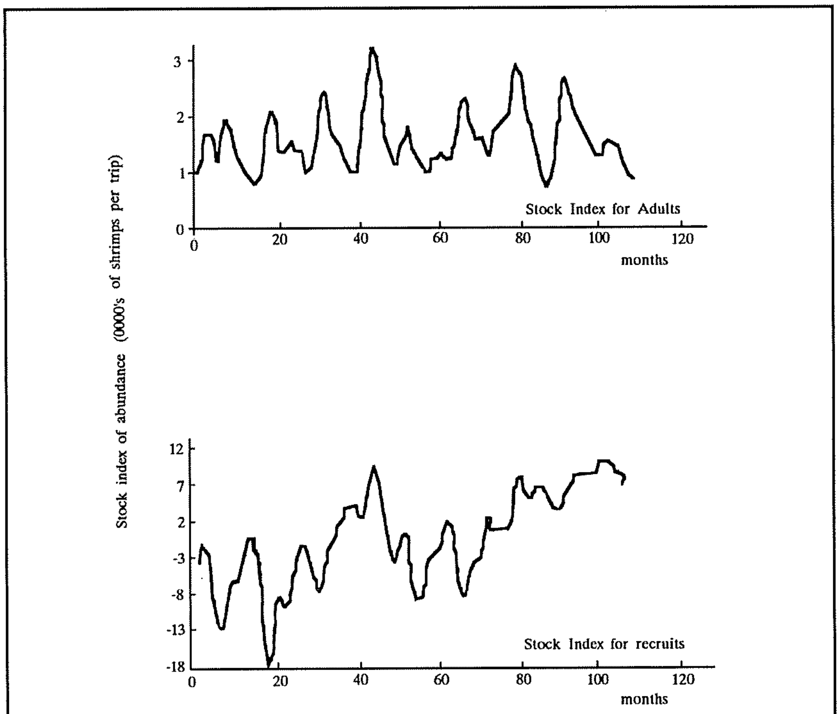

Figure 2. Times series of stock abundance indices for adults and recruits in the brown shrimp (*P. aztecus*) fishery, North West Gulf of Mexico, estimated from the PCA. In 1981 and 1982 adults tended to increase in abundance as a consequence of a 50% decrease in offshore fishing effort.

For the correct interpretation of these stock indices, it was assumed that all recruits or adults are incorporated in their respective stock at time t (Jack-knife selection type), and that the fishing effort is homogeneously distributed over all ages in time and space (i.e. there is no size-specific targeting).

The trends of recruits (SIR) and adults (SIA) stocks indices are shown in Fig. 2. Both indices show seasonal variations expressing changes in population abundance. Seasonal patterns correspond to the influence of recruitment pulses, however the amplitude of the fluctuations is higher for adults. The general trend for both adults and recruits is similar. An exception occurred in the period 1980 to 1982, when there was a reduction in fishing effort of around 50% (10% reduction when U.S.A. and Cuban fleets were retired from the Mexican EEZ in January 1980; and 40% reduction when changes in the Mexican fleet ownership were introduced 1980-1982) which resulted in fewer vessels. This decrease in fishing effort did not affect recruits, but rather only the survival of the offshore adults stocks. Survival of the earlier life history stages (including juveniles which emigrate from inshore waters to the continental shelf) depends on the quality of the coastal waters.

Correlation between stock and environmental variables

In order to determine those environmental variables likely to influence prawn abundance, a cross correlation analysis was developed. Results (Table 1) suggest fluctuations in population abundance are a response to recruitment pulses and the fishing effort following them. Good fishing seasons were also correlated with high levels of recruitment and heavy rainfall in the previous year. High rainfall results in high amounts of organic matter and nutrients being deposited in inshore waters which promotes high productivity for the next season. As a consequence, food availability and juvenile prawn survival rates are increased. Yáñez-Arancibia *et al.* (1985) reported correlations between population abundance and river discharge for several species.

Generally, high temperatures have been associated with reproductive activity. For *P. aztecus* high temperatures at certain times of the year coincide with peaks in gonad maturation. Six months after these peaks recruitment to the offshore fishery was observed. A similar correlation is found between adults and recruitment stock indices (Table 1).

Table 1. Delays estimated from the cross correlation analysis. N = Population size in numbers; R = Recruits; A = Adults; E = Fishing effort; P = Rainfall (mm); T = Temperature °C; MAR = Moving average of recruits; MAA = Moving average of adults. Time delays are given in months.

Variables	Delay Time	Interpretation
N - R	0	variation in population abundance follows recruitment pulses
A - R	-6	adults follow recruitment pulses (origin of co-linearity problems)
R - E	1	fishing effort follows recruitment (and population) pulses
R - P	-12	recruitment abundance is positively related with rainfall intensity from the previous year
R - T	-6	temperature is directly related with maturity of shrimps six months before recruitment to the offshore fishery
MAR - R	0	moving average of ages involved in recruitment have same tendency as the recruitment index from PCA
MAA - A	0	moving average of ages involved in recruitment have same tendency as the adult index from PCA
MAA - MAR	-3	average delay between trends of recruits and adults

Because several age-classes were present within both recruit and adult stocks, moving averages were obtained with the original age-abundance data and correlated with the respective indices obtained from the PCA. For the moving average of recruits (MAR), shrimps of three to five months of age were used. For adults (MAA), the moving average of shrimps that were six-months and older were used. Results (Table 1) suggest that indices from the PCA and moving averages for recruits and adults show the same non-delayed, tendencies. However, analysis of the moving averages for adults and recruits resulted in an average delay of three months. This period was taken as the average difference between age at recruitment and age at first maturity.

A population - environmental regression model

A canonical correlation was used to describe a model incorporating population and environmental variables. The canonical variable representing population was constituted by the SIA and SIR indices, while the environmental canonical variables were rainfall (P) and fishing effort (E). Results indicate changes in SIA are marked and directly correlated with changes in E, while change in SIR, although marked, is inversely correlated with rainfall (Table 2).

Table 2. Results of the canonical correlation test. The population was represented by indices of adults (SIA) and recruits (SIR). Environmental variables considered were rainfall and fishing effort.

	Variable 1 (Population)	Variable 2 (Environment)
Adults (SIA)	0.900721	0.493578
Recruits (SIR)	0.275045	-0.98958
Rainfall	0.155206	0.989122
Fishing Effort	0.995588	-0.106095
Eigenvalue	0.3518	0.0162
Can. Corr. Coefficient	0.5931	0.1274
Lambda	0.6377	0.9838
X^2	35.766	1.301
d.f.	4	1
sign. level	0.0000	0.254

Trends in Recruitment/Spawning Stock ratio (R/SSr)

Both indices (SIA and SIR) were determined separately for each year using an average delay of three months. Each point represents a particular value for the R/SSr. Each year exhibits a particular monthly trajectory which, despite interannual variation, has a "common origin". Fig. 3 illustrates the trajectories for all the years analysed. The only year with both right and left tendencies was 1974.

The general pattern describes an "eight" in form of "v". The trajectory begins at a "common origin", moves to the right or left, and then converges back to the origin after an annual cycle. This origin or crossing point corresponds to the Base Population Level (BPL), defined here as that population level representing the minimum average recruitment required for population maintenance. It corresponds to the average abundance of adults (Fig. 4). The form of each branch (flattened or rounded) depends of the seasonality of the recruitment pattern at each year. This means that in 1974 two peaks of recruitment were represented (Fig. 4A), while one peak of recruitment was observed for other years. In 1975 a well defined peak of recruitment occurred (flattened), while in 1980 recruitment was almost constant throughout the year (rounded).

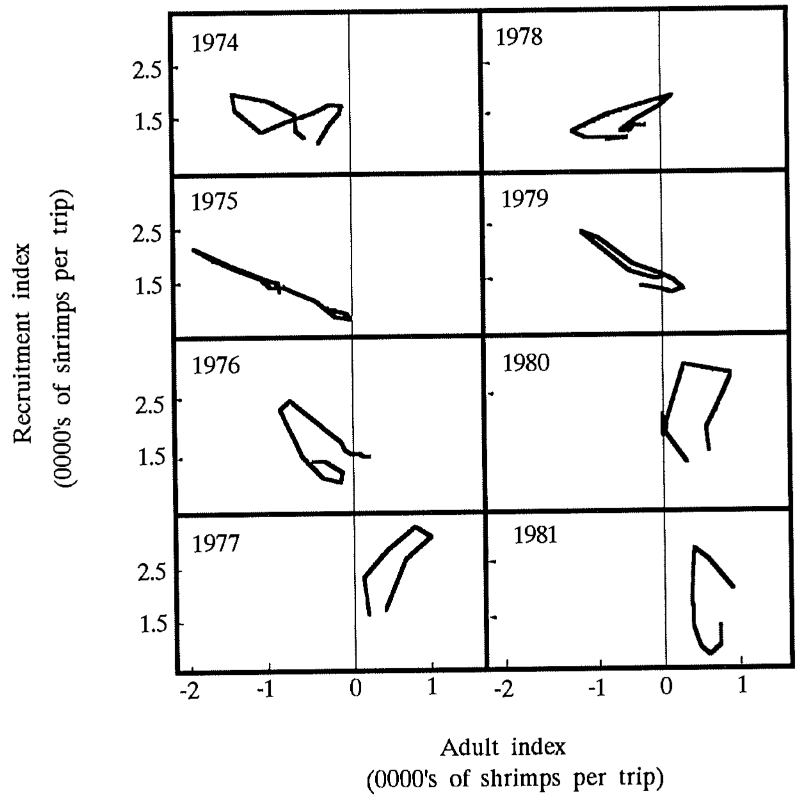

Figure 3. Observed annual patterns of the R/SSr for brown shrimp. Trajectories were drawn using an average delay of three months.

The positive slope of the right side indicates that recruitment increased as abundance of adults increased. This can be considered as typical for a shrimp fishery where population density effects are not severe. The left side initially suggested density-dependent type effects because of the inverse relationship between adults and recruits. However, this tendency is a consequence of high adult mortality.

Changes in the mortality rates affect the trajectories. Because natural mortality was assumed to be constant within each year (Castro 1987, Castro and Arreguín-Sánchez 1991), it's likely that fishing mortality has a significant influence on the trajectories. In general, low values of fishing mortality were associated with the right side trajectories and high fishing mortality with the left side. This means that the trajectories are directly associated with survival rates. Starting on the base population level, recruitment tends to increase, but the specific trajectory is defined by the amount of fishing mortality applied in the following month. A high fishing mortality will result in a left side trajectory and a low mortality rate will result in a right side trajectory. The trajectories are cyclical, independent of interannual variation and population abundance, and will always converge at the BPL (Fig. 4C).

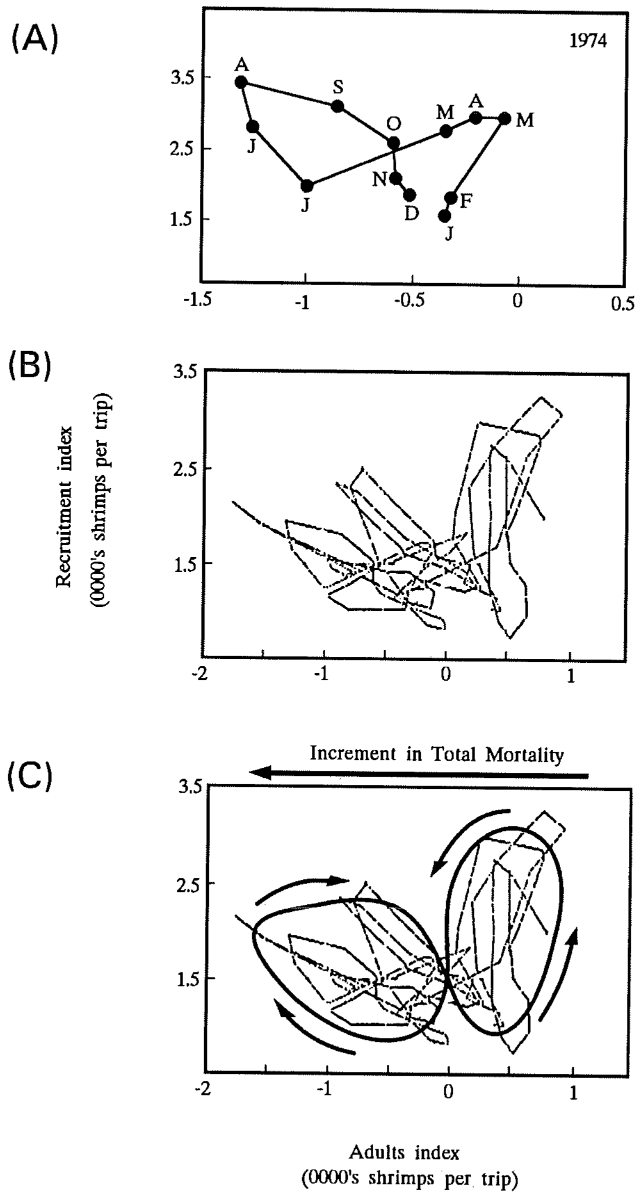

Figure 4. Monthly trajectories of the R/SSr of the brown shrimp *Penaeus aztecus* fishery in the North West Gulf of Mexico for 1974 (A), for all three years combined (B), and the generalised trajectory (C) showing the relationship with changes in total mortality. The crossing point in the generalised trajectory corresponds to the base Population Level (see text).

Analogies with Ricker's Stock Recruitment Relationship model

The BPL defined above is analogous to the replacement level in Ricker's model. When this level is exceeded, the population is unable to recover to its original size. In Ricker's model, annual data representing whole cohorts are needed to identify the stock recruitment relationship. Under this scheme, a replacement level could be found which is dependent on the relative proportion of adults and recruits each year, and any density-dependent effects. The replacement level represents the minimum recruitment level required for population maintenance. When this level is exceeded, the population will decrease because recruits will enter the population at a rate which is lower than the total mortality rate.

When fishing mortality causes the mortality of recruits to be higher than the level required for convergence to the BPL, the trajectory will change and turn to a new, but lower BPL (Fig. 5).

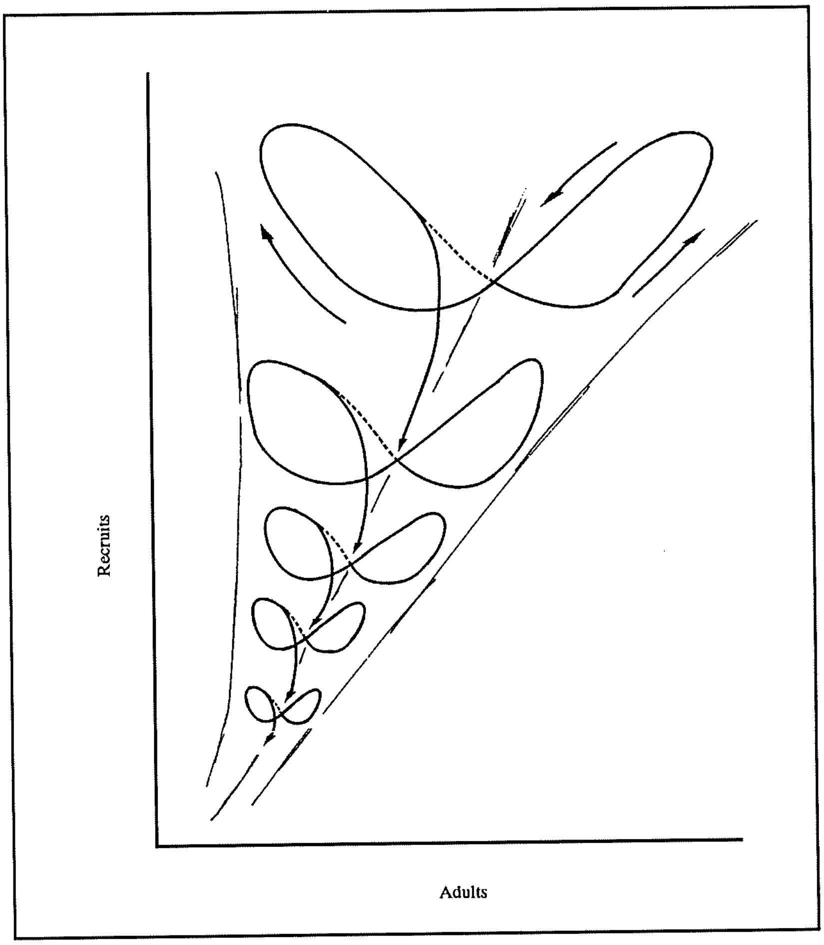

Figure 5. Hypothetical sequence of the R/SSr showing population decrease when Base Population Level is surpassed. Reduction in the width of the trajectories represents decreasing population size. The collapse of the fishery occurs when the population changes from one stage to another.

The maximum recruitment (distal point from the BPL along the trajectory) and abundance of adults will tend to decrease. According to the trajectories described by the monthly sequence of R/SSr, if this tendency is maintained the population will gradually decrease. The trajectory of the diminishing base population level is analogous to the collapse of a fishery described by the Ricker's model. The overfishing concept is represented when the population is not able to converge to the BPL. It is analogous to the concept suggested by Sissenwine and Shepherd (1987) and Sissenwine *et al.* (1988) who proposed an alternative definition of recruitment overfishing when SRRs are indeterminate. In the approach presented here, both recruitment and growth overfishing can be hypothesised.

Sequential fisheries

The main problem in sequential fisheries is that exploitation in inshore waters must be controlled in order to permit sufficient escapement of juveniles and recruitment to the offshore fishery. After a few months, these recruits grow to adults and contribute to egg production. Mortality of adults must also be controlled to permit survival of a sufficient number of spawners which will ensure the population recovers.

Following trajectories of the R/SSr, the sequence of exploitation can also be explained (Fig. 6). If population is intensively exploited in inshore waters, the number of recruits for the offshore fisheries will decrease and the trajectories will be negative. The population could be maintained if, despite the high mortality, the trajectory converges to the BPL. Similar trajectories could occur when environmental stress causes high mortality in the early stages life history stages in nursery areas.

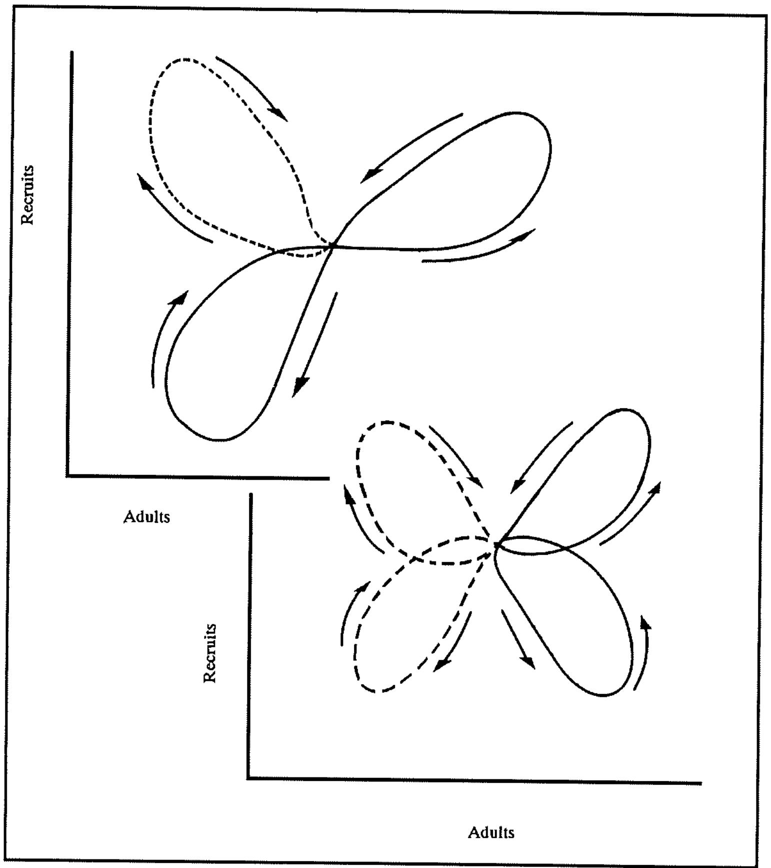

Figure 6. Hypothesised trajectories of the R/SSr for sequential fisheries. Abundance of adults decreases from the Base Population Level (above), Adult abundance increases (below). Dashed line indicates alternative trajectories.

Applying the new approach to other shrimp populations

Even when different species of shrimps share similar population characteristics, there are important differences in the way they are exploited and how they respond to fishing. The analysis of the R/SS ratios was also developed on three years of monthly age-structured data of the offshore pink shrimp (*P. duorarum*) fishery from the Campeche Bank, southern Gulf of Mexico. However, PCA could not separate the recruit and adult components. This was because the age at recruitment for *P. duorarum* coincides with the age at first maturity and the offshore population behaves as one stock. Nevertheless, using shrimps of three to months of age as recruits, and five-month-old and over as adults, a plot of recruits versus adults stocks can be observed (Fig. 7). These trajectories describe patterns which are very similar to those observed for the brown shrimp.

Conclusions

Although a considerable amount of research is still required to test the hypothesis suggested herein, some general conclusions can be made.

PCA permitted identification of indices of abundance for recruits and adults. For this, a clear differentiation of recruitment and age at first maturity is required. Trajectories described by the R/SS ratios, on a monthly basis, suggested specific seasonal patterns where a Base Population Level (BPL) can be identified. The trajectories are influenced by mortality rates, and particularly fishing mortality.

Whatever combination of R/SSr and mortality used, the trajectories always converge towards the BPL, which is analogous to the replacement level in Ricker's model. Auto-correlation among stock indices (SIR and SIA) could be argued, however the trajectories are only describing the time sequence of the R/SSr, not a cause-effect relationship as in the SRR model. Moreover, the relative contribution to adults from a given recruitment age three months earlier constitutes the structure of the recruitment (seasonal) patterns. This effect is represented by the form of the trajectories when the R/SS ratios are analysed. The trajectories are rounded when constant recruitment occurs throughout the year, or flattened when a well defined peak of recruitment occurs. Situations where the BPL is exceeded were hypothesised to be analogous to the trajectory followed by collapsed populations. The dynamics of sequential fisheries was also suggested.

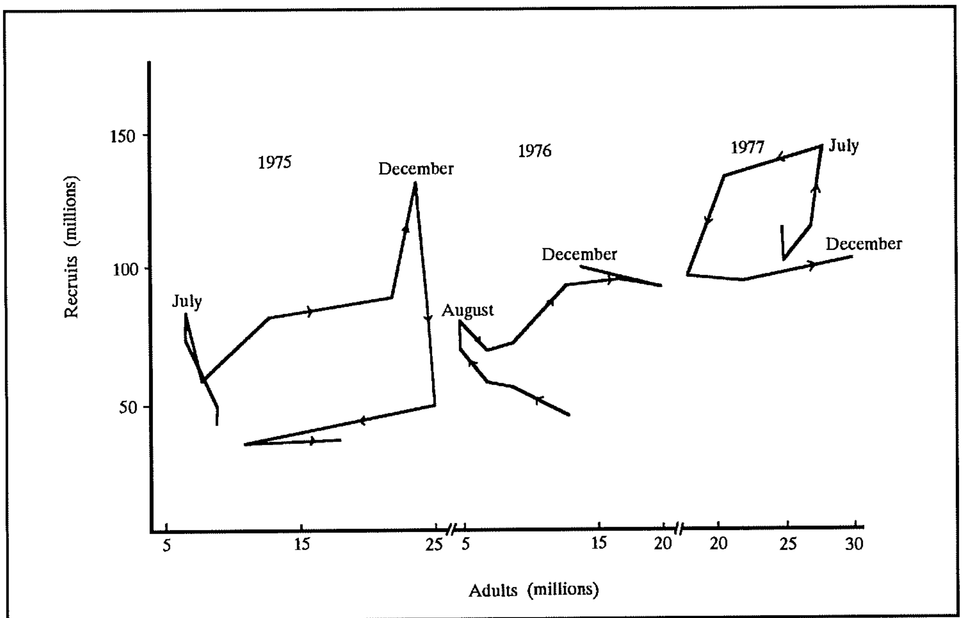

Figure 7. Trajectories of the monthly R/SSr for the pink shrimp (*P. duorarum*) from the Campeche Bank, Mexico.

García (1983) proposed the use of a three-dimensional SRR model for shrimps. These models are usually described as a Ricker type model with one or more environmental variables included. Trajectories described by monthly R/SSr also suggest that a three dimensional model could be defined, with mortality as the third variable.

Experience with both brown (*P. aztecus*) and pink (*P. duorarum*) shrimp populations suggests the approach described here could be applied to other shrimp populations. The main constraint is likely to be due to the fact that recruitment and age at first maturity must be clearly defined and different from one another.

Acknowledgments

The author recognises the importance of the sampling work developed by colleagues from the Centro Regional de Investigaciones Pesqueras de Tampico, INP. Thanks to my colleagues R.G. Castro, M. Medellín, R. Solana and E. Valero, for their help during early stages of data analysis. Thanks also to staff of the fisheries groups at CINVESTAV, RRAG and EPOMEX, where I discussed advances of this study. Thanks to CONACyT and to the Government of the State of Campeche who partially supported this investigation.

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Questions and discussion following Dr. Arreguín-Sánchez's presentation.

Die: Could you clarify how you defined recruits?

Arreguín-Sánchez: The most abundant age in the age structure for the fishery.

Die: Does it change from month to month?

Arreguín-Sánchez: Yes, but it isn't a consequence of selection, it is a consequence of relative difference in the abundance of the different ages each month and depends on the immigration from estuaries to offshore grounds.

An Assessment of the Prawn Fisheries of Shark Bay Western Australia

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Abstract

Assessment of recruitment and spawning stock levels in the multispecies prawn fishery of Shark Bay in the 1990s has been complicated by both environmental and management factors. In 1990, the fleet size was reduced from 35 vessels to 27 through industry funded restructuring. Improvement in average catch per vessel resulting from this "buy back" was less than expected, raising concern among fishers that recruitment of the dominant species, the western king prawn (*Penaeus latisulcatus*), might have declined. However, the effort reduction was confounded with management strategies to optimise prawn size that delayed the opening of the fishing season, and with seasonal closure of fishing grounds to reduce the proportion of small prawns within the catch. As a consequence of effort reduction and increased size at first capture, there is a possibility that the resource may currently be under-utilised. A further factor influencing the catches of prawns has been the environmental change within the Shark Bay region which resulted, in 1991 and 1992, in a 3 to 5 fold increase in the catches of scallops (*Amusium balloti*) over the previous maximum catches.

As a consequence of these changes within the fishery, assumptions required by the algorithm previously used to estimate recruitment indices for the prawn stocks are no longer reasonable. An alternative approach to the determination of the parameters of the stock recruitment relationship and the current level of recruitment is required, and accordingly a new model of the fishery is proposed. Using this model, the stock recruitment relationship for each species has been determined, and the sensitivity of the relationship to the model assumptions has been assessed. As with previous assessments, the historical data base shows that the relationship for brown tiger prawns (*P. esculentus*) continues to show a marked decline as the stock was depleted, however there is little indication of a fall in recruitment for the western king prawn associated with the increased level of exploitation over the course of the fishery.

Questions and discussion following Mr. Hall's presentation.

Hilborn: You have two competing hypotheses; one is where you have a very large stock that has not been fished very much and is intrinsically not very productive. The other is that the stock is very productive. These make very different predictions about what the fishing mortality rate (F) is. The first hypothesis indicates very low fishing mortality, the second indicates very high fishing mortality, such is the case with the rock lobster population in New Zealand. If fishing mortality is very high could you detect it in the in-season depletion pattern for these stocks?

Hall: Yes, that is what I have put forward. Depletion does occur throughout the year. In the early part of the season the prawns are available and exploited, and by the end of the year they are depleted. We made the assumption that catchability in two adjacent months was the same, or was similar. I now intend to treat the catchability in each month separately and refit the model. Estimates of partial recruitment to the exploited part of the population could then be obtained. I will do this before imposing the constraint, that the catchability for each two months is constant.

Somers: You showed with the king prawns that the model was very sensitive to natural mortality.

The picture changes completely with different estimates of natural mortality.

Hall: The tiger prawn example was given to give the impression that the area of uncertainty was not great. However, I agree that it does require the same amount of evaluation for both natural mortality (M) and catchability. Those two parameters have not yet been examined and they are part of the uncertainty. In terms of competing hypotheses, you have to assign some sort of probability to those competing hypotheses and bring them into the Bayesian analysis.

Somers: Was it unstable?

Hall: It was certainly unstable with the kings but I haven't examined it yet for the tigers but I suspect it would be.

Somers: We found that to be the case and you could have two completely different scenarios simulated equally well.

Hall: You still then have to recognise that you haven't got very good measures of the natural mortality rate. You're changing the problem to something which might in fact be attacked by some other approaches.

Caputi: Hilborn talked about the use of depletion over the whole fishery in terms of narrowing in on the catchability. What research experiments have been done?

Hall: Depletion studies were undertaken on small areas and they provide some measure of the trawl efficiency. You can use the swept-area type approaches. The distribution of the prawns on the grounds is one of the problems. This is why I chose to lump all the data into a single area. Although you measure the depletion within an area, there may be difficulties in extrapolating it to the broader part of the fishery. It does provide some insight though.

Loneragan: With regard to your assumption about the single recruitment at one time of the year, what effect do you think that has on the model output?

Hall: The fact that it's not continuous is not going to be a major problem. We know the numbers of prawns coming through to the fishery. There are very few available in January, numbers build up and by May most of those that will recruit have done so. The timing depends partly on lunar phase and varies from season to season. Variation in catchability from year to year is also a minor problem and likely to be due to seasonal differences in temperature. What is becoming apparent is that you're driving this by taking out the observed catches. You assume that this pool of animals, which was regarded as being present at the beginning of the year, is being depleted. It's an artefact of the model. They may not really be there but it makes no difference in terms of the model because at the end, you're trying to match up the catch rate within a particular month and you're probably not going to be having a major problem with that.

The real problems are the stock and recruitment indices. We choose arbitrary indices and assume they can account for all eggs and all recruits. In reality we're not too sure, as in Nick's case, whether the Abrolhos egg index is really the critical factor that is driving the whole stock-recruitment process for the whole of Western Rock Lobster fishery or whether it's one particular component. It's difficult to decide whether or not to amalgamate all these various indices of egg production through the various months or whether to simply take a single measure during one month. No matter where you make your selection of the recruitment or the stock, you still have the basic problem with an extended spawning period and an extended period of recruitment. You still have to simplify it some way. I prefer to make the simplification but realise that I've made the simplification, and so try to make it explicit by exploring a few other possibilities.

Trainor: What happened in 1981?

Hall: That was a disaster.

Penn: The fishery was very stable for many years and there were always complaints about the cost of the logbook system. We therefore decided in one year to move to putting monitors on engines and record engine hours and run a logbook every 3 years. That was the year (1981) in which the tiger prawns collapsed and the king prawn catch was higher than previously recorded. We rue the fact that we didn't have the logbook system running, but it was a cost cutting measure, in the days of cost cutting measures.

Hall: There was one positive aspect - we got total catch.

DISCUSSION SESSION - DAY 1

Following the day's presentations, participants were separated into groups to discuss three key questions based upon the day's topics and presentations:

(1) Are reference points based on recruitment levels useful for providing targets or limits to fishery operations?

(2) What evidence is there to suggest a relationship between life history type (i.e. behaviour, aggregating vs non-aggregating) and susceptibility to recruitment overfishing?

(3) Is there evidence of non-sustainability (recruitment decline) in crustacean fisheries?

Each group nominated a speaker and the following points were made.

Group 1. (Staples) One of the problems with target and limit reference points is that limits often become targets. If catch is limited to go no lower than 10% of the virgin biomass, the fleet treat this figure as a target. Reference points are a useful concept because they can be used to assess management. Reference points can be set by managers and in retrospect, they can be used as performance criteria to determine how well the fishery was managed and whether or not the objective was attained. Target reference points may be useful but limit reference points may not because they are very arbitrary limits (i.e., why 20% and why not 10%). Another criticism was that they don't include the use of risk analyses when in fact they should be based on risk analysis and not just something 'plucked out of the air'. Lastly, they are useful for comparative purposes. When you don't have any information it's quite useful to go to other fisheries and find out what happened at various levels of fishing.

In regard to Question 2, animals that are more catchable, and therefore more vulnerable, are going to be more susceptible to fishing. However, just because some species are more vulnerable and are going to be fished down doesn't necessarily mean they are going to be more susceptible to recruitment overfishing. For example, the banana prawn (white shrimp) aggregates and throughout its range it seems to be very sustainable. An exception occurs on the edge of its range (Exmouth Gulf). Catchability and recruitment overfishing are two different things. It also applies in reverse - just because it may be less vulnerable to fishing doesn't mean it isn't going to be overfished.

There also appears to be behavioural changes that occur in some aggregating species with fishing. It may be due to a genetic change occurring over the relatively short history of the fishery. Banana prawns, *P. merguiensis*, *P. semisulcatus* in Kuwait and *P. setiferus* don't school as they used to. The aggregating characteristics that used to be there, are no longer there and that maybe why the hypothesis may not apply. Fishing may have changed behaviour.

In regard to Question 3, most of the penaeid prawn catch comes from the tropical areas of the world and there is evidence to suggest that those tropical stocks are quite sustainable. However, there is increasing evidence that in some local circumstances where large industrial fleets exist, the prawn population can be significantly reduced. The evidence for non-sustainability comes from more temperate regions in developed countries with heavy, industrial trawl fisheries. This may be because we have studied them better in the more temperature regions and therefore know what's going on. The other reason is that the tropical regions are much more productive and that the fishing pressure there at present is sustainable.

Group 2. (Koslow) We addressed Question 2. We started with Jim Penn's observations that certain characteristics are associated with species that are more susceptible to overfishing. For example, some species have a higher catchability because of their behaviour. Questions of aggregation versus dispersion are quite important. If the aggregating characteristics of the species are learnt by fishers, then it will be more susceptible to being overfished than other species which are more dispersed. Also in regard to distribution, stocks at the edge of their range appear to be more susceptible to recruitment overfishing. This may be that they are more localised, also that they are more susceptible to changes in environmental variability. If the stock is fished down, it's going to be more susceptible to changes in the environment which can lead to collapse.

In a recent publication on fish, Mace and Sissenwine looked at 90 species and stocks. They generalised that despite all the variability in SR data, species with high fecundity, large body size and low mortality can be grouped. Those species, typified by a cod, would seem to be less susceptible to recruitment overfishing, although since their paper was published the cod off Canada have completely collapsed. Species such as herring are typical of species that are more susceptible to recruitment overfishing. The life history characteristics of the crustaceans were concluded by us not to vary much at all. There isn't the variability as there is in the fish groups. Thus, we didn't come up with any consensus that there was a relationship or not within the crustaceans between life history parameters and recruitment.

The exercise that Mace and Sissenwine went through is valuable, because in the past people have looked at the hopelessly variable stock recruitment data in fisheries and concluded that there are no patterns. When data from 100 stocks over a wide range of groups are brought together, patterns emerge even out of all the variability. It might be a worthwhile exercise for this group to bring it's data sets together to carry out a simple analysis like Mace and Sissenwine did and see what patterns do emerge.

Penn: With regard to SR modelling, you don't have the other options available in normal fishery modelling. You obtain the data by way of the fishery's collapse. Thus, you do have to look more broadly as Mace and Sissenwine did to get some indication of which species you want to pay special attention to. The ability to manipulate stocks and find out how it's going to work isn't available in stock-recruitment. The results are too catastrophic and researchers usually get fired in the process. There is a great deal of merit in trying to look more widely and use some of those generalisations in this particular area of fisheries science.

Group 3 (Somers). We addressed Question 3 and had difficulty quantifying evidence from the various fisheries. We tried to list the crustacean fisheries where there had been declines in recruitment and determine what the associated drop in spawning biomass was. We had a great deal of difficulty not only quantifying it but also in separating any recruitment declines in terms of whether it was induced by fishing or induced by environmental degradation. The examples we looked at were the banana prawn fishery in the northern prawn fishery, where the spawning biomass is actually down to 1% or less, of the virgin stock levels. Despite the evidence from Western Australian researchers, the fishery has been fairly resilient to that drop and there is no decline in recruitment which can't be explained for through rainfall models. A note of caution though, we are concerned that what we might be monitoring isn't the real spawning stock. The next fishery considered was the white shrimp (*P. setiferus*) fishery in Mexico where the spawning stock is down to about 5% of virgin stock levels and recruitment to about 10%. The third fishery was the brown tiger prawn (*P. esculentus*) fishery in the northern prawn fishery where recruitment has declined to about 50% and was associated with a 75% decline in spawning stock. It is difficult to measure and the effort is compounded with increased fishing power. With regard to the Kuwait fishery, the figures indicate a recruitment decline of about 80% and it is unknown what spawning stocks that's associated with. That is one where environmental degradation was brought up as a possible cause. A "Fishbyte" article in the last couple of years talked about a huge increase in recruitment in that same fishery that was associated with river discharge.

Penn: Run-off from the Euphrates and Tigress rivers flows directly into that area. The Saudi

Government banned all inshore fishing by the artisanal fleet. The stock bounced back, the schooling behaviour returned and the four W.A vessels which were bought by the Saudi company to fish industrially took an average 280 tonnes for a four month season. Thus, the stock did rebound when the fishing pressure on it was reduced. It was possibly due to growth overfishing and maybe a behavioural change. Subsequent to that, when the war broke out the stocks on the Iranian side recovered dramatically to the point where they were embarrassed by the supply of prawns. Thus, they did bounce back and there's evidence of the impact of fishing because they have a very large fleet of small trawlers operating close inshore which is confounding the effort data. When you take that away for whatever reasons, the stock recovers.

Somers: With regard to non-penaeid examples, possibly local stocks of spanner crabs, but no-one had any firm data. There was an Hawaiian spanner crab fishery that collapsed but again no precise figures.

With regard to the second question pertaining to life histories, susceptibility and overfishing, increased catchability means an increased ability to reduce spawning stocks. Whether that reflects in recruitment overfishing depends very much on your slope at the origin, so the two are quite distinct and that's where vulnerability versus resilience comes in. An example, is endeavour prawns. It is thought that their catchability, as Penn suggested, is in that lower category. It might be one-third that of tiger prawns. Evidence of that is from the tagging work of Buckworth and also from data on fish gut analysis, where the prawn species ratios in fish guts were very different from those in associated prawn trawls.

Conclusion of Day 1.

Day 2. Biological Considerations for Defining Spawning Stock and Recruitment Indices. (Session I chaired by Dr. Derek Staples)

Penaeid Prawn Recruitment Variability: Effect of the Environment

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Abstract

A long standing paradigm of penaeid prawn biology and management has been that recruitment is extremely variable, especially between years, and that this variability is mostly attributed to variability in the environment. As a consequence, there has been considerable research into the effects of environmental changes on prawn recruitment. More recent models of prawn dynamics, on the other hand, also include density-dependent effects. In these models, environmental effects have either been included by simply treating the effect as random variation around a stock-recruitment curve, or by adding the effect as an additional parameter in the relationship.

A wide range of correlations between environmental variables and recruitment have been documented. In reviewing these studies, we have grouped species into ecological groups and compared the effects of different environmental variables across these groups. The data are very incomplete but some generalisations are possible. For example, the paradigm of extreme variability in recruitment appears to be based on only a small number of case studies, mostly from the sub-tropical and temperate areas. The influence of the environment is greater in some ecological groupings than others. Much work is needed, especially in the tropics, before environmental variables can be widely used as predictors of prawn recruitment and hence used as a management tool.

Introduction

The scientific literature contains many accounts of how the environment affects variability in the recruitment of penaeid prawns. Several paradigms have emerged from these studies, including the contention that penaeid prawn abundances are characterised by high inter-annual variability which can be explained by variability in the environment. More recently, these paradigms have been challenged and stock recruitment relationships have been described for several populations of penaeids in which the effect of fishing on the parental biomass has been included as a major cause of the variability (Penn and Caputi 1986). These changes in the way recruitment variability has been viewed have resulted in three conceptual models being used to describe the variability in prawn recruitment. In the first (Fig. 1a), only the effect of the environment is considered and it is assumed that spawning stock has little influence on recruitment levels over most of the range of stock size (obviously recruitment is zero at zero spawning stock). In the second, a traditional spawning stock-recruitment relationship is applied with the environmental effect being treated as random variation about the mean recruitment level for any given spawning stock size (Fig. 1b). In the third (Fig. 1c), the effects of spawning stock size and the environment are combined into a spawning stock-recruitment-environment model. In this paper, we briefly review the life history classification of penaeids, the effect of the environment on different classes of prawns and the implications for management.

Life history classification of Penaeids

Dall *et al.* (1990) recognised four major life history patterns among penaeids. These range from the species which complete the whole of their life cycle in marine waters (Type 4 species, e.g. *Parapenaeus* spp.) to those which complete their life cycle in brackish water (Type 1 species, e.g. *Metapenaeus moyebi*). Type 2 or estuarine species spawn in marine waters but inhabit estuarine waters as juvenile prawns (e.g. *Penaeus merguiensis*), while Type 3 or inshore species undergo similar migrations but inhabit inshore coastal habitats as juveniles (e.g. *P. semisulcatus*).

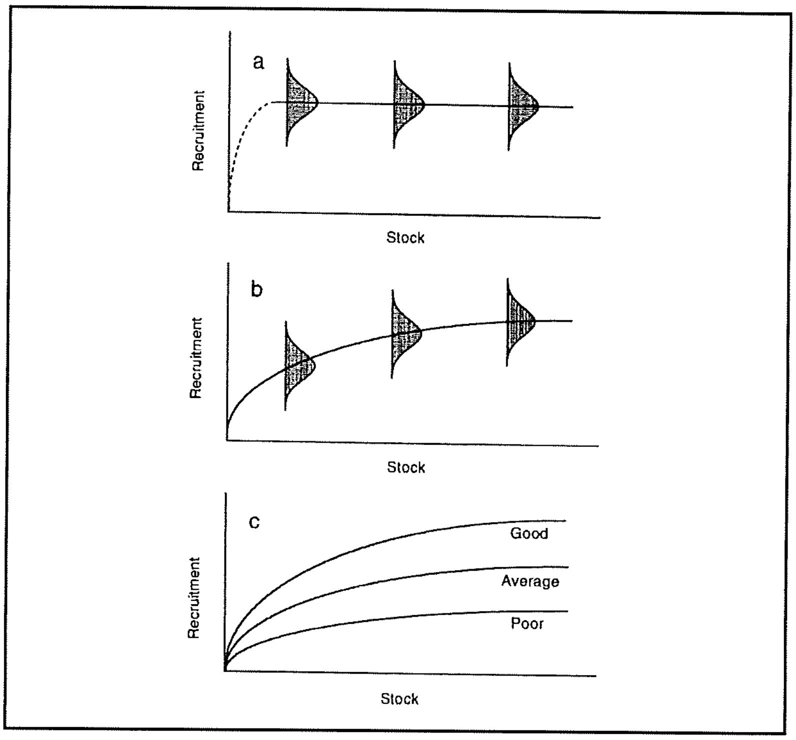

Figure 1. Theoretical stock-recruitment-environment models where; (a) only the effect of environment is considered; (b) environment is treated as random variation around a traditional stock-recruitment curve; (c) spawning stock size and environment are incorporated into the model. "Good", "Average" and "Poor" are levels of environmental variation.

Effects of the environment

In this review we have concentrated on the effects of the environment on estuarine (Type 2) and inshore (Type 3) species. A lack of data prevented a comparison of all four life history types. Intuitively, we would expect that non-estuarine species such as the Type 3 and 4 species, because they live in a more stable environment, would be less influenced by environmental factors. For the estuarine and inshore species, several authors have found a wide range of factors responsible for recruitment variability and that the response is also extremely variable even within the same species (Table 1).

For example, several authors have noted significant correlations between adult abundance and rainfall, salinity and river discharge of two estuarine species (*P. merguiensis* and *P. setiferus*) (Table 1). Within the same species, however, this effect can be positive in one location and negative in another. Thus, rainfall is positively correlated with *P. merguiensis* catch in the Southern Gulf of Carpentaria (Australia), not significantly correlated with catch in the northern Gulf of Carpentaria and negatively correlated with catch in the Gulf of Papua (Papua New Guinea) (Vance *et al.* 1985, Vance 1991). Similarly, *P. setiferus* catches are positively correlated with rainfall/discharge in some parts of the U.S.A. but are not correlated with rainfall in others (Zein-Eldin and Renaud 1986). Similar findings have been reported for correlations between *P. setiferus* catch and temperature. Temperature is positively correlated with catch in the northern extreme of the range of *P. setiferus* but not in the warmer tropical areas. For *P. merguiensis* and *P. setiferus*, adult catch is also positively related to the amount of nursery area available. This correlation is due to decreased estuarine salinities making habitat temporarily unsuitable for postlarval and juvenile survival. The extent of mangroves is positively correlated with the production of *P. merguiensis* in Australia (Staples *et al.* 1985).

Table 1. Summary of some reported correlations between environmental variables and penaeid prawn catches. The number of asterisks represents the overall relative strength of the environmental relationships for each species; a higher number means stronger correlations. na = not available. +ve = positive correlation. -ve = negative correlation. 0 = no significant correlation. See text for explanation of juvenile habitat correlations.

Species	Location		Rain, Discharge	Temperature	Wind	Juvenile habitat
Estuarine (Type 2)						
P. merguiensis 28°S - 30°N	Karumba (17°S)	****	+ve	0	0	+ve
	Weipa (13°S)		0	0	0	+ve
	Papua New Guinea (8°S)		-ve	na	na	+ve
P. setiferus 18°N - 41°N	Mexico (18°N)	****	+ve, -ve	0	0	+ve
	Texas (29°N)		+ve	na	na	na
	Louisiana (29°N)		-ve	na	Yes	+ve
	Sth Carolina (33°N)		na	+ve	na	na
Inshore (Type 3)						
P. semisulcatus 34°S - 35°N	Weipa (13°S)		0	0	0	+ve
P. aztecus 18°N - 41°N	Texas (29°N)	**	0	+ve	Yes	na
	Louisiana (29°N)		-ve	+ve	na	+ve
	Nth Carolina (35°N)		-ve	+ve	0	na
P. duorarum 18°N - 41°N	Florida (25°N)	*	+ve	na	na	na
	Nth Carolina (35°N)		na	+ve	na	na
P. esculentus 35°S - 10°S	Exmouth Gulf (22°S)	*	+ve, -ve	na	na	+ve

For the inshore (Type 3) species (e.g. *P. semisulcatus*, *P. aztecus*, *P. duorarum* and *P. esculentus*), the environmental effects are again extremely variable across different study sites. The most consistent finding is the positive correlations between catch and temperature for *P. aztecus* (Table 1). Further, the correlations for these inshore species are not as strong as those for the estuarine species, and the effects associated with rainfall (i.e. river discharge, salinity, area of available habitat) appear to be more important for the estuarine than the inshore species.

Assessing correlations between catch and environment

Several factors must be considered when assessing the variation in effects of environment on adult prawn abundances.

Correlations versus causal mechanisms

To ensure that the observed correlations are not due to chance, it is critical that we understand the causal mechanisms underlying the correlations. If this can be done, we will have some confidence in making predictions about the effect of future environmental variation on catches.

Processes

Environmental factors can affect adult abundances by acting on prawns at different stages of their life cycle.

- Factors such as temperature and salinity can directly affect prawn mortalities, particularly in the early life history stage.
- Environmental factors, particularly rainfall-related factors, can affect migrations of prawns from one life-history stage to another.
- Variability in recruitment can be masked by changes in the catchability of prawns which may be affected by factors such as temperature or turbidity.

Interdependence of factors

Environmental changes are often linked to each other, for example, rainfall affects river discharge, water temperature, salinity, turbidity, nutrients and habitat availability. It is very difficult to separate these effects statistically.

Signal to noise ratio

Many environmental factors will have some effect on prawn abundances. However, the effects of most of the environmental variables are too small to measure clearly in adult abundances and can be regarded as being background "noise". Unless a particular environmental factor varies substantially, its effect will be difficult to pick out from all the other low-level variation in the environment. Moreover, a particular environmental variable may vary widely at one location and be strongly correlated with catch, but only vary slightly at another location where its effect on catch may consequently be indistinguishable from other environmental "noise". An example of this is discussed for *P. merguiensis* in Case 1 below.

Time scales

In general, effects of the environment on prawn catches are usually considered at a short-term or, at the longest, an inter-annual level. Environmental changes, however, occur on levels ranging from very short time scales (seconds and hours) to decadal scales. The effect of the longer-term shifts in climate and the environment have received little attention despite the fact that long-term changes in global climate are well documented. There are some current studies on small-scale pelagic resources in which major regime shifts in the ecological systems are occurring, however, we know little about changes in demersal systems on these long-term time scales.

Case studies

Estuarine (Type 2) life history

The banana prawn, *P. merguiensis*, inhabits the coastal waters of most countries throughout the Indo-west Pacific region. Adults spawn in offshore waters and the postlarvae migrate inshore after a larval life of two to three weeks. The juvenile stage spends several months closely associated with mangroves in the estuaries before moving offshore to the adult grounds.

In the southern Gulf of Carpentaria, Australia, the climate is extremely seasonal with over 80% of the annual rainfall occurring between December and March (southern hemisphere summer). In this region (about 17°S), there is a strong correlation between annual rainfall and annual adult commercial banana prawn catch in the offshore waters (Vance *et al.* 1985) (Fig. 2a). Over a four-year period, Staples and Vance (1986) showed that the emigration of prawns from the juvenile nursery area was closely associated with the amount of rainfall occurring in the catchment area. In years of low rainfall, only a small number of large juveniles were stimulated to leave the estuary, while in wetter years a large number of juvenile prawns of all sizes emigrated (Fig. 3). As a result of this size selective effect of rainfall on emigration, probably acting through the differential osmotic responses of different sized prawns, there is a very high correlation between rainfall and commercial prawn catch in the southern Gulf of Carpentaria.

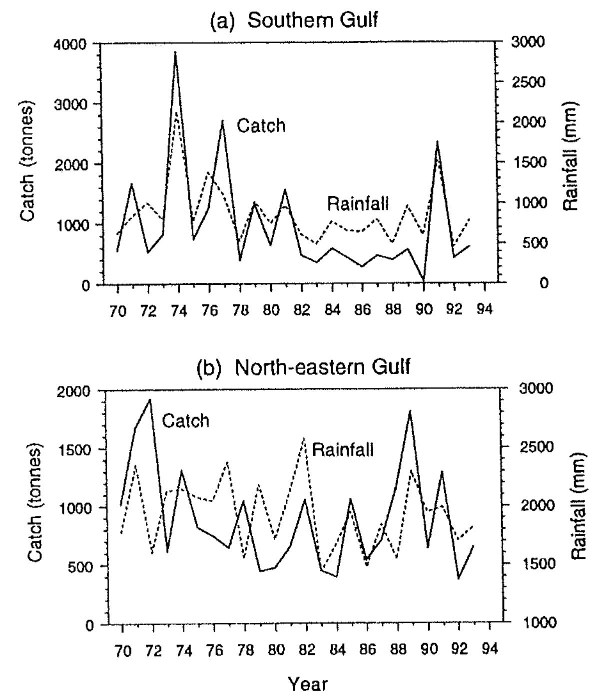

Figure 2. Annual commercial banana prawn catch and annual rainfall from 1970 to 1993 for the (a) southern and (b) north-eastern Gulf of Carpentaria.

In contrast, about 200 km further north-east in the Gulf (about 13°S), the correlation between rainfall and commercial banana prawn catch is not significant (Fig. 2b). This can be attributed to two substantial differences in the local climate and topography leading to a very low signal to noise ratio for rainfall in the north-eastern Gulf.

- Rainfall in the southern Gulf is more than twice as variable as rainfall in the north-east.
- The catchment areas feeding freshwater into the southern Gulf region are about 20 times the area of the catchments feeding water into the north-eastern region.

These two factors mean that heavy rainfall in the north-eastern Gulf can have an immediate effect on the salinity in the estuaries. However, because of the smaller catchments in the north-eastern Gulf, the influence of rainfall on the juvenile banana prawn nursery grounds in the downstream reaches of the rivers is quickly overwhelmed by the high salinity Gulf water. In the southern Gulf, heavy rainfall in catchments, which extend for up to 500 kilometres inland, causes a much larger volume of freshwater to impact on the juvenile prawn habitat. Consequently, the effects of heavy rain last for a much longer period and have a much larger impact on the prawn nursery grounds in the southern Gulf than in the north-east. Salinity at the mouth of rivers in the southern Gulf can be zero for several months during the wet season whereas in the north-eastern Gulf, salinity rarely falls below 10 ppt. Since rainfall has a smaller and less variable impact on the river systems in the north-eastern Gulf it also has a weaker relationship with the subsequent offshore commercial catch in this region.

In the Gulf of Papua (about 8°S), again both the climate and geography have a marked influence on the effect of rainfall on prawn stocks. Rainfall in the Gulf of Papua is highest in the winter but is also more consistent throughout the year than in the adjacent Gulf of Carpentaria. The main catchment area of the region drains into the large Fly River, which has lower salinities than the Gulf of Carpentaria rivers for most of the year. In the Gulf of Papua, the correlation between annual rainfall and banana prawn catch is negative. Presumably, years of higher rainfall result in more of the river being influenced by freshwater, which therefore reduces the habitat available for survival and growth of juvenile *P. merguiensis*.

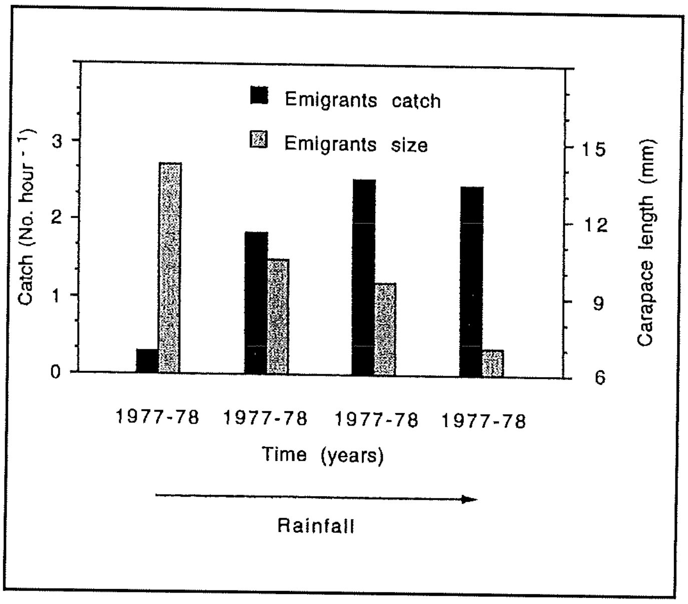

Figure 3. Mean emigration rate and mean size of emigrating juvenile banana prawns for each 4 years in the Norman River ranked by increasing annual rainfall.

Inshore (Type 3) life history

Juvenile tiger prawns are known to require vegetated habitats such as seagrass areas in estuaries, sheltered bays, reef tops and on open coastline for their successful survival and growth (Staples *et al.* 1985). In the Gulf of Carpentaria, Australia, three main species groups inhabit these vegetated areas - the commercial endeavour (*M. endeavouri* and *M. ensis*) and tiger prawns (*P. esculentus* and *P. semisulcatus*) and the non-commercial greasy back prawns (*Metapenaeus moyebi*).

In contrast to the banana prawn (*P. merguiensis*), no consistent relationship has been found between annual commercial tiger prawn catches in the Gulf of Carpentaria and any environmental variable. However, climatic changes have been shown to have a more long-term effect on prawn catches. In March 1985, cyclone Sandy swept along the western shore of the Gulf of Carpentaria destroying large areas of seagrass. About 180 km^2 or 18-20% of the Gulf seagrass was lost. Following the cyclone, the species composition of juvenile prawns in areas of no seagrass loss (control) were compared with areas of total seagrass loss. In the control area the usual species mix of greasy back, endeavour and tiger prawns persisted, while in the bare areas a large proportion of the endeavour and tiger prawns were replaced by king prawns (*P. latisulcatus*) (Fig. 4). In the years following the cyclone, commercial catches of tiger prawns offshore from the cyclone-affected seagrass also declined substantially compared with catches in unaffected areas (Poiner *et al.* 1993). The impact of one cyclone, therefore, has had a long-term effect rather than an annual effect and would not normally be

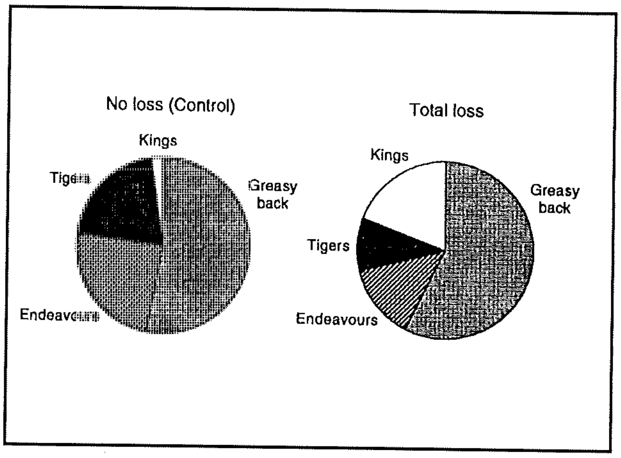

Figure 4. Mean percentage composition of the 4 main penaeid species groups in beam trawl catches on seagrass areas unaffected (no loss) and affected (total loss) by cyclone Sandy. Trawls were made on 3 occasions from 1988 to 1990.

detected by short-term biological studies. The extent to which these long-term impacts affect other prawn stocks is not known.

Implications for prawn management

There is no doubt that environmental factors can have a major influence on prawn stocks. However, the effect of environment and deciding which environmental variable is the key factor can be difficult to elicit. Furthermore, most of the studies reported in the literature come from the more sub-tropical or temperate areas where environmental variability is probably greater than that in the tropics where the bulk of penaeid prawns live. To this extent, the effect of the environment on penaeid prawn recruitment may have been over emphasised. More studies in tropical environments are urgently needed and a regional geographic approach to prawn ecology needs to be more fully developed.

Perhaps the most useful approach to modelling stock variability is to combine both stock-recruitment effect with the environmental effect in a stock-recruitment-environment model as has been done for tiger prawns (*P. esculentus*) in Exmouth Gulf, Western Australia. A variation of this is to introduce environmental variables into surplus production modelling as is currently carried out in the U.S.A.. In this approach a family of either stock-recruitment curves or production curves are used, each curve relating to a different level of effect of the environmental variable. In this way, the sustainable yield changes according to the prevailing environmental condition.

Although the combination of stock-recruitment (or production curves) and environmental factors is theoretically appealing, the extreme variability of responses which can occur for the same species to one environmental variable probably limits the approach to cases where the environmental signal is both simple and strong. For example, in the southern Gulf of Carpentaria, annual predictions of next season's *P. merguiensis* catches are made on the basis of the wet season rainfall. Any significant deviation between predicted and annual catch signifies that other factors, such as reduction in the spawning biomass, have become important and other management measures have to be considered. Based on the stock-recruitment-environment model, the extremely low catch from 1982 until 1990 was interpreted to be a result of the low rainfall during these years. In 1991, following an above average rainfall, the catch of *P. merguiensis* was predicted to increase from less than 100 t in 1990 to 2010 t in 1991 (see Fig. 2a). The actual catch in 1991 was 2343 t, thus confirming the healthy state of the stocks despite continued low catches.

Good knowledge of the effect of the environment, combined with stock-recruitment relationships (SRRs) can lead to better stock assessment and better management. However, benefits and costs need to be analysed for individual cases before further studies are attempted. In regions of the world where prawn catches appear to be stable, at least on an annual basis, studies of this kind would appear to be less cost effective. In other regions, such as in the Gulf of Carpentaria, the research has been extremely cost effective, especially in the southern Gulf. Millions of dollars have been saved by not wrongly introducing management regulations as a result of the low catches in the 1980s.

As a next step towards a better understanding of the importance of environmental factors, a comparison of the variability of prawn catches across the world is needed. Unfortunately, problems with the quality of commercial data, especially at the species level, makes this almost impossible at this time. However, given the large benefits and possible cost savings of such an analysis, collection of good quality basic catch and effort data should be given the highest possible priority.

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Questions and discussion following Dr. Staple's presentation.

Hall: With regard to the relationship between rainfall and banana prawns, you suggested that it would be a "brave manager indeed" who believed that everything was going to come back according to the relationship. Then, in the conclusions, you mentioned that most of the environmental correlations will breakdown in the fullness of time. What then, are the implications for managers in that situation? Do they have to take a much more conservative approach and not rely on the correlation coming good? Should they try to remedy the situation by reducing effort?

Staples: In an ideal situation the best thing to do is to get the causal mechanism, understand the system and then use that prediction. That situation is unlikely to arise. The correlation should be used cautiously. With that cautious approach being, that in most cases, there was historical evidence to indicate that correlations are usually fairly spurious. I would not ignore it and I'd certainly use it but I'd use it in retrospect with a lot more information about these types of events.

Hall: So you'd still use it in a cautious way without full reliance on the result.

Staples: I wouldn't put reliance on it unless I knew the causal mechanism and even then you probably could have the wrong one.

Hilborn: It's understandable that managers could base their decision making upon a correlation if they knew the causal mechanism underlying the correlation. However, if only the correlation was known (and the causal mechanism remained unknown) would you recommend giving some credence to reducing effort to rebuild spawning stocks?

Staples: I would give that information to the manager but I would also give the advice that in a case like that where if you only had a correlation, a fairly tight correlation (it's been there since we started monitoring that fishery) I would adhere to the optimistic view that the stock would come back.

Hilborn: In such a case you would have predicted the poor return anyway, right?

Staples: At that stage in the time-series, yes.

Koslow: You could have had the situation where rainfall was largely a causal factor but that in particularly low stock sizes, other factors take over. Thus, you can't assume that just because you have a causal mechanism it's going to last until eternity. Systems change and other factors can become important.

Gracia: With regard to the relationship with rainfall, I suspect for very high levels of rainfall the relationship could work in reverse.

Staples: That's true. The fishery for *P. merguiensis* in the Gulf of Papua New Guinea is influenced by the very large Fly River. There, rainfall has the negative effect and it's influencing habitat availability. When you get a low-rainfall year, more of the estuary is available for the nursery habitat. Rainfall will act on many different mechanisms which affect prawn catches.

Caputi: In a lot of cases when fisheries collapse it's due to a combination of poor environmental conditions resulting in poor year classes. Management may impose no new changes because the decline is considered as an environmental effect and the heavy fishing pressure which was sustainable under *good* year classes, continues. Thus, you've got to be very cautious about concluding that it's just an environmental effect and allowing heavy fishing pressure on poor year classes. Western Australia is going through that experience with the lobster fishery. We had two below-average year classes due to environmental conditions. If the heavy fishing pressure of the last few years and the increased fishing *power* from those years is combined with these poor year classes, such a combination can lead to recruitment overfishing in the future.

Staples: I would agree that where you are on that flat curve will influence what your conclusions are going to be.

Caputi: The trouble is you never know where you are on that flat curve.

Staples: I agree and therefore again if you want a precautionary approach, a combination of bad environmental conditions and heavy fishing is the nail in the coffin.

Wang: Your conclusion for the banana prawns, *P. merguiensis* is that it is mainly environmentally driven. Can we therefore conclude that there is no SRR for them?

Staples: No.

Wang: There must be a threshold level, which if exceeded, will collapse the stock.

Staples: The conceptual model of the SRR is one of a large, flat curve and then a precipitous drop off. It's not saying there is no SRR. We should get that out of the literature. There is some point that is going to be extremely critical and we're going to get a major collapse in that area. The environmental influence on *P. merguiensis*, in most of its range, is going to be much less then we see in the southern Gulf and probably there will be a much tighter detectable SRR.

Wang: Can anything be done to detect that threshold level?

Staples: There is research being done to detect that threshold level.

Glaister: With regard to the threshold level, it's physically impossible for the stock level to go much lower than where it was (near zero catch).

Staples: True, the population is resilient enough to bounce back.

Glaister: So the practical implications of that as far as management is concerned is that there is no SRR?

Penn: I disagree. What you experienced is a very low stock level, a very low catch period when the fishery may have been overfished. They only fish on the schooling phase of the fishery and the stock collapsed in that period. Then, because fishing effort was negligible for a couple of years, the stock rebounded. The model of Exmouth indicates that when there is effectively no fishing, the stock can bounce back in two years. In that data set, you could have significantly reduced the breeding stock level, reduced recruitment, (the environmental factors not withstanding) and then had a recovery. The switching-off of the fishery in the preceding year may have been what saved it. There was no management action taken, it took its own action. What is of concern is that if the recovery rate is quick enough - and the indications are a one or two year no-fishing-period will bounce the stock back in most cases - then a sequence of "boom and bust" situations can occur in many stocks and it is easy to conclude that there is no SRR in these stocks because it simply comes back at regular intervals. The model we have of Exmouth indicates it would come back at regular intervals if you took the effort off whenever it went down to a very low level.

Patterns in Landings and Size Composition of Eastern King Prawns, *Penaeus plebejus* in Waters off New South Wales

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Abstract

Eastern king prawns have been exploited in the waters of New South Wales since at least the early 1800s. Currently, this species annually contributes approximately 42% and 58% by weight and value respectively, to the total production of prawns in New South Wales. Annual landings have remained relatively stable over the past two decades and average around 900 tonnes. Two-thirds of these are taken in oceanic waters. There has been a shift in the distribution of landings along the New South Wales coast over the past decade with a greater proportion of landings now taken south of the traditional prawning grounds.

Information on the distribution of lengths of eastern king prawns from waters off New South Wales was collected as part of a two year study on the abundances of animals caught in prawn trawls offshore. Distributions of lengths of eastern king prawns in random samples taken four times per month at four locations between March 1992 and February 1993 were pooled into seasons and analysed by the Kolmogorov-Smirnov two-sample test. There were significant differences in these distributions between sexes, place and season. Mean lengths of prawns caught in oceanic waters off New South Wales ranged from 46 mm carapace length (CL) to 25 mm CL and 38 mm CL to 23 mm CL for females and males, respectively.

Preliminary results from a three year roving creel survey of recreational prawners suggested that in certain months of the year the recreational catch can be as great as one-third of that of the commercial catch in the same estuary in the same month. There is no difference in the distribution of lengths of prawns caught between commercial and recreational prawners in estuaries.

Questions and discussion following Mr. Montgomery's presentation.

Hall: Are they trying to track migrating groups of prawns? Does GPS play a part and what is there in terms of technological problems and monitoring?

Montgomery: GPS has had a big effect because the fishers don't have to know the grounds that they're going to fish on all that well. All they have to do is follow the other boats out and click on the GPS. GPS gives fishers more incentive to move around. They all know that eastern king prawns move from south to north along the coast, starting in late summer. When management was introduced, fishers in the south of the state suddenly assumed that they had to demonstrate their participation in the fishery, and so started to put in more fishing effort. In response, the fishers further north began moving south to also share in the catch before the prawns migrated north and now this has become an annual practice.

Hall: Do they actually focus on a particular depth range when they're fishing and at a time of the year when they know the prawns are going to be there? Do they visibly have to search?

Montgomery: They go there when they know the prawns are there. They don't move from their home grounds until they know the prawns are there.

O'Brien: Is there much of a temperature gradient between Queensland and New South Wales with respect to change in the size of the prawns?

Montgomery: Yes, there is. In New South Wales the surface water temperature falls to 13° C in winter and rises to 22 - 23° C in summer.

O'Brien: Do you think that could be affecting the growth rates more than the migration of individuals?

Montgomery: No, the migration from Botany Bay to the north of New South Wales takes around five months. By winter time they're all more or less in the northern part of the state.

Loneragan: What is the size of the fleet and are vessel numbers stable?

Montgomery: At the beginning of management there were about 350 boats. Currently there are about 280. Fleet dynamics have stabilised since the introduction of management. There is a management formula where each vessel is restricted to a certain length of net and that varies between vessels. They've all put on GPS since then, so in terms of real effort, effort has probably increased.

Time-series Data : Everybody Wants It, Few Have It, So How Do You Get It ?

N. Trainor

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Abstract

The implementation of detailed catch and effort logbooks and a comprehensive fisheries information system in recent times has provided both managers, researchers, and industry with an invaluable tool to monitor Queensland's fisheries and evaluate management options.

With the present rate of development in information technology this is a very exciting time for fisheries information systems (FISs). Modern technologies such as satellite tracking and data logging, visualisation, spatial modelling, satellite imagery are now becoming accessible to everyday users. The immense benefits these technologies offer suggests they will form a major part in the natural evolution of modern FISs.

These technologies are dependent on comprehensive FISs to maximise their impact as decision support tools. Although there are a few exceptions, comprehensive programs to collect time-series catch and effort with detailed temporal and spatial resolution are fairly new in Australia. While such programs provide a data set for the years to come there is often a wealth of data available for the past, although it is generally not readily visible.

This paper focuses on recent developments in Queensland with regards to the development of a time-series catch and effort data set. While this data set is growing daily with the information collected through the current catch and effort logbook program, it is also growing backwards in time. By identifying and amalgamating data sources which have been 'lost' or forgotten over the years, very detailed data is now becoming available, providing a continuous time-series back to the late 1960s.

Questions and discussion following Mr. Trainor's presentation.

Dredge: How the information attained in this system is going to be used requires consideration. It must not become a database for which there is no end-user. The process of getting the information to managers also requires consideration.

Trainor: Yes. It would be nice to have a lot of other indices but quite often catch and effort systems are the only indices available. If the data being collated is to be used it's going to have to be done carefully, particularly in the next few years as new technology comes along, there's going to be many end-users trying to get up to speed.

Staples: One of my tasks in Canberra is to co-ordinate the national fishery statistics as they come through and go overseas. I've worked quite a lot with Neil Trainor on this and I was interested to see that he picked up an *existing* system when designing this rather than re-inventing the wheel.

Trainor: When the system decided to get into logbook databases it wanted one quickly. The first logbook database had a programmer come in for a three-month period. You could get data in, but it was not very accessible. It was going to cost many hundreds of thousands of dollars to bring in a comprehensive system. At that stage, the Australian Fisheries Service and CSIRO had done considerable work revamping their whole information system and that had millions of dollars spent putting it together. We asked them and they let us get a good look at their system. They were very helpful and made it open. We took all the information back with us and spent three months deciding whether to use it. In the end we approached them to adopt it. It's worked out fairly well. To move onto it was basically a weekend operation. We shut down the old system on a Friday and moved onto the new system on the Monday. There was a bit of tailoring over the next couple of months in order to fine tune. The big advantage we've found is with the common system, particularly on the east coast due to the overlap with Torres Strait and the Northern Prawn Fishery running similar systems. It makes things easier, from looking at vessel movements to the liaison people working out where boats are and whether they have sent logs in.

Chubb: It's extremely important that you document, as completely as possible in any one year, what's happening with the fishery. Because although you may not use it in your lifetime there'll be someone come along 20 years down the track who'll be so glad you did.

Trainor: That's right. I mentioned earlier that Somers and Dredge ran early logbook programs. Their data is the only data now available for those periods.

The Importance of Logbook Liaison in Fisheries Data Collection

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Abstract

With 800 trawlers operating in an area exceeding one million square miles, data collection and management in the Queensland prawn fishery is no small undertaking. The SUNFISH database is presently comprised of over one million catch records for the trawl fishery alone. Whilst 98% of the trawl fleet are submitting timely returns there is undoubtedly a component of error in the data. Liaison has revealed intentional mis-recording of logbook information resulting from industry suspicion about the uses of logbook data. This is a result of two well defined problems. Firstly, a basic lack of understanding about the role of biological analysis in effective fisheries management. Secondly, recent fisheries management strategies which have required an individual's logbook for validation of his fishing privileges. Data is subsequently often mis-represented by industry in an attempt to protect their interests in the fishery.

It is difficult to determine accurate catch/effort data without strict validation procedures. Many of these are presently built into the SUNFISH database and the framework for others is in place. 'Breaking off' selective subsets of the data can minimise intentional and unintentional error. This may be as simple as accounting for incomplete records when extracting data from the database. Educating industry about the biological uses for catch/effort data and its implications for management through liaison has been shown to improve data quality and completeness. Raising the profile of biologists and their work, and emphasising the role of biology in management is invaluable for good natural resource management.

Questions and discussion following Ms. Eliason's presentation.

Hall: One of the major impediments to a logbook program is the introduction of management controls. In Western Australia, if you introduce a reduction in pot quota you find an immediate reaction from fishers who feel aggrieved. Suddenly the logbook coverage goes down considerably. Conversely, with the introduction of limited entry programs, you suddenly get huge influxes of records. It generates catch history that was not there before. Management programs seem to have quite adverse effects because any change seems to inspire this sudden change in response that fishers give you on a logbook program.

Eliason: I'm hoping that you can counter-act that to some extent by educating them about the research. If you stress the importance of education and research then you would negate some of the problems you mentioned.

Staples: It's not just change fishers react to, but it's *perceived* change. You'll notice a lot of those things were perceived changes.

O'Brien: How would fishers react to having a "black box" on their boat? This would record their position and activity. Then you could co-ordinate the catch with what came into the co-op.

Eliason: It would be a very delicate situation and would depend on how you introduced it. If the "hard stick" method was used, you'd get an adverse reaction. You could introduce it on a voluntary basis.

O'Brien: It would improve your accuracy.

Glaister: The fishing industry currently pays for surveillance and enforcement. Many fishers facing increased costs through this would argue that if they weren't doing the wrong thing they wouldn't mind having a black box on board and they then would not have to pay for costly patrol vessels. The concept therefore has some positive merits.

Penn: In regard to the Western Australian logbook system, the management plan wasn't all that acceptable to some in the industry, but it came back up again. The important thing is what the data is to be used for, and who owns the data. Our experience is that there are data that management requires and there are data that researchers require. If you mix the two things together, you can get into some difficulty. If you ask fishers for compulsory data (as QDPI does) it is the minimum management requirement. The research logbook programs can then become voluntary if you take away the compulsion. Once you've got voluntary logbook data, then you select out those fishers who understand research requirements better, and you don't get into the problems of fudging data for quota allocation arguments.

Eliason: We can select subsets that are more useful for research, than others.

Trainor: The important thing is how data collection programs should be handled whenever management is having a big impact on a fishery. In the Southern Bluefin Tuna (SBT) program, the Western Australian fleet was severely cut back by quotas. Over that 12-18 month period, by maintaining very strong liaison with industry the logbook compliance was maintained around 95-98% mark. Without that compliance it would have been drastic. In regard to the "black boxes", at the last trawl committee meeting the Queensland Commercial Fisherman's Organisation endorsed a pilot study to implement some satellite tracking devices.

Montgomery: Has any thought been given to size monitoring of the catches to supplement the logbook?

Eliason: The only effort we've made to get a size break down is by adding a tally box at this stage through the logbook program. The data is available through our buyer's return program which is indicated on a boat-by-boat basis, so there could be some correlation there. QDPI have done some research programs where size classes are measured in certain areas over time.

Turnbull: In Torres Strait we're doing catch monitoring at the moment.

Hilborn: In contrast to your program, New Zealand has introduced a voluntary logbook program on several of their rock lobster fisheries. It is funded by industry. They've levied themselves to pay for the technician who does it. The big difference is that they know very specifically what they want. They are measuring a sample of catch to get size frequency for CPUE. They had catch, but they didn't have total catch, in relation to existing management regulations. The moment that was started in the Bay of Plenty, all other areas of the fishery wanted a similar program.

Staples: In many fisheries worldwide monitoring is going over to the industry. The "black box" is undergoing trial in the Commonwealth now. The Orange Roughy boats have transponders on board and the fishers are mostly supportive. The Torres Strait fishers also want transponders. There is a move within the industry and it is a better way of going.

Trends in Catches of Eastern King Prawns, *Penaeus plebejus* from Queensland Coastal Waters - Considerations for the Spawning Stock - Recruitment Relationship

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Abstract

The eastern king prawn, *Penaeus plebejus* is endemic to the east coast of Australia and is of major commercial significance. It differs from other Australian penaeid prawns in that it is more migratory and oceanic. In Queensland, trawling occurs up to 250 km from the coast and to depths exceeding 250 m. The fishery is largely mono-specific, and in this respect it again differs from most other prawn fisheries in the state and elsewhere. This is fortunate as it improves the chances of obtaining accurate estimates of CPUE. The only major area where eastern king prawns are taken as part of multi-species landings is Moreton Bay. The relationship between spawning stock and recruitment is largely unknown. In this presentation, indices of spawning stock and recruitment for the Queensland component of the fishery are put forward. Long term trends in the levels of these indices suggest that while annual recruitment strength appears to have declined, it has done so independently of the spawning stock levels which have remained relatively stable.

The fishery

In Queensland, the eastern king prawn fishery extends from the New South Wales-Queensland border (28°S) north to the Swain Reefs (22°S) (Fig. 1). All fishing takes place on the continental shelf. In the northern parts of the fishery, trawling extends out to about 250 km from the coast. In the southern parts, near Moreton Island (27°S) the shelf width narrows and fishing extends out to about 70 km.

The fishery is of major commercial importance to the state, and is the most valuable commercial fishery in southeast Queensland. About 1500 - 2000 tonnes are landed annually with an approximate value of \$20-25 million. Highest annual landings occur in the southeast corner and in the Wide Bay Bar region near Fraser Island (Fig. 1).

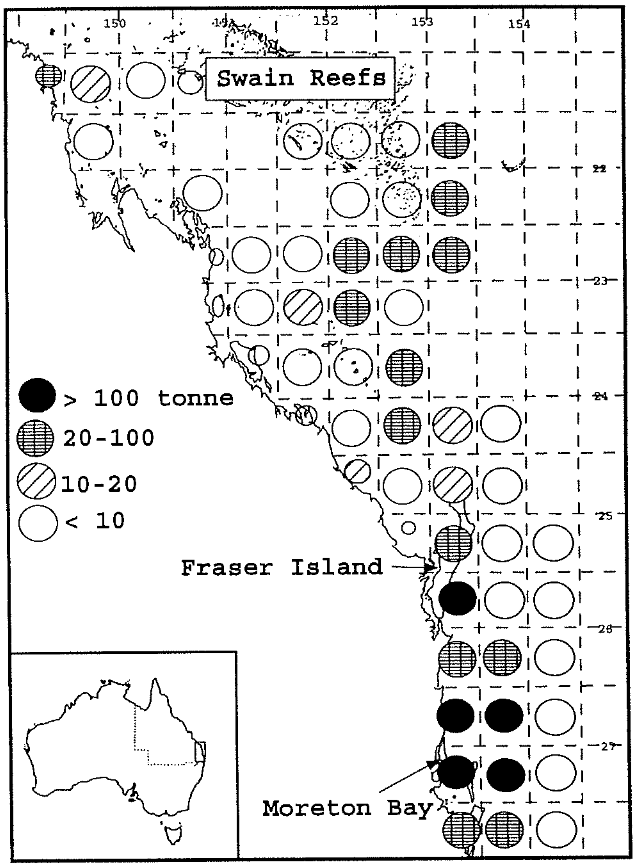

Figure 1. Geographic distribution of catches of eastern king prawns, *P. plebejus* in Queensland coastal waters. The tonnages are from SUNFISH logbook database and based on average annual landings from 1988-93.

Stock structure

From the literature, there appears to be two general schools of thought on the structure of stock. Tag-release studies (Ruello 1975, Montgomery 1990) concluded that because of the highly migratory nature of the species, there is enough mixing of individuals from different estuaries for the entire stock to be considered as a single unit. This hypothesis was independently supported by the enzyme polymorphism work of Mulley and Latter (1981) which showed genetic homogeneity for samples from Moreton Bay (Queensland) to Lakes Entrance (Victoria). Others have suggested that there are two sub-stocks (Glaister *et al.* 1987, Lucas 1974, Potter 1975). The uncertainty of the stock structure remains and has been complicated in recent years by the establishment of additional trawl grounds in the north near the Swain Reefs (22° S, Fig. 1) (Dredge and Gardiner 1984). The gene frequencies and geographic origins of prawns trawled in this area are unknown.

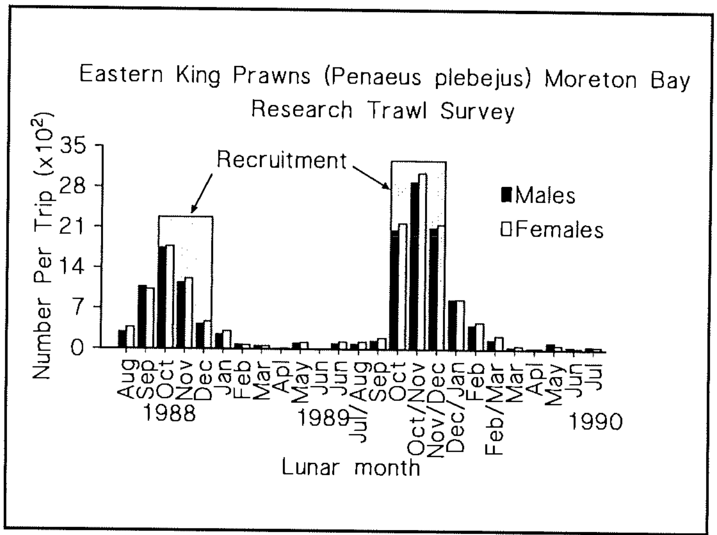

Figure 2. Time-series of recruitment. Based on the number caught from 9 sites sampled on a lunar-monthly basis in Moreton Bay.

Trends in Recruitment

Because individuals are migratory it is relatively simple to distinguish areas of recruitment from areas associated with catches of the larger, older adults. Areas associated with recruitment are characterised by large catches of relatively small prawns in shallow water. Moreton Bay and the Wide Bay Bar (Fraser Island) fit these criteria. Succinct recruitment timing occurs from October to December (Fig. 2). Mean CPUEs from these temporal-spatial "windows" are suggested as indices of recruitment. These indices indicate a general decline in recruitment over the 1988-93 period (Fig. 3).

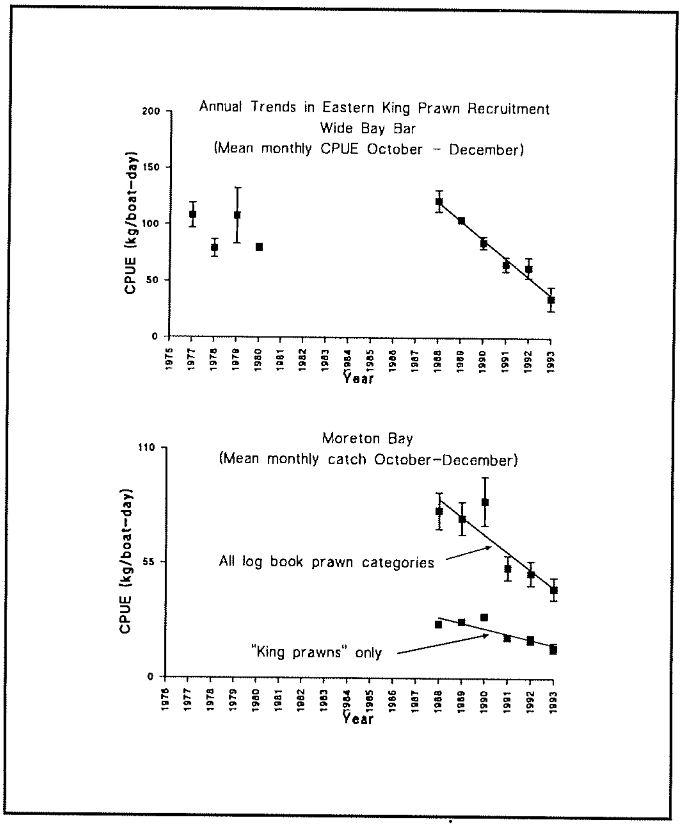

Figure 3. Annual time-series trend in recruitment indices for the eastern king prawn fishery in southeast Queensland. Data for the 1970s in the Wide Bay Bar area are from a research logbook. The remaining data are from SUNFISH logbook database.

Trends in Spawning Stock

Defining indices of spawning stock in the eastern king prawn fishery is more difficult than defining recruitment. Egg production is likely to be determined mainly by a combination of the proportion of ripe/mature females and the abundance of adult females. In southeast Queensland, results from the histological examination of ovaries obtained from monthly samples of females from different areas over a two-year period indicate that spawning is relatively widespread in time and space. There is a slight increase in the proportion mature from May to July. The main limiting geographic factor appears to be depth; mature females being largely restricted to deep water (> 100m). Abundance of adults, as determined by monthly CPUE (Fig. 4), is also relatively high from May to July.

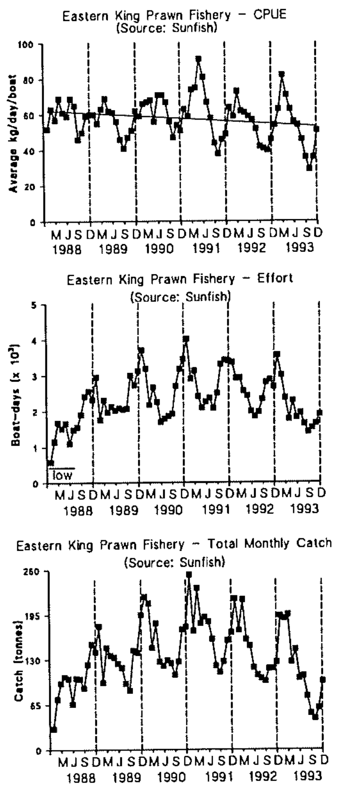

Figure 4. Monthly time-series of average CPUE (top), total effort (middle) and total catch (bottom) in the Queensland eastern king prawn fishery. Early 1988 data are likely to be unreliable due to "teething" problems with the introduction of the logbook program.

When results from the *monthly proportion of mature females* is considered in combination with the results on *abundance* (as CPUE), it is reasonable to suggest that there is major egg production from May to July. Thus, the CPUE from deep water parts of the fishery from May to July are suggested as suitable indices of annual spawning stock. These CPUEs, presented for four relatively deep water parts of the fishery in Fig. 5, suggest that there is little or no evidence of decline in levels of annual spawning stock since the SUNFISH logbook database was introduced in 1988.

The main conclusions of this presentation are that:

- There appears to be a slight declining trend in monthly CPUE (Fig. 4) in the Queensland component of the eastern king prawn fishery since the logbook program was introduced in 1988.
- A recruitment index, which is relatively well defined in time and space, can be put forward. It suggests that annual recruitment levels have declined since 1988 (and possibly earlier) in the two main recruitment areas of southeast Queensland.
- A spawning stock index is suggested for the Queensland component of the fishery, but defining this index is more difficult and less precise than for the recruitment index. The spawning stock index appears to have remained relatively stable since 1988.

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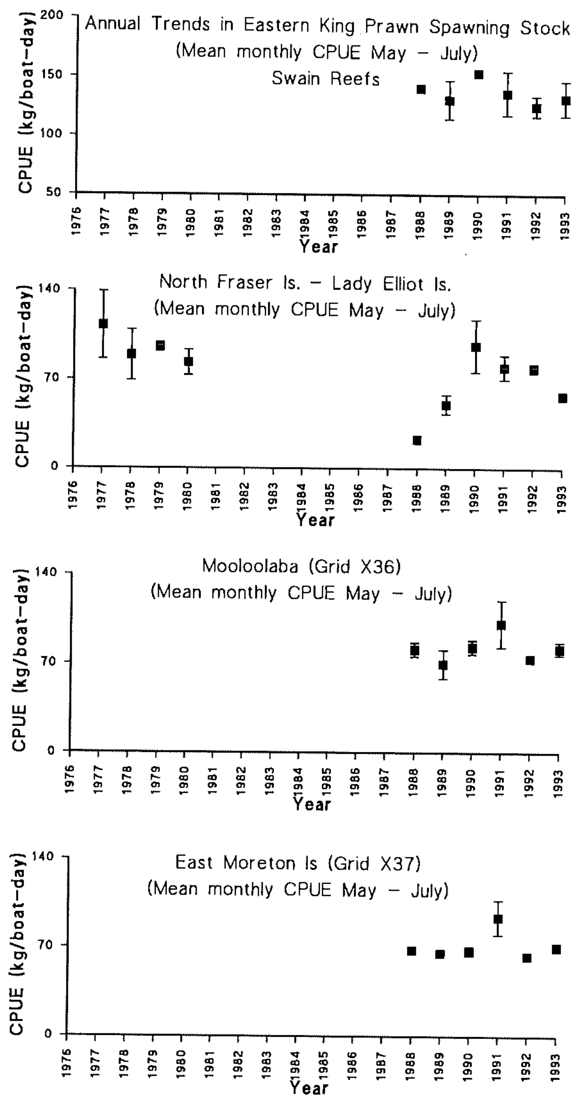

Figure 5. Time-series of spawning stock index in the Queensland eastern king prawn fishery. Four areas were considered. Early data from the North Fraser Is. - Lady Elliot Is. area are from a research logbook program. The remaining data were obtained from the commercial logbook database, SUNFISH.

Questions and discussion following Mr. Courtney's presentation.

Montgomery: It's likely that the fishery is based upon a single unit stock. For management of the resource, even your own data shows the population is one stock. You've monitored recruitment in the main areas and shown a decline and yet the spawning stock is holding up quite well. If you examine the New South Wales data, there is no decline in the estuaries and I can assume that effort has remained relatively stable in those estuaries over a long time. So, even your own data are suggesting that there is one spawning stock that is feeding the east coast of Australia. On that one premise, the population needs to be managed as a single unit stock.

Caputi: Could the fishing in New South Wales be having a negative impact on Queensland catches?

Courtney: Yes. That's quite a possibility. The prawns undertake significant migrations in a northerly direction. It's therefore quite possible that increased catch and effort in New South Wales waters would reduce the number available in Queensland waters.

Caputi: What proportion of recruitment comes from the Queensland estuaries compared with the recruitment coming from New South Wales?

Courtney: I don't know what the proportion of recruits is from Queensland estuaries.

Montgomery: That's the question that needs to be answered. What is the relative contribution to recruitment from various areas along the east coast of Australia to the spawning stock? Recruitment from the various areas is likely to be highly variable and dependent upon the East Australian Current.

Glaister: Don't place too much emphasis on defining stock structure. In the 1970s the only reason Lucas partitioned stocks of eastern king prawns in southeast Queensland was for convenience. In my own studies, I partitioned the stock on the basis of a manageable problem. A stock is, to some degree, an isolated group but the precise definition of a stock is not that important.

Day 2. Biological Considerations for Defining Spawning Stock and Recruitment Indices (con't). (Session II chaired by Dr. Burke Hill)

Time-Series Analysis of Historic King Prawn Data From the Moreton Bay Area for Possible Stock-Recruitment Relationships

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Abstract

As discussed in a companion paper given by Neil Trainor, the importance of archived catch-effort (logbook) data cannot be overstated. As an example, data collected by CSIRO in the late 1970s and voluntarily by trawler skippers into the early 1980s was analysed for evidence of a stock-recruitment relationship (SRR). Historic catch-effort data of the Moreton Bay fleet from 1976 to 1986 show a temporal link between the abundance of smaller inshore king prawns (recruits) and the larger offshore adult prawns (spawning stock). This relationship was investigated as a time-series with temporal cross-correlation between the inshore and offshore catches. A lag time of approximately one fishing season was apparent but it was not possible to determine whether this was a stock-recruitment or recruitment-spawning stock relationship. Cautious interpretation of these results, consistent with the precautions raised by Caputi (1988), are presented.

Introduction

The night-time king prawn trawl fishery in southeast Queensland is centred in Moreton Bay and adjacent offshore areas. A compulsory trawl catch/effort logbook program covering these areas has been in place since 1988. Catch and effort data were also available from an earlier CSIRO logbook project that had been run for southeast Queensland in the 1970s. Some fishers had continued filling out these logbooks into the early 1980s for their own benefit after the CSIRO project had finished. The latter data and a limited number of personal diaries have become available although not fully collated nor validated. A general overview of historic trends in the Moreton Bay prawn trawl fishery was presented by Neil Trainor at the 1991 Australian Marine Sciences Association conference in Brisbane. This preliminary analysis showed an apparent drop in catch per unit effort of eastern king prawns, *Penaeus plebejus* (reflecting a drop in either abundance or catchability) between the 1970s data and the more recent SUNFISH logbook data. One of the possible explanations for this decline was a spawning stock - recruitment dysfunction between the Moreton Bay population (mainly juvenile) and the offshore population (larger adult prawns). A certain amount of controversy exists in the fishing industry concerning the inshore Moreton Bay fishers taking the smaller prawns that would migrate/recruit into the offshore fishery.

Lucas (1974) made preliminary stock estimates of *P. plebejus* in southeast Queensland based in part on the early 1970s logbook data. In the current study, exploratory data analysis was performed on the historic catch-effort data for *P. plebejus* from Moreton Bay and adjacent areas. The catch-effort data of the Moreton Bay fleet from 1969 to 1979 showed an apparent temporal link between the abundance of smaller Bay eastern king prawns (?recruits) and the larger offshore adult prawns (?spawning stock). This relationship was investigated as a time-series with temporal cross-correlation between the inshore and offshore catches as a possible spawning stock - recruitment relationship (SRR). Cautious interpretation of these results, in line with Caputi (1988), are discussed.

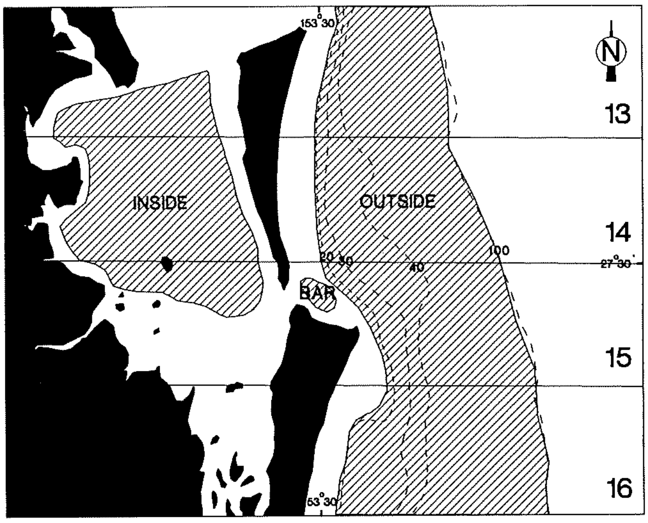

Figure 1. Map of Moreton Bay and adjacent trawled areas. Bands from SUNFISH trawl logbook shown along the right edge.

Analysis

The initial step was simply to examine the data as time plots. All subsequent exploratory analysis has also been presented graphically. Autocorrelation, partial autocorrelation, and cross-correlation were carried out using STATISTIX (Analytical Software) for both within and between data sets from inside Moreton Bay and the offshore fishery (see Fig. 1). Data was differenced to standardise for the means. Partial autocorrelation was carried out to identify possible parameters, and parameter estimates, for higher order time-series models (e.g. ARIMA) but given the exploratory nature of the analysis, modelling has not been attempted at this stage. Computations follow those outlined in Box and Jenkins (1976).

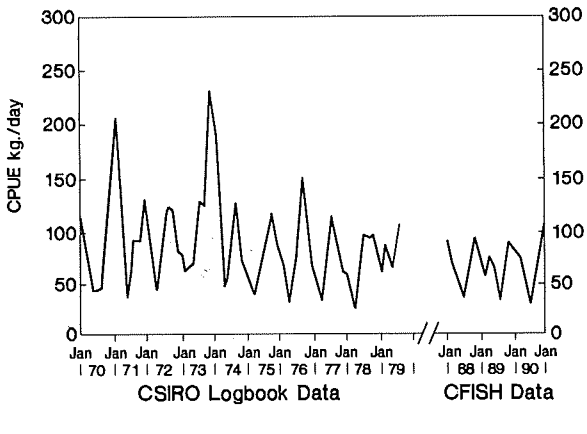

Figure 2. Time plot of total monthly catch-per-unit effort of *P. plebejus* from Moreton Bay and adjacent offshore trawled areas.

Results

The time plot of catch data for *P. plebejus* (Fig. 2) as monthly averages shows distinct seasonal periodicity, peaking in October to November, and an apparent decline in the average catch per unit effort from 1969-79 through to 1988-92. The decline was from an average of 100 kgs/boat/day to approximately 65 kgs/boat/day. Differenced time-series of the 1969-79 average annual CPUE from "inside" (Bay) and "outside" (outside the Bay) is presented in Fig. 3 and together with auto-correlograms (Figs. 4 and 5), show that a between-year periodicity is also present. For the "outside" time-series there was a reasonably strong negative auto-correlation at a lag of one year and again at a lag of four years (i.e. values were just outside the approximate 95% confidence bounds about the autocorrelation). The "inside" time-series showed no significant auto-correlations however maximum negative correlations occurred at lags of one and two years.

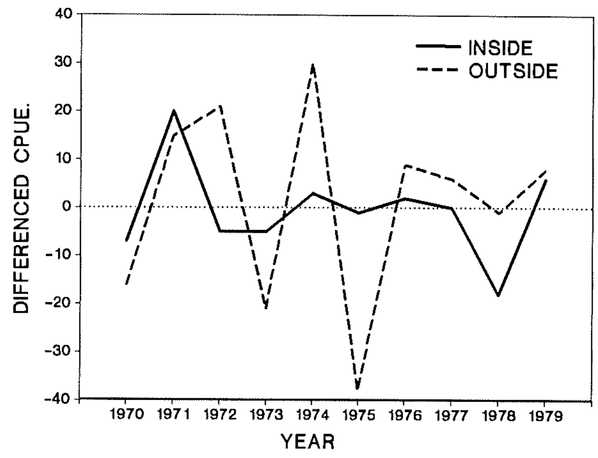

Figure 3. Differenced time-series plot of the annual *P. plebejus* CPUE from inside Moreton Bay and trawled areas outside Moreton Bay.

The cross-correlogram of the inshore to offshore CPUE time-series (Fig. 6) showed:

1. A positive cross-correlation between catches at zero lag. This suggests that within the first year a peak of abundance in king prawns within the Bay is followed by a peak in abundance outside the Bay. Given that fishing seasons are approximately three months apart (a Christmas break, see Fig. 2) then the relationship can be lagged by a season at most.
2. A strong positive cross-correlation occurs at the plus 3 year lag, and is mirrored at the minus 3 year lag.
3. A strong negative cross-correlation occurs at the plus

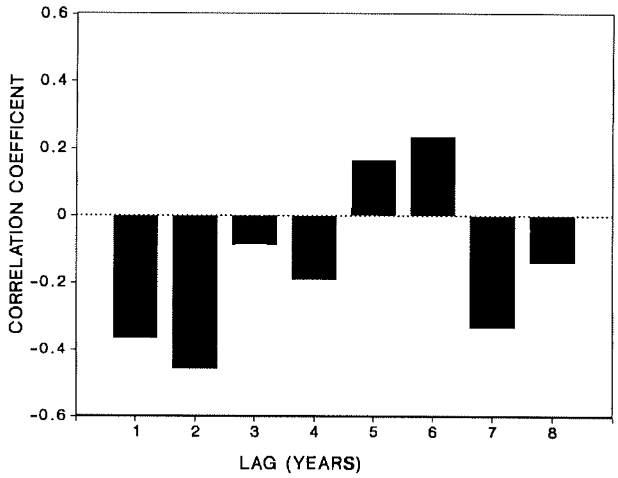

Figure 4. Partial auto-correlogram of the annual *P. plebejus* catch-per-unit effort from inside Moreton Bay.

4 year lag, and is mirrored at the minus 4 year lag.

The relatively minor negative cross-correlations at plus and minus one year lag are a reflection of the pattern seen in the auto-correlograms.

Discussion

Haysom (1975) showed that *P. plebejus* made up 50% of the total catch for Moreton Bay in the early 1970s. However a two-year monthly research survey conducted on the commercial trawl grounds of Moreton Bay from 1988 - 1990 suggested that the *P. plebejus* component of the Moreton Bay fishery was well below this figure (Courtney *et al.* 1991). Also, studies on postlarval and juvenile prawns in the nursery areas of Moreton Bay in the early 1970s (Young 1978) showed that *P. plebejus* comprised over 70% of the total prawn abundance. Similar studies on postlarvae and juveniles undertaken in the late 1980s (Courtney *et al.* 1991) and the early 1990s (Masel *et al.* unpublished) indicate that there has been a change in the species composition in some areas and that, in most juvenile prawn nursery areas, *P. plebejus* is no longer the numerically dominant species.

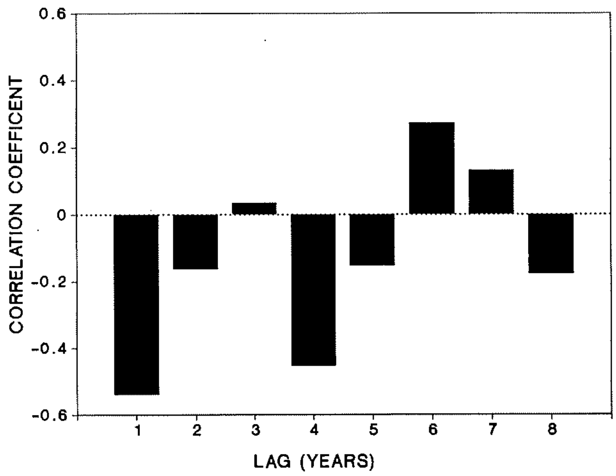

Figure 5. Partial autocorrelogram of the annual *P. plebejus* catch-per-unit effort from trawled areas outside Moreton Bay.

Together with the time plots presented in the current study, these results suggests a real possibility of reduced recruitment of *P. plebejus* in Moreton Bay.

It should be noted that in the current analysis no adjustment has been attempted for increases in fishing effort due to improved technology; such as improved trawling gear, increased vessel horsepower, depth-sounder advances, nor for improved navigation aids such as GPS. If these advances in efficiency were factored into the kg/boat/day estimates of CPUE then the effective effort would have increased dramatically between the 1970s and the 1990s.

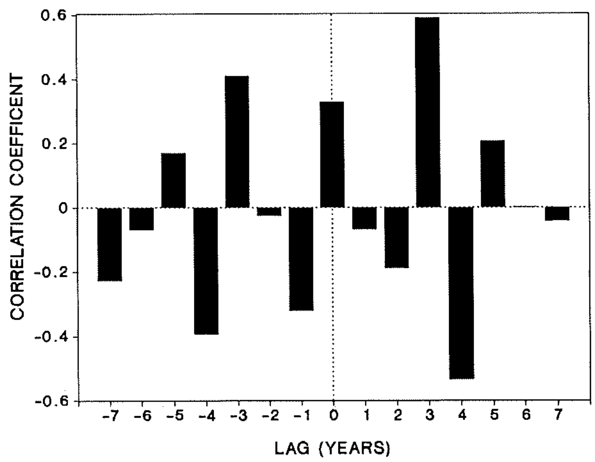

Figure 6. Cross-correlogram of the annual *P. plebejus* catch-per-unit effort from inside Moreton Bay and trawled areas outside Moreton Bay.

Hence the current CPUE would be even lower compared to historic levels.

The link between the Bay population and the population outside the Bay is provided firstly by prawn tagging studies (Lucas 1974, Potter 1975a, Montgomery 1981) and by direct observation from the so-called Bar fisheries (Potter 1985). These are localised fisheries directed at sub-adult *P. plebejus* as they migrate out from inside the Bay - an example being through the South Passage Bar. Tagging studies by Lucas (1974), Potter (1975a) and QDPI (Courtney, unpublished) indicate that the majority of tagged prawns move to the north. This movement is consistent with the results of a sea-bed drifter study which concluded that, during May to October, the currents generally move north (Potter 1975b). The logbook records for this northern section of the coast outside Moreton Bay were selected both by Lucas (1974) and in the current study for analysis.

The simple time-series analysis of the *P. plebejus* logbook data highlights the complexity of factors that could possibly affect abundance of this species. The predominant positive cross-correlation of the Moreton Bay to "outside Moreton Bay" populations was at a three year interval. The most probable explanation for this cycle is the flood history of southeastern Queensland. A major flood in the Moreton Bay area occurred in 1973-74, the effects of which could be seen even in the raw data as a peak in CPUE for outside the Bay, presumably as more juveniles were flushed out. Increased rainfall and subsequent flooding may be an interaction between the El Nino cycle and prawn abundance. A similar 3 - 4 year cycle has been observed in West Australian catch/effort time-series which was correlated with the Southern Oscillation Index, (J. Penn pers. com.).

The positive cross-correlation observed at zero lag and the negative cross-correlations at plus and minus one year lag are more difficult to explain. Within a given year, a peak of abundance in king prawns in Moreton Bay is apparently followed by a peak in abundance outside the Bay (or vice versa). As fishing seasons are approximately three months apart (the fleet reduces effort over Christmas), the peaks can be lagged by a season at most. This would be consistent with the growth and life history of *P. plebejus* (Lucas 1974), reflecting the timing of the movement of juveniles offshore. The interpretation of the periodicity seen in the logbook data has to be cautious however, as both the environmental bias seen in the current analysis, and the combined effects of measurement and random variation can cause spurious correlations (Caputi 1988).

Walters (1985) and Caputi (1988) note that inherent biases and variation in fisheries time-series data may make recruitment appear to be independent of the spawning stock. The current analysis does establish that there is temporal inter-dependence between the juvenile and adult prawn populations in the area of Moreton Bay, although it could not fully describe this relationship. Future analysis would require a completion of the logbook time-series, particularly for the years between 1979 and 1988. This task is currently being carried by the QDPI, SUNFISH logbook program. Furthermore the rainfall and possibly the Southern Oscillation Index need to be incorporated into any SRR. Finally, given that *P. plebejus* may migrate over 1000 km in a northerly direction (Potter 1975a) the actual spawning stock that gives rise to the juvenile recruits in Moreton Bay, southeast Queensland, may originate in northern New South Wales. Relationships need to be tested for temporal correlation between a number of contiguous sites along the central and northern regions on the eastern seaboard.

Acknowledgments

The authors wish to thank Ian Somers of the CSIRO Marine Laboratory, Cleveland, for making available data from CSIRO logbook project covering southeast Queensland in the 1970s. Mark Connell assisted with the preparation of the manuscript.

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Questions and discussion following Dr Gribble's presentation.

Somers: Data from 78, 79, and 80 were missing from the Moreton Bay data, which shouldn't be the case. Secondly, care should be taken with what you call your "offshore stock" and relating that to recruitment in Moreton Bay. Moreton Bay recruits contribute more to the area north of Moreton Island than to *outside* of Moreton Island. The area south of Moreton Island (Jumpinpin, Southport Bar, Ballina and other areas in New South Wales) contributes more to that stock outside, and east of the Bay.

Glaister: Another interpretation of this information could be due to what Montgomery put forward, that the decline is due to the fishery in New South Wales expanding southwards to Coffs Harbour. The fishery has also expanded eastward to deep-water grounds. Fishers used to only fish to 40 fathoms in the 1980s and now they're fishing much deeper. The decline in catch is not dramatic and could be explained by catching more of the prawns in New South Wales rather than in Queensland. I agree with Somers, the offshore stocks may not be coming from Moreton Bay. Most are probably coming from New South Wales. The CSIRO data for catch and effort hasn't changed dramatically, except for within Moreton Bay. There may be a problem within Moreton Bay, but that should not be concluded as recruitment overfishing.

Gribble: What you've just described is an *extended* stock-recruitment. The stock in New South Wales has been reduced which is reducing catches in Queensland.

Glaister: No, the prawns are now being caught in areas where they weren't previously being caught. Instead of migrating northward along the coast and being caught off Moreton Bay, they're being caught off Coffs Harbour.

Hilborn: You've shown us the catch rates, but what is the catch like? The catch rates are going to change in that period for many reasons. You should look at the catch as well.

Gribble: It's the same. It's reflected in the catch, the total catch as well.

Hilborn: It's dropped about 25% as well?

Gribble: In Moreton Bay, yes. As a proportion of the fishery it has dropped.

Somers: I don't believe *catches* actually exist.

Gribble: Percentage of catch, in terms of the total amount caught, it is now a smaller proportion.

Glaister: But only in Moreton Bay.

Gribble: Yes, only in Moreton Bay. That's all I'm saying.

Hill: Could that have something to do with catch composition - as one species increases the other decreases?

Rothlisberg: As the "bay prawns" catch increases, then that alone might drive the king prawn catch down.

Dredge: I know of no overt or massive destruction of habitat or nurseries over the last 20 years in Moreton Bay. Therefore, it's unlikely that any changes in the catch rates from Moreton Bay have been due to disturbance. Secondly, the most obvious change in the fishery between 1978 and 1988 is the development of the deepwater fishing grounds north of Fraser Island. Thirdly, Moreton Bay is a remarkable fishery because effective effort per boat hasn't changed greatly because the boats are limited to two four-fathom nets and many are very old vessels. The total effort hasn't changed very much. The number of boats fishing now is probably fewer than it was in the early 1970s, or about the same.

Pond: No. The number of boats has increased three-fold.

Trainor: There was a period of expansion in the fishery over 20 years. The spatial boundaries of the fishery have changed. With regard to the number of vessels operating in the Bay, the number of boats hasn't changed greatly.

Hill: There is some discrepancy with regard to whether the number of boats has changed. Moreton Bay has been reasonably tightly controlled. It's always been a limited entry fishery on top of an open fishery.

Trainor: Over the last few years there have been about 180 - 220 boats fishing per year. In the 1970s, the CSIRO logbook was up to 120 - 140 vessels and the anecdotal evidence suggests that the number of boats fishing was up around 200.

Glaister: The behaviour of the fishers has also changed over time. Many more fishers are more mobile and go up north for the season. A percentage of those boats are migratory vessels.

Poiner: I disagree with Mike Dredge, that there has been no major change in Moreton Bay over the last 20 years. There has been one significant phenomenon, the massive dredging for the airport. The signal showed up in the benthic community all around there and it was large scale. Secondly, the data coming out on the catchment areas around Moreton Bay suggest there has been a large amount of catchment change affecting the rivers draining into Moreton Bay.

Glaister: Yes, but would that be king prawn nursery ground?

Poiner: I don't know. The question is what is king prawn nursery ground and how does all this catchment change impact upon it? Nobody really knows that for Moreton Bay. The striking thing about Moreton Bay is the *lack* of information, except in terms of mapping, on the effects of these changes on the species' populations.

Dredge: Some work undertaken by Young in the 1970s has been repeated over the last three years, but the data were not available for this workshop. They should become available very shortly and will throw considerable light on the changes in abundance of juveniles in nursery grounds.

Stock and Recruitment Indices for the Western Rock Lobster (*Panulirus cygnus*) Fishery - Biological and Other Considerations

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Abstract

Due to the foresight of previous researchers, several long time-series of data are available for the calculation of indices of egg production from the spawning stock of the western rock lobster. These indices are useful for examining trends in egg production and have been used in the recent revision of stock-recruitment-environment relationships for this species (Caputi *et al.* 1995b). The spawning stock indices are calculated from a combination of fisheries based catch and standardised effort statistics and reproductive biological research data. While western rock lobster fecundity-size relationships and brood size were uniform throughout the fishery, geographic variation in size at maturity and proportion of the population spawning repetitively were important considerations in estimating indices of egg production (spawning stock indices). Recruitment to the fishery is measured independently of fisheries data by the number of puerulus settling on collectors of artificial seaweed stationed along the west coast of Western Australia. The reliability of these data as a measure of recruit abundance is discussed.

Introduction

Australia's most important single species fishery is that for the western rock lobster (*Panulirus cygnus*). In 1993/94 the landed catch of 11,000 tonnes was valued at $300 million. Because of its importance, *P. cygnus* has been the target of intense co-operative biological research between the Western Australian Fisheries Department and CSIRO Division of Fisheries over many years. The availability of long term fishery data sets and detailed biological information permits the calculation of a variety of indices of abundance for life history stages of the western rock lobster. The indices, based on commercial catch and effort statistics and fishery independent surveys, have been used to re-examine the stock and recruitment relationships (SRRs) presented earlier by Morgan *et al.* (1982) (Caputi *et al.* 1995b). This paper briefly examines the spawning stock and recruitment indices used in SRRs in the western rock lobster fishery.

Data Sources

Commercial catch and effort statistics. Collected since 1944, these compulsory monthly returns from the entire fleet provide information on individual fisher's total catch and number of pot-lifts in 1° x 1° blocks.

Research logbooks. Voluntary research logbooks started in 1965 and provide daily catch and fishing effort information from 10 fathom depth categories in 30 x 10 nautical mile transects. Additional information on numbers of ovigerous females and sub-legal size lobsters and environmental conditions is given. About 30% of the fleet participate in this program.

Commercial monitoring. Commercial monitoring commenced in 1969. The on-board monitoring of the catches of commercial rock lobster vessels operates in four depth categories from four ports along the Western Australian coast and provides detailed size frequency data for legal size animals, sexually mature females and sub-legal sized lobsters in each month of the fishing season (November to June).

Processors' production. Monthly production figures are submitted by all holders of licences to process rock lobsters. This system provides total coverage of the landed catch noting that direct sales to the public from commercial vessels are effectively nil. These data have been collected since the fishery's inception and are used to validate the compulsory monthly catch and fishing effort statistics submitted by commercial fishers.

Puerulus settlement. Data on levels of settlement have been collected since 1968 at Jurien Bay and Dongara in the centre of the fishery. Collection of puerulus occurred over short time periods at several other sites until the program was expanded in 1984 to examine the spatial and temporal distribution of puerulus settlement along the west coast at 10 different sites.

Reproductive biological data. Extensively revised reproductive data, such as size at maturity (which varies geographically); fecundity - carapace length relationships; and levels of repetitive breeding, have been available since the late 1980s.

Fishing Power. Data on increases in the fishing efficiency in the fleet since the early 1970s are detailed in Brown *et al.* (1995).

Spawning Stock Indices

Biological considerations. Development of indices of egg production for the spawning stock of the western rock lobster required a detailed understanding of the reproductive biology of this species. In particular, since *P. cygnus* extends over such a large range of latitude, it was important to consider the timing of breeding; the depth and extent of the breeding grounds; geographic variations in size at maturity, repetitive breeding and consequent brood sizes and the fecundity-size relationship (Chubb 1994).

Abundance estimate considerations. The greatest abundance of breeding western rock lobsters occurs in waters deeper than 20 fathoms (36 metres). These depths preclude diver surveys and visual census techniques. Therefore, indices of average breeding-female abundance necessarily are based on catch rates (kg of commercial catch per pot lift). For long time-series data, increases in fishing efficiency over time clearly must be taken into account as failure to do so will result in more recent estimates of abundance being grossly overestimated.

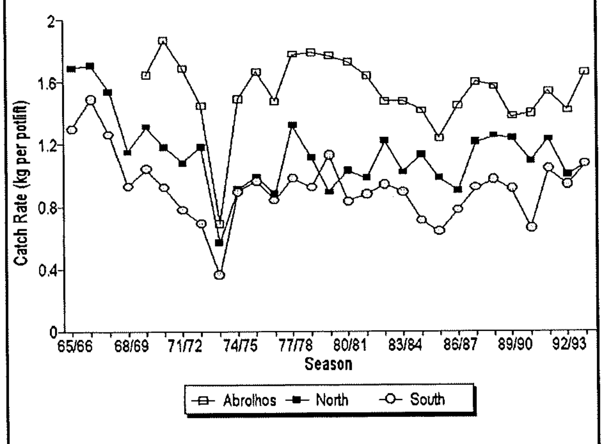

Figure 1. Research logbook catch rates (unadjusted for efficiency increases) for the three fishery management zones.

Indices of egg production. Two different spawning stock indices currently are calculated for the western rock lobster fishery. Research logbook data provide the basis for one index and commercial monitoring data for the other. Catch rates of rock lobsters in March from 20-50 fathoms (36-91m) from the north and south coastal management zones and from 10-40 fathoms (18-73m) at the offshore Abrolhos Islands zone are used to provide indices of abundance for the breeding stock (Fig. 1). The depth ranges chosen represent the major breeding grounds in those sectors. While breeding ceases in February, March catch rates were chosen for two reasons. March is the first period in which protected breeding females are represented in the catch following the end of breeding moult, and secondly it is the month in which fishing commences at the Abrolhos. Monitoring on board commercial rock lobster vessels is conducted from four ports. Data from the two northern and two southern locations are combined to represent the north and south coastal regions respectively. The catch rates of all females from 20-50 fathoms (36-91m) and 10-40 fathoms (18-73m) in the north and south respectively, for all months of the season are used with an adjustment for growth due to a general moult in February.

Catch rates from both logbook and monitoring data sets are standardised for the efficiency increases described in Brown *et al.* (1995). Rock lobster size-frequency distributions for the various regions from the monitoring data and the regional reproductive biological data are utilised in the calculation of both the logbook and monitoring egg indices (Figs. 2&3). There is good agreement between the two sets of indices (Fig. 4).

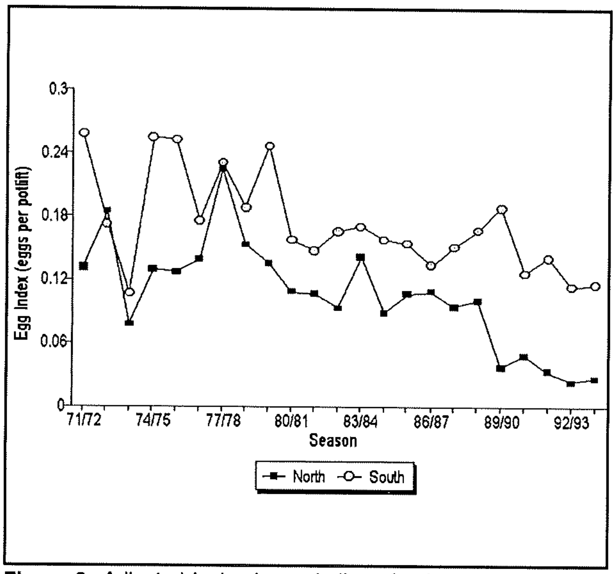

Figure 2. Adjusted logbook egg indices for the north and south coastal regions.

The Abrolhos Islands zone presents difficulties for two main reasons. Monitoring on commercial vessels only commenced in the mid 1980s and is undertaken in this zone for only the first few days of the season (mid March). Secondly, 70% of the egg production comes from sub-legal size rock lobsters This area is receiving more research attention, however, for the time being since most breeding females will moult into legal size rock lobsters and be available for capture sometime during the fishing season, the total catch from the Abrolhos zone is being used as a first approximation for the abundance of the breeding stock in that zone. Past research data provides size composition and egg production estimates for this region.

The regional indices can be used separately to indicate trends in egg production within various sectors of the fishery or they may be combined using an area weighting or more sophisticated ANOVA techniques to give a fishery wide annual index. While the latter index provides an overall indicator of the "health" of egg production, the regional indices have been used to assist managers in determining the extent to which exploitation rates must be reduced within the major management zones of the fishery.

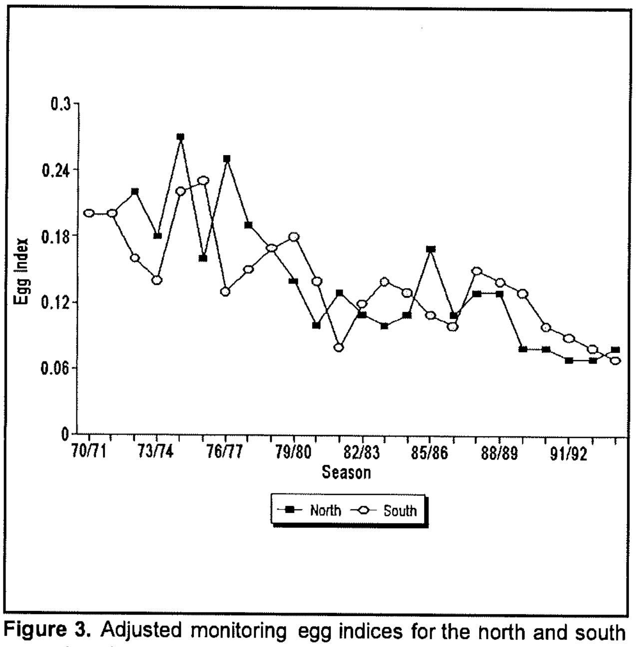

Figure 3. Adjusted monitoring egg indices for the north and south coastal regions.

Other indices. Other spawning stock indices have been generated from the spatial model of the western rock lobster fishery (Walters *et al.* 1993), and a new time-series is being generated from the fishery independent survey of the breeding stock being developed under a grant from the Fisheries Research and Development Corporation. Plankton surveys of early phyllosoma larvae have been suggested as an independent method of assessing egg production (reproductive success), however, larval patchiness, logistics and cost appear to mitigate against such surveys at this time.

Recruitment Index

Puerulus settlement. The monthly collection of puerulus settling on collectors of artificial seaweed provides an annual index of the strength of recruitment to the nursery areas of the western rock lobster fishery (Phillips 1972, Phillips and Hall 1978). This recruitment index is independent of the industry generated fisheries databases. The question of whether the puerulus settlement index actually provides directly comparable measures of abundance of juvenile recruitment to the nursery areas is a valid consideration. The puerulus collectors only sample those puerulus that survive to reach the very shallow coastal waters where the collectors are sited and there is evidence, both research and anecdotal, suggesting that some settlement also occurs in deeper waters. However, research by CSIRO supports the view that the settlement on the collectors provides a good measure of what actually settles on the inshore reefs (Jernakov *et al.* 1994). In addition, there exists an excellent predictive relationship between puerulus settlement and catch three and four years later (Caputi *et al.* 1995a), thus giving strong support to the hypothesis that the index of puerulus settlement does reflect real levels of juvenile recruitment throughout the fishery (Fig. 5).

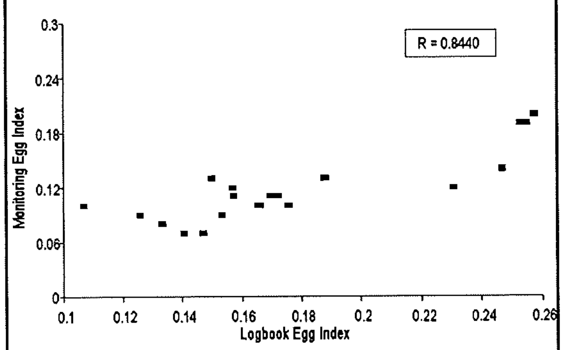

Figure 4. Comparison between the adjusted logbook and monitoring indices for the south coastal region.

Conclusion

Due to the foresight of previous researchers, several long time-series of data now are available for the calculation of indices of egg production from the spawning stock and recruitment to the juvenile populations of the western rock lobster. The spawning stock indices are calculated from a combination of fisheries based catch and standardised effort statistics and reproductive biological research data. While western rock lobster fecundity-size relationships and brood size were uniform throughout the fishery, geographic variation in size at maturity and proportion of the population spawning repetitively were important considerations in estimating indices of egg production (spawning stock indices). These indices are useful for examining regional and fishery trends in egg production and recruitment and provide the basis for the recent revision of stock-recruitment-environment relationships and future stock assessments for this species (see Caputi *et al.* 1995b and these proceedings).

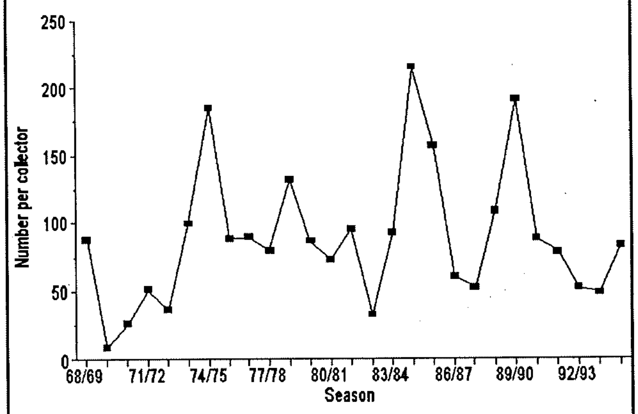

Figure 5. Time-series for average puerulus settlement at Jurien and Seven Mile Beach in the central region.

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Questions and discussion following Dr. Chubb's presentation.

Warburton: Is repetitive spawning or breeding frequency related to growth and feeding conditions and if so, do you think that is an important component of population regulation?

Chubb: In our particular case probably not. It happens regardless of the conditions, although food supply obviously influences egg viability and survival of larvae. In other areas it might do, but in the western rock lobster it doesn't seem to be the case.

Die: How do you determine those percentages of repetitive spawning?

Chubb: Individual lobsters are checked on research boats. If an animal has a spermatophore attached to it and has eggs, we determine whether there is another set of eggs inside. This is done by pulling the abdomen away and observing the bright orange (ovarian mass inside). I'm publishing a paper on it as a technique and although it's effective, on occasions you can miss it. These estimates tend to be best-minimum values for the number of animals repetitively breeding.

Rothlisberg: Was the incidence of repetitive breeding as high as 60 or 80%?

Chubb: Yes, most breed twice.

Rothlisberg: So it's almost the rule?

Chubb: It is common and a very important part of the breeding strategy of the western rock lobster.

Caputi: Do they vary in size, in terms of repetitive spawning? As far as the repetitive spawning goes, is there size variation?

Hill: The graph suggests the smaller ones have a much lower incidence.

Chubb: It tends to be the same as size at maturity. The younger, smaller animals, have one brood when they start breeding, the larger or older ones have the second brood.

Glaister: What is the age difference between the animals that spawn at a small size at the Abrolhos compared with the large lobsters elsewhere?

Chubb: We don't know. There's a great deal of density dependence in the stock. They breed at six to seven years of age. At the Abrolhos it is unknown how old they are when they breed. For an animal at 52 mm CL it's difficult to believe it's six or seven years old. There are large density-dependent effects at the Abrolhos Islands. There are high densities and limited space and food. The growth rates there are likely to be slow.

Glaister: Could they be spawning at a younger age?

Chubb: Yes. Our recent tagging studies will provide some information on growth rates at the Abrolhos Islands. There is also a university study using electrophoresis to determine genetic differences between the two stocks. Mike Johnson from the University of Western Australia and I will also be utilising mtDNA of puerulus settling throughout the fishery to determine genetic differences.

Glaister: There seems to be a similar sort of thing with barramundi in Weipa.

Spawning Stock and Recruitment in the Brown Tiger Prawn, *Penaeus esculentus* in Moreton Bay, Queensland

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Abstract

The brown tiger prawn *(Penaeus esculentus)* fishery in Exmouth Gulf (22° S) Western Australia is one of very few penaeid prawn fisheries where a SRR has been demonstrated. Although this species is of major commercial significance to Queensland trawl fisheries, no such relationship has been delineated on the east coast of Australia. *P. esculentus* is one of three commercially important species in the Moreton Bay fishery (27° S, east Australian coast). The fishery has some features which are similar to that of the Exmouth Gulf fishery. Both occur in partially enclosed embayments, are relatively isolated from other populations of *P. esculentus* (and therefore can be considered as single unit stocks), and occur at latitudes near the southern distribution of commercial catches. An obvious challenge therefore exists. That is, if recruitment overfishing in *P. esculentus* can occur in Western Australia, what is the status of the SRR for this species in similar fisheries on the east coast? In this presentation indices of spawning stock and recruitment for the tiger prawn fishery in Moreton Bay are put forward and recent (SUNFISH) and historical (CSIRO data) records are used to examine the long-term trends in the relationship between spawning stock and recruitment.

Defining the indices

The onset of maturation and seasonal egg production in *P. esculentus* in Moreton Bay is succinct. A population fecundity index (PFI) based upon the percent mature, abundance and mean size of adult females indicates that the bulk of egg production occurs from October to December (Fig. 1). Abundance of adult females in the Bay is low during this period. There is also relatively little seasonal variation in the mean size of adult females (Fig.1). Thus, egg production appears to be driven mainly by the relatively rapid increase in the proportion of mature females, rather than any dramatic increases in abundance or size of females.

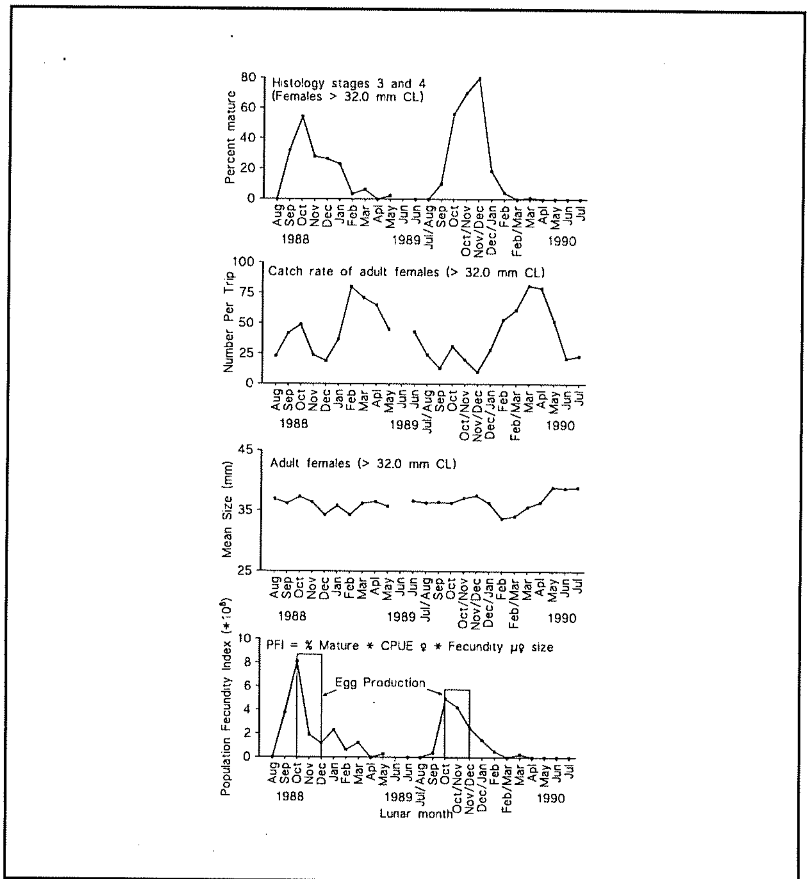

Figure 1. Time-series of factors influencing egg production in *P. esculentus* in Moreton Bay.

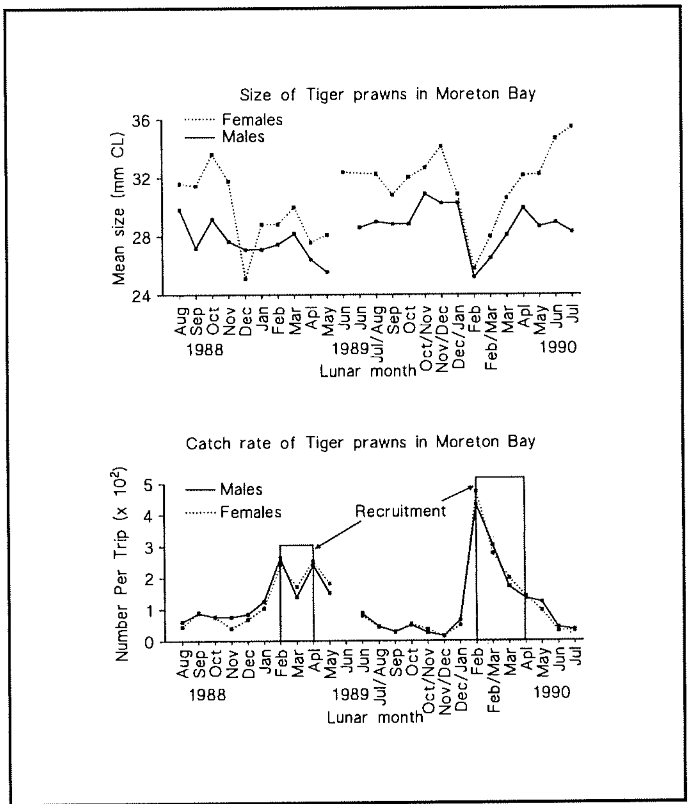

Figure 2. Monthly time series of the size and abundance of *P. esculentus* in Moreton Bay used to define recruitment timing.

The catch rates (CPUE) of tiger prawns in the Bay during this period, determined using logbook data, are suggested as a suitable annual index of the spawning stock.

The mean size and abundance of prawns (Fig. 2) obtained from the same 1988-90 research sampling program (Courtney *et al.* 1991) was used to identify the main recruitment period and to put forward a suitable index of recruitment. Recruitment to the fishery was found to occur from February to April. Again, logbook data on the catch rate of tiger prawns for this period are suggested as the most appropriate method for defining an index of recruitment.

Once the indices were defined, long term records of the CPUE for these periods were sought. SUNFISH logbook data was used to obtain recent estimates of the indices, while data obtained from the concluding report for the East Coast Prawn Research Project (CSIRO report #92, by P. C. Young) was used to obtain estimates from the 1970s. A preliminary assessment of the SRR for *P. esculentus* in Moreton Bay is presented in Figure 3. Each data point represents the mean of three mean monthly CPUEs (i.e. October to December for spawning stock, February to April for recruitment). It should be noted that the data from the SUNFISH logbook database don't include corrections for increasing fishing power, standardisation of effort, or the deletion of non-valid data (as carried out by Penn and Caputi 1986).

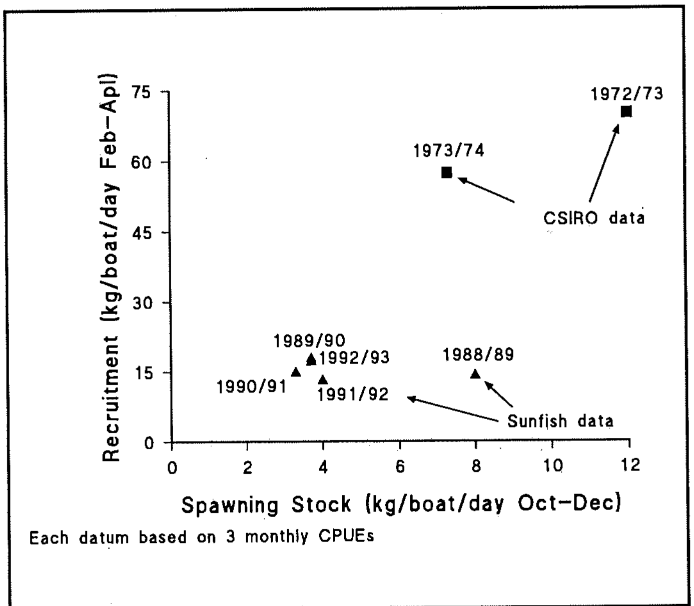

Figure 3. Scatter plot of Spawning stock and recruitment indices for *P. esculentus* in Moreton Bay

One of the problems interpreting this data (Fig. 3) is that the number of vessels and therefore total fishing effort during the early 1970s remains unknown. Anecdotal evidence suggests that the total number of vessels fishing in the Bay has remained relatively stable, or declined slightly. If it is assumed that effort has remained stable, Fig. 3 suggests that catch rates (CPUE) of spawning stock and recruits for *P. esculentus* have declined since the early 1970s.

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Questions and discussion following Mr. Courtney's presentation.

Glaister: Do you think the prawn species composition in Moreton Bay has changed in recent years?

Courtney: Jo Masel is determining that with juvenile and post-larval prawns. In some areas of the Bay there has been a change in the nursery areas, from a dominance of eastern kings (*P. plebejus*) to a dominance of greasyback prawns (*Metapenaeus bennettae*). However, some areas haven't changed. *P. esculentus* has remained the least abundant of the three commercially important species. In terms of hierarchy tigers appear to have remained stable.

Caputi: Do you know the total catch over that period?

Courtney: In publications of his early work on post-larvae, Young stated that the Moreton Bay fishery supported an annual catch of about 2000 tonnes. I've spoken to him about that but it remains unclear to me as to whether he was referring to catches taken solely in Moreton Bay, or to the total catch for the Bay and adjacent, outside waters.

Penn: It would have been better to make the comparison with Shark Bay (26°S - 27°S), rather than Exmouth Gulf. Moreton Bay's seagrass beds are more similar to those of Shark Bay, than those of Exmouth Gulf. Exmouth doesn't have the southern seagrass beds that Shark Bay and Moreton Bay have. Any decline in the Moreton Bay tiger prawn stocks is likely to have occurred a long time ago, given the intensity of fishery. The stock and recruitment indices are now most likely to be at the bottom corner of the stock recruitment graph; the slope is fairly steep. Being a by-catch in an eastern king fishery it's unlikely that there has been too much targeting of the tiger prawns.

Courtney: It's difficult to get an exact measurement of effort targeted at *P. esculentus* and the corresponding catches. In Moreton Bay there are at least three species of major commercial importance and three or four others of *some* commercial importance as well. Delineating exact CPUEs for the various species is quite difficult.

Penn: Is there any possibility of getting the market production of tiger prawns going as a broad indication of what the catch might be?

Courtney: Yes, we can get total catch from some of Haysom's work.

Glaister: There is a complication in that there was, and still are, many retail outlets in the Bay area. The early CSIRO work had the same problem trying to cover all of the possible outlets. Lucas' earlier paper refers to only an approximation because of that problem. Other sources of information are contained within the Queensland Fish Board records. Neil Trainor is currently collating them.

Hilborn: The variations in CPUE that you are observing, in both the king prawns and tiger prawns, may be due to fishers changing their activities. They are profit-driven and when they move further off-shore it is presumably to make more money. It costs more to operate and therefore they have to get a higher catch rate to make it worthwhile. You should stratify your data geographically and examine the catch rates. Variation in catch rates, or a lack of variation may reflect a switch in targeting. In general, be careful using CPUE data, as it can show patterns that are not really there.

Staples: Catchability of tigers in areas like Moreton Bay is very likely to be influenced by temperature. The prawns bury through the winter months and this seasonal pattern in catchability is likely to be imposed over CPUE.

Somers: The tiger prawn catches were highly variable in the period you showed high recruitment. Secondly there were more years with data on tiger prawn catch rates. Why didn't you present that?

Courtney: I included data from 1972-74. Although the historical data presented was only two data points, it consisted of data from three years. The x-value is the catch rate of spawning stock in October-December 1972 and the y-value is the catch rate of recruits in February-April 1973. This was repeated to 1974, so it's actually over three years. I wanted to include data from as many years as possible, but there was the massive flood in 1974 in southeast Queensland. Although catch rates were continued to be recorded, I haven't used the post-1974 data because I consider the flood had a major disturbance.

Somers: The historic catch records go for at least 10 years.

Courtney: Nevertheless, I decided not to use it as it appears catch rates never recovered during the period that Young was recording the data. I selected two - three years where it looked like a relatively normal, undisturbed pattern.

Questions and discussion on the day's presentations thus far:

Hill: In regard to the Western Australian rock lobsters, is there any concern with the decline in egg output?

Chubb: At present the data suggest that recruitment overfishing is not occurring. However, fishing pressure on the stock is high and a management package designed to reduce the number of pots by 18% was recently introduced. It also includes throwing back females that are mature (those with tar-spot, setose, berried females) to reduce the exploitation rate and to boost egg production to late 1970s - early 1980s levels, which were around 25% of the virgin egg production. Fishers didn't like the idea because their catch rates were good due to the fishing efficiency and the aggregating behaviour of the animal. However, there is a 50% reduction of puerulus settlement around the Abrolhos Islands compared to the 1970s and this is indicative of a future decline in catches. The lack of settlement in the southern parts of the fishery for the last 2.5-3.0 years and other information also indicate that we should be cautious. The advisory committee therefore took the decision to go back to that level of egg production..

Glaister: Most indices mentioned thus far have the advantage of being *fishery independent* estimates. For penaeids the *fishing industry* provide the indices through CPUE. If the indices are based upon commercial CPUEs for prawn, is it likely to lead to anything useful, given the changes in catchability and fishing power that occur?

Hill: GPS has altered CPUE. Effort has changed incredibly in a way that is difficult to measure. It's not just more fishing days, or more net being towed, it's vague and difficult to quantify.

Penn: Researchers use this CPUE data as a measure of the fisher's activity. The behaviour of fishers, changing the horsepower of boats and putting on GPS result in spending less time searching. All of this information is important and should be considered. Many people *collect* it but not many people *use* it. Simply taking days fished, or hours trawled is not giving a true figure over time. It's critical having those databases in place. We regard the state of the fishers, in terms of understanding the fleet effort dynamics, just as critical as studying the animals themselves.

Staples: There is a good conceptual model of eastern king prawn migrations and stock, yet we're trying to get *local* indices which are not on a *stock* basis. Although the tiger prawn stock is relatively isolated and well defined, the king prawn fishery is very widely distributed.

Glaister: With regard to Chubb's suggestion of collecting early stages, you could stratify along the coast and work out a way of extrapolating that as an index of recruitment. The problem is measuring the spawning stock which is producing those recruits. At present we are solely dependent on what the fishers do to measure that.

Caputi: You need to do both fishery dependent and independent measures. You also need to be aware of the spatial variation in recruitment because it may provide information about recruitment overfishing on the fringes. You also need to be aware of the combined recruitment, so you shouldn't do just one or the other. You need to do both to get a balanced picture of whether recruitment is varying in the same way, year by year, or whether there's unusual trends in certain areas.

Penn: In Queensland there are 900+ trawlers sampling all stages of the life history. It's unlikely that any sort of research sampling program can provide anything like the accuracy that those 900 can harness. It is more useful to utilise them to measure and quantify the units of effort, even if it means sub-sampling, getting a standard fleet, encouraging them to fish in particular areas, or having some of them pull out data for particular areas. It will tell you much more than getting out and trying to sample it yourself. There's a lot to be gained by utilising the database system that's already there rather than trying to ignore it.

Hill: Carolyn Robins is looking at changes in effort in the northern prawn fishery. A meeting with industry earlier this year estimated that it had increased effort by 30%. Has effort changed in other fisheries and specifically what effect is GPS having?

Caputi: Rhys Brown and I have been looking at that for the western rock lobster. It varied depending on the area (inshore or offshore) and on the behaviour of the animal at different times of the year. In the migratory phase it wasn't that important. In inshore fisheries where the areas could be found by land markings it wasn't that important. In the offshore sedentary part of the life history it was significant, and that came out consistently for three or four years in a row by comparing boats with and without GPS. It also depends on the abundance of the animals. When you remove the catch, you reduce the areas of high abundance. Once those areas of high abundance are reduced and the variability in catch between areas is not that great, the use of GPS is of minimal benefit. When there are areas of variation in catch rates ranging from very good to very poor, having GPS and being able to find those good areas first is quite important. If you apply the use of GPS to a spawner catch rate (spawners are returned to water), there are variations in abundance of spawners from so called good grounds and poor grounds. The correction factor you have to apply to that is 4-5% per year compared to the catch which you retain which is 1-3% per year. Thus, there is a lot of work to be done in terms of those fishing power studies and in particular GPS. It's not simply coming up with one figure per year and applying it to everything. It depends on life history and whether you throw back the animals and there's a lot more work to be done.

Chubb: GPS has enabled new entrants to learn very quickly where the "good ground" is and to be able to target certain areas. The learning curve is very rapid at present for new entrants in the fishery, whereas before you had to know what you were doing and it took a number of years to learn. It's most likely to be the same with the prawn fishery.

Dredge: The trawl fishery in Australia has historically had quantum leaps in efficiency. It went from single gear to twin gear, then the lazy line, echo sounders, automatic pilots, sonar, and GPS. There's one major increase in efficiency every five years and fisheries' managers and biologists don't anticipate them. It's never going to get less efficient. It needs consideration by managers and ourselves.

Die: In regard to measuring indices of recruitment and spawning stock, I agree with Caputi that it is important to take both approaches. Given that it took several years for the Western Australian researchers to identify suitable indices in their fisheries, is it worthwhile identifying such indices in the eastern king prawn fishery?

Caputi: It's best to have both fishery-dependent and fishery-independent estimates of recruitment and spawning stock because they provide two different estimates. You may find that both estimates of recruitment co-vary for 10-15 years, but then suddenly differ. It would be unwise to rely solely upon one source of information.

Hill: In the northern prawn fishery the banana prawn fishery is likely to be unaffected by the introduction of GPS since the main targeting method is by way of aircraft spotting schools of banana prawns.

Penn: In terms of quantifying what that measure is, we regularly go through a fishing power estimation each year for the trawl fishery. We handicap vessels and estimate an average which gives a standard fleet from year to year. When radar came into the fishery the majority of the fleet didn't use it greatly. We used it as a research tool and in the process, were able to locate particular areas of tiger prawns in the Shark Bay fishery. We were using commercial vessels for the survey and they twigged onto this immediately. The fishing power of the 4-5 vessels which decided to use it went from an average of 1 to an average 2. They immediately started to use radar as a means of locating aggregations. That occurred two years prior to the Shark Bay fishery collapse and was likely a major contributing factor. Radar alone gave them a 50% increase. GPS is making every "mug fisherman" a "good fisherman" because they can now all locate aggregations and when they do so they can go back and find it again, which they could not do in the past.

Hill: Major catastrophic events can occur. The Western Australian data showed one terrible year for catches of the lobsters and a similar decline occurred in the banana prawn fishery in the northern prawn fishery. We tend not to factor-in the possibility of such catastrophic events or the effects they have on the fishery, or its management. Is there any way we can take into account these "rare events"?

Chubb: A decline in catch rate that Tony Courtney showed earlier corresponded to a big El Nino southern oscillation (ENSO) event occurring during those same years. Given that the ENSO affects fisheries on the west coast, should it be an important consideration on the east coast of Australia?

Penn: There seems to be cycles in the king prawn catches on the east coast. Has anybody examined the sea levels to determine whether the East Australian Current or the ENSO events are correlated with these cycles on the east coast?

Glaister: There are people in other disciplines who have looked at the frequency of ENSO events on the east coast. DPI have looked at that in terms of cropping and other primary activities. The logbook program was developed in 1988 and therefore there aren't a large number of years of data to examine for such correlations.

Penn: We have distinct environmental influences on the west coast which show up in many areas. Consequently, a number of correlations can be found. There is a good correlation between puerulus settlement and scallop settlement. A poor Leeuwin Current generates high scallop recruitment but it looks to be generating low catchability due to the temperature effect on the king prawns in the same year. In the last three years of this ENSO event we've had world record scallop catches. Prawn catches, however, were the worst on record and lobster puerulus settlement was down for those years.

Hill: Ron Thresher found a tender correlation between westerly winds and lobsters, wallabies and rabbits. The westerly winds affect rainfall and therefore land vegetation and it seems to affect gemfish.

Koslow: There's an enormous tendency to fix onto the ENSO events. In many areas, even areas where ENSO strikes very hard, such as the coast of California, there often aren't very good correlations between the ENSO events and fishery recruitment. ENSO does have an effect along the east coast, but there are also different processes working on different time scales. When you start looking at relationships with recruitment it's important to look at a variety of types of data and be aware of the fact that there are distinctly different processes working on different time scales.

Staples: "Inter-decadal shifts" is a term being used to describe changes in pelagic fisheries. These refer to complete changes in ecosystems, i.e., changes from anchovies to sardines. It has not been applied to crustacean fisheries as yet.

Hilborn: The concept of inter-decadal shift is being examined by a number of people at the University of Washington. It appears applicable in the North Pacific to stocks of sockeye and pink salmon, a crab fishery that disappeared, the pollock fishery, another salmon species, and the chinook and koho which are endangered. It puts a completely different perspective on things and is very complicated because it suggests that the data you collected in the *old* regime is really not relevant to the *new* regime. It's not the same as separating out another variable in a multiple regression. Although nothing discussed here so far appears applicable, inter-decadal is worth keeping in the back of your mind.

Rothlisberg: The effects from environmental occurrences are species-specific. Off the Oregon coast there was an intense upwelling which was generally considered to be very productive. However, for a pandalid shrimp it proved to have a negative effect because they were trying to get their larvae offshore rather than onshore. Secondly, it may be appropriate to relate inter-decadal shifts in the North Atlantic or North Pacific to fisheries with 100 year data sets. On the east coast, with 5, 6 and 3 year data sets, no such shifts will be detected.

Staples: Just because we don't have the data doesn't mean it's not going on. Recruitment of tiger prawns in the Gulf of Carpentaria is lower at present than it was 10 years ago. Is that a decadal shift in the recruitment level?

Somers: I don't know.

Warburton: Much of the variability may be due to ongoing changes in the trophic interactions between predator and prey. You can generate a lot of the noise in stock recruitment type curves from bio-energetic models that incorporate those sort of trophic interactions under certain circumstances. Much of the noise there might be deterministic and it might be very biological. It might not be directly related to climatic events.

Hilborn: With short lived species, it would be very easy to conclude that there has been a change in the SRR, when in fact there has been a trophic shift. A change in trophic interactions could result in recruitment being halved. With the longer-lived species you're more concerned with the opposite problem, that you fail to detect a SRR curve when it's there.

(End of tape).

Day 2. Biological Considerations for Defining Spawning Stock and Recruitment Indices (con't). (Session III chaired by Dr. Jim Penn)

Characterising the Spawning Population of Grooved Tiger Prawns

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Abstract

Definition of the spawning population is essential to be able to relate the spawning stock to subsequent recruitment to the fishery. For grooved tiger prawns, *P. semisulcatus*, the important features of the spawning stock can be summarised in four categories: critical seasonal spawning periods, age composition of spawners, spawner performance, and spatial spawning patterns.

The major spawning period is from August to October, both in terms of the overall amount of egg production and the subsequent survival of larval and juvenile stages to result in recruitment of young adults back to the fishery during December to March. Another spawning period in January and February results in recruitment after May and contribution to the fishery after August. As a result of recruitment from these two spawning periods, the spawning stock during the major August to October spawning is composed of two age classes of females: 6 and 12 months old. The seasonal and age variability in the reproductive performance of live spawners taken from the Gulf has been assessed under controlled conditions at the Cleveland laboratory. Spawning rates and larval production rates vary both with season and with the age of the female. The diet of the females also affects spawner performance in the laboratory, suggesting the possibility that in the wild different spawning habitats could result in different levels of spawner performance. Since larvae rely on tidal and wind-driven currents to be able to reach nursery areas, the distance of spawning from suitable nursery habitat determines the effectiveness of a particular spawning. The spatial distribution of spawning in relation to seasonal spawning peaks is described.

Effective spawning can be defined as that part of the overall spawning output which results in recruitment to the fishery. Estimates of the spawning stock used in models for management of the fishery can be continually refined by incorporating the effects of the above factors.

Questions and discussion following Mr. Crocos' presentation.

Hilborn: There's no evidence in your data that there are two peaks in the number of spawners.

Crocos: It's supported by the recruitment indices that follow. In some years there is a significant second peak. There's also a switch between the contribution of spawners at six and twelve months of age in January. It's also supported by the larval data, which consistently support two peaks in larval abundance.

Hilborn: How do you know which part of the unimodal average distribution the two larval peaks come from?

Crocos: We work backwards in time from the stock through the larval stages. The larval data supports two peaks and the bimodality of the larval data continue through to the older life history stages. *P. semisulcatus* operates in the same way as *P. merguiensis*. The trouble is that for *P. merguiensis* it stops later on in one cohort but *P. semisulcatus* continues through. It's not the same magnitude by any means but it does carry through.

Staples: The larval life history is very short and the link between the larvae and spawning is within a month.

Milton: You spoke of them spawning in July offshore, but that doesn't contribute to the juveniles in the inshore habitats. Why do you think they would be doing that?

Crocos: There is spawning activity there and therefore, egg production but it doesn't show in the larvae. It doesn't show in any of the estuarine stages. It's similar to the banana prawn situation in the southern Gulf where there's massive spawning going on during March but because larval vection is off the coast, you never see anything of them.

Hill: If you take the east and west sides of the Gulf, an onshore wind on one side of the Gulf is offshore on the other side. What Crocos is presenting for Albatross Bay might be the complete opposite for the other side of the Gulf. It's likely to be one of the keys to the success of the penaeids. Their life cycle can cope with living in many different areas because they're not dependent on the conditions of only one environment. Two spawning peaks is a classic example, where in one area, one spawning period is the important one and in another area the other spawning period is the important one.

Milton: I wanted to know if it might be a continuous spawning and that survival of the larvae might be restricted to only two critical periods.

Crocos: Yes, there is a certain amount of spawning at other times, but the amount of recruitment that comes from those other spawning periods is negligible.

Penn: You said that there's actually only one spawning per year with most of the species you've examined. What's the evidence that these animals, which you're recording as ripe, are not multiple spawning right through that period?

Crocos: I suspect they are, at a rate that we make assumptions about, at approximately a monthly rate. There are two spawning periods for the *population* as opposed to multiple spawnings of *individuals* within that whole four-month period.

Penn: So an animal spawning in July will then spawn again and later contribute to the other peak.

Crocos: Yes.

Penn: So July is only one spawning that is wasted out of four or five spawnings?

Crocos: Yes. There is a low level of spawning throughout the year. The point is that the spawning in July happens to occur well offshore and so it's got an even further handicap to being effective.

Staples: According to one of Serge Garcia's papers, the movement to offshore and then back in to spawn is common in all penaeids. Have you got any comment on that?

Crocos: Serge Garcia has a number of cases where that's applicable to varying degrees. *Metapenaeus chinensis* is the example where the greatest distance is involved but he categorises the return migration as a *spawning* migration. It goes from deeper to shallower water and you see evidence of it in banana prawns.

Staples: There must be some reason for that.

Postlarval Recruitment Dynamics and Coastal Oceanography used to Estimate the Spawning Location of the Eastern King Prawn, *Penaeus plebejus*[1]

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([1]This paper is a precis of: Rothlisberg, P.C., Church, J.A. and Fandrey, C.B. (1995) A mechanism for nearshore concentration and estuarine recruitment of postlarval *Penaeus plebejus* Hess (Decapoda, Penaeidae). *Estuarine, Coastal and Shelf Science* **40** (in press), plus two original figures presented herein)

Abstract

Postlarval *Penaeus plebejus* abundances were monitored during both the full and new moon at three adjacent sites in southeast Queensland, Australia: in the mouth of the Nerang River; 2 km offshore; and 12 km offshore. At the offshore sites postlarval abundance peaked during the night. In the mouth of the estuary, peak abundances were always within 3 to 4 h of the start of the flood tide, regardless of day or night. Postlarval densities were 10 to 12 times greater in the mouth of the estuary than offshore. We suggest that this coastal concentration is caused by the postlarvae being trapped inshore by tidal currents once they become tidally active. The variability in postlarval abundances on each flood tide is caused by the interaction between the alongshore currents, the varying distances between estuaries, and the number of tidal cycles the postlarvae have been trapped. This mechanism of tidal trapping and delivery explains how postlarvae can enter nursery grounds without sensing horizontal gradients in estuarine properties such as salinity. Current speed measurements at two offshore sites (4 and 17km) and postlarval age estimates were used to calculate across-shelf and alongshore advective trajectories and thereby estimate the proximity of effective spawning areas to nearby nursery grounds. The importance of near-shore spawning, limited advection and local recruitment may have been underestimated in *P. plebejus*.

Introduction

Penaeus plebejus Hess is endemic to eastern Australia and has a relatively limited distribution in commercial quantities from 21°S - 38°S. This distribution superficially overlaps with the East Australian Current (EAC) which has been invoked for transporting larvae and postlarvae from northern deep-water spawning grounds to nursery grounds from Moreton Bay, Queensland to Lakes Entrance, Victoria. Long distance, northward migrations of adults have also been documented and these have been invoked as the mechanism whereby the northern spawning populations are replenished. However, there have not been any systematic studies of spawning distribution or larval distribution and transport. This study addresses the larval transport question in an attempt to get a clearer understanding of the potential spatial relationship between spawning populations and postlarval recruitment.

Methods

Vertical migratory behaviour of postlarval *Penaeus plebejus* was monitored every 2h for 96h during both the full and new moon at three adjacent sites in southeast Queensland, Australia: in the mouth of the Nerang River; 2km offshore (20m depth); and 12km offshore (50m depth). Coastal currents were also measured at stations 4 and 17km offshore. See Rothlisberg *et al.* (1995) for details.

Results and Discussion

Coastal concentration mechanism

At the offshore sites postlarval abundance peaked during the night (Fig. 1a). In the mouth of the estuary, peak abundances were variable in magnitude but were always within 3 to 4h of the start of the flood tide, regardless of day or night. The mechanism that initiates tidal behaviour of the postlarvae occurs shoreward of our nearshore sampling station (20m depth, 2.2km from shore) and may simply be a response to a pressure change. When the pressure change at the bottom becomes a significant fraction of the total pressure, we suggest the postlarvae change from a diurnal vertical-migration pattern to a tidal vertical migration. Postlarvae become inactive after 3 to 4h by an endogenous clock.

Postlarval densities were greater in the mouth of the estuary than offshore. We suggest that this coastal concentration is caused by the postlarvae being trapped inshore by tidal currents once they become tidally active (Fig. 1b). Estimates of the effectiveness of this mechanism are consistent with the observations - densities 10 to 12 times greater in the mouth of the estuary than offshore. Further evidence for the widespread nature of the mechanism is the surf-zone fishery for *Penaeus* postlarvae in Ecuador to supply their aquaculture industry.

Postlarvae within 500m of the coast and 2000m up-current of the estuary mouth will be swept into the estuary on the first 3h of the flood tide. Postlarvae are not exposed to estuarine cues because they are inactive and up-current. This mechanism explains how postlarvae enter nursery grounds without sensing horizontal gradients in estuarine properties such as salinity and therefore be found in both positive and negative estuaries.

The variability of the alongshore currents together with the varying distances between estuaries will result in a variable number of tidal cycles over which postlarvae can accumulate in the nearshore zone before being swept into an estuary on flood tide. This variability is consistent with the observed differences in postlarval abundance between successive tidal cycles.

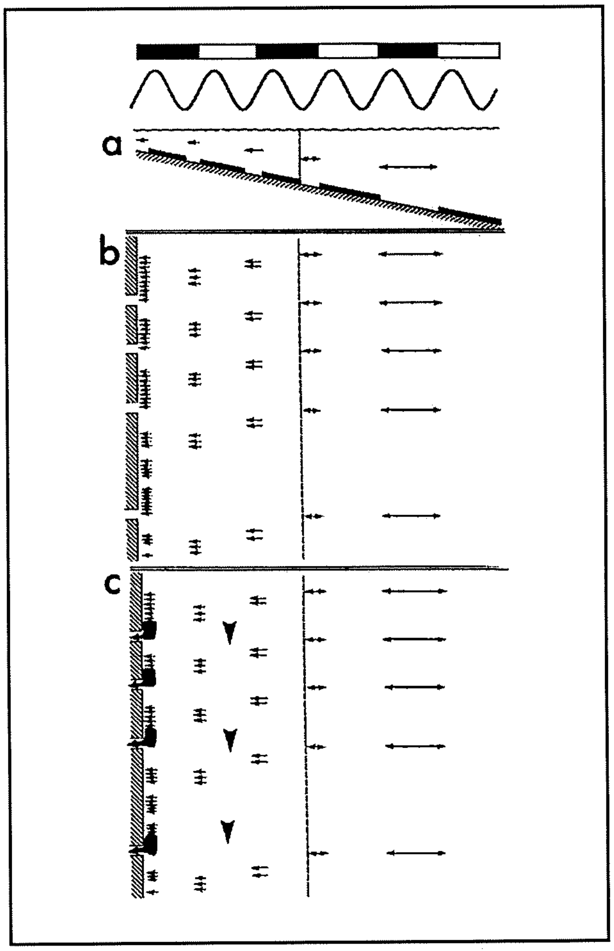

Figure 1. Schematic representation of the coastal concentration mechanism for *Penaeus plebejus*. (a) Cross sectional view showing diurnal vertical migration offshore and tidal vertical migration inshore of transition point (vertical dashed line). Offshore of the transition point postlarvae are transported both onshore and offshore with the tidal currents. Inshore postlarvae only move shoreward during the first 3h of each tidal cycle. (b) Plan view, with coast (hatched bars) and estuaries openings. With each tidal cycle postlarvae are concentrated on the coast. (c) Plan view with southerly current (arrows). In the first 3h of the tidal cycle those larvae within the tidal influence of the estuary are removed from the coastal zone and deposited in the mouth of estuary. The number of postlarvae deposited in a tidal cycle depends on the number of tidal cycles since crossing the transition point and the distance between estuaries.

Coastal transport distances

Current speeds and postlarval age estimates were used to calculate across-shelf and alongshore advective trajectories and thereby estimate the proximity of effective spawning areas to nearby nursery grounds. Larvae released at the shelf break (200m), on the inner edge of EAC, will be transported south probably at least 400km before they reach the coast. However, most of the larvae will be taken offshore as the EAC swings eastward, north of Sydney. Larvae released on the mid shelf will have a higher probability of reaching the coast and would also drift south and recruit to estuaries within 200km of release. Larvae released on the inner shelf have the highest probability of reaching the coast and would recruit to estuaries both north and south of the release point.

There are two pieces of evidence that near-shore spawning is contributing to *P. plebejus.* recruitment. Firstly, we found early larval stages in our 20m station samples, located 2.2km from shore. These larvae are only a few days old and therefore, spawning was happening nearby, and, because of the small cross-shelf currents, close to shore. The second piece of evidence that spawning may be localised is a re-analysis of the tagging data of Glaister *et al.* (1987) for northern New South Wales. The tagged prawns dispersed slowly and moved both north and south (Fig. 2). After 1 month 80% of the released prawns were still stationary and equal numbers had moved both north and south. After 2 months about 40% had not moved, 37% had moved north and 22% south. After 3 months almost 30% still hadn't dispersed, 50% went north and 20% had gone south. While the long distance northward migrations are undeniable, they must be put in a population context with the number that don't move, or move south. These non-migratory females, or southerly migrants, could be the 'effective spawning population' responsible for the postlarvae recruited to the estuaries. Therefore, near-shore spawning, limited advection, and local recruitment has probably been underestimated in defining a spawning stock and recruitment relationship for *P. plebejus*.

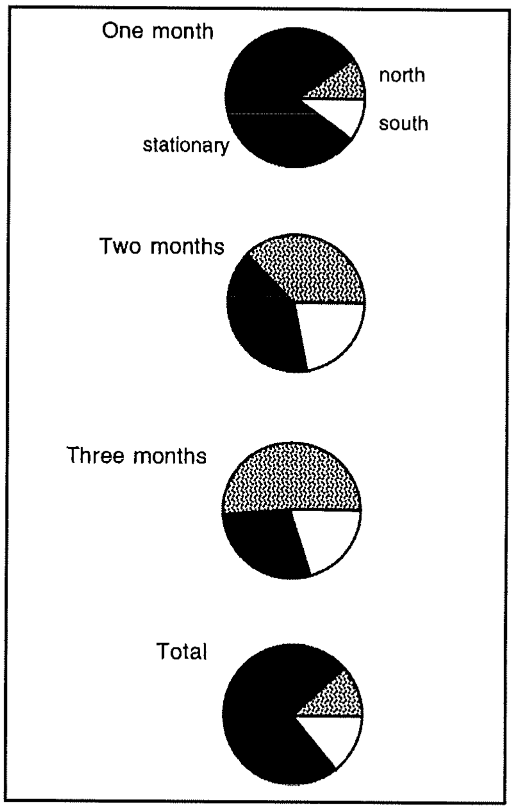

Figure 2. Pie charts summarising recapture data from Glaister *et al.* (1987). After 1, 2 and 3 months at liberty. Total recaptures (dominated by the 1 month recaptures) are also given.

Reference

Glaister, J.P., Lau, T. and McDonall, V.C. (1987). Growth and migration of tagged eastern Australian king prawns, *Penaeus plebejus* Hess. *Aust. J. Mar. Freshwater Res.* **38**: 225-241.

Questions and discussion following Dr. Rothlisberg's presentation.

Glaister: Racek's early work suggested *P. plebejus* spawn as far south as Sydney. He suggested that there was a relative change in temperature that would produce the spawning rather than a *particular* temperature, which is consistent with what you are saying.

Rothlisberg: *P. plebejus* is more temperate than most penaeid prawns. It lives in deeper water than most and is probably capable of spawning at lower temperatures than we're used to dealing with in the more tropical penaeids.

Penn: It's likely to have a short spawning season. If you compare it with the western king prawn *P. latisulcatus*, the spawning season gets shorter and shorter the further south and it's harder and harder to detect.

Rothlisberg: At Southport the post-larval recruitment is very protracted. There's post-larvae coming into Southport every month of the year. I don't know whether that would diminish the further south you went. It probably would for those same reasons as you've described.

Dredge: Your descriptions of the East Australian Current (EAC) tend to diminish its variability and potential speed. You're looking at an average situation, whereas in reality there are going to be times when the EAC goes much faster than 15km/day and it's going to transport larvae much faster.

Rothlisberg: That 15 km/day was *not* EAC speeds. If I'd used EAC speeds I'd come to the same conclusion Ruello came to - that the larvae end up in Tasmania. I'm suggesting that the larvae are up on the shelf *away* from the EAC, that they are still on the edges and effected by wisps and eddies. This makes their transportation rate much lower and more variable, in both speed and direction, than previous estimates.

Dredge: I disagree because even on the shelf there are periods when there's a consistent 2 knot southerly set on the shelf. It's a dynamic, noisy system and there are periods when larvae are going to move long periods.

Rothlisberg: I've spoken with the oceanographers about that and nobody is measuring up there. It's too difficult and they don't want to look at anything shallower than 200 metres because there's too much noise. In some of the more northerly waters are coastal trap waves, which are driven by wind events in Bass Strait. They're propagated up the east coast. Thus, pulses of wind events in Bass Strait can effect larval transport as far north as Brisbane. These are the types of factors that should be considered when defining the dynamics and dimensions of recruitment variability.

Patterns in the Distribution and Abundance of Female Eastern King Prawns, *Penaeus plebejus*, in Spawning Condition in Waters off Eastern Australia

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Abstract

Sampling was done between March 1991 and February 1993 off New South Wales to collect information on the distribution and abundance of the spawning stock of female eastern king prawns off the east coast of Australia. Preliminary results suggested that the proportion of stage III and stage IV oocytes in ovaries was greater in waters off northern New South Wales than further southwards. The number of females classed as having stage III or stage IV ovaries was significantly greater between autumn and spring in each year of sampling and there was no difference in the number of stage III and stage IV females between places sampled.

When data from New South Wales were combined with those collected off Queensland during the same period, the abundance of females classed as having stage III or stage IV ovaries was significantly greater in waters off northern New South Wales and Queensland than further south.

Questions and discussion following Mr. Montgomery's presentation.

Crocos: You've showed clearly that there's an increase in the abundance of spawners as you move north. Are there enough spawners as far south as Port Stephens to constitute local recruitment?

Montgomery: Yes, particularly given Rothlisberg's scenario, but the number of spawners is very low and they only occur for short periods. Commercial fishing of eastern king prawns occurs as far south as Gippsland Lakes in Victoria. South of Port Stephens the prawns are generally below the size at maturity (i.e. less than 35-40mm CL). Most prawns >35mm CL occur at Coffs Harbour and northwards. Our tagging results indicate that relative rates of movement vary between release times and places. They generally don't move south. Those prawns shown by Rothlisberg to move south were associated with only very localised movements (< 50km).

Staples: Were these samples from commercial boats and at what depth?

Montgomery: All samples were obtained from commercial vessels. In New South Wales the depths ranged from 30-60 fathoms. The three areas sampled from Queensland were from Mooloolaba at 70 fathoms, Lady Elliot Island at 120-140 fathoms and the Swain Reefs at about 120 fathoms.

Glaister: That refutes Rothlisberg's theory because the prawns are further out to sea and in greater depths.

Rothlisberg: No, the inner edge of the East Australian Current (EAC) occurs in depths greater than 180 fathoms.

Montgomery: Much depends on how you define the EAC. The influence of the EAC goes out past the continental shelf.

Rothlisberg: Of course it does.

Montgomery: The EAC moves onshore during spring to summer. The tongue of it extends down below Sydney from spring to summer and then backs off over winter. The structure of the EAC changes in space and time and compounds the situation.

Rothlisberg: Much more systematic sampling of the EAC and the temporal and spatial distribution of spawners needs to be done. I didn't say I had the whole answer I was just trying to set some new bounds.

Montgomery: The other question is, do juvenile eastern king prawns require an estuary phase?

Penn: Is it possible there are large females in low abundance in deep, unfished waters in southern New South Wales? Does the fishery stop in deeper waters because abundance is simply too low? On the west coast you can catch *P. latisulcatus* in 60-80 fathoms almost anywhere on the coast in very low numbers and they're mostly very large spawners. Commercial fishing occurs much closer to the coast. The number of very big animals that are out there can contribute to egg production.

Montgomery: The commercial fleet is going to fish where the main abundance of eastern king prawns are. Off Port Stephens boats don't go to the continental slope, but we do have a trawl fishery that does go to the slope and generally there is no evidence to suggest that large females are caught there. Off Eden, the trawl fish boats may catch one or two king prawns from 70-100 fathoms but they're only very small prawns (20 - 35mm CL)

Glaister: There was a great deal of trawling done by Kaparla in the mid to late 1970s. There is also the royal red (very deepwater prawns) boats working in that area as well.

Montgomery: In 1992 we used the Kaparla in waters north of Coffs Harbour to study the distribution of spawners outside the main fishing grounds. We never even found small quantities.

Rothlisberg: The skipper of a vessel we contracted from Tweed Heads assured us that he could catch spawning kings prawns in close to the shore. Tony Courtney also made the comment that proportion of tiger prawns spawning was at a maximum when the population was at a minimum. Very small numbers were contributing to spawning. That's also the case for *P. merguiensis*. Almost imperceptible numbers of adults (a time when it's not commercially viable for fishing) are producing postlarvae.

Penn: Is there much variation in recruitment strength and timing between years in New South Wales?

Montgomery: No, recruitment is generally stable for most of the coast. It is more variable in the south near Gippsland Lakes.

Rothlisberg: Does the recruitment of those post-larvae occur at a certain time of the year?

Montgomery: We haven't looked at the post-larvae in those estuaries.

Somers: Why haven't you just had a look for early stage larvae?

Montgomery: It has been a high priority on our list and we have an externally funded study starting in Botany Bay this year to examine some of those questions.

Die: We examined the reproductive condition of females from six transects in three different depths during an FRDC project off Moreton Island and the data showed there was no spawning whatsoever under 40 metres.

Hill: *Penaeus indicus* in South Africa recruit in waves which progress from north to south. Spawning occurs in the north around Mozambique and the northern part of Natal, at latitudes similar to those of Brisbane and the recruitment occurs down the coast for 500 - 1000km. You can follow distinct waves of recruits down the coast from one estuary to the next. Similar waves of recruitment may occur in the eastern king prawn fishery.

Lunar Variation in Population Structure and Reproductive Activity in *Penaeus plebejus*

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Abstract

In the offshore waters (depths greater than 100m) of southeast Queensland, eastern king prawn fishers regulate their fishing activities according to lunar phase. They argue that catches increase leading up to the full moon phase. Although early research undertaken by Racek (1959) suggested that there was a lunar periodicity in migration from estuaries to open water, there is very little known about activity patterns in adult *P. plebejus* in relatively deep, offshore waters.

With this in mind, a study was initiated to test the hypotheses that population structure and reproductive activity in adult eastern king prawns are independent of lunar phase. Three transects were established off Moreton Island in approximately 150m and sampled every three days for two consecutive lunar cycles (May to July 1993). Hypotheses tested included that sex ratio, moulting frequency, abundance, ovary weight and histological condition are independent of lunar phase.

The sex ratio varied significantly with lunar phase and was heavily biased towards females. Females were frequently 2 to 3 times more abundant than males. Males showed greater variation in abundance over the lunar cycle and were therefore responsible for most of the variation in sex ratio. Male abundance generally increased at the time of the full moon, which was the only period when the ratio approached 1:1. There were no obvious trends in moulting frequency for either males or females.

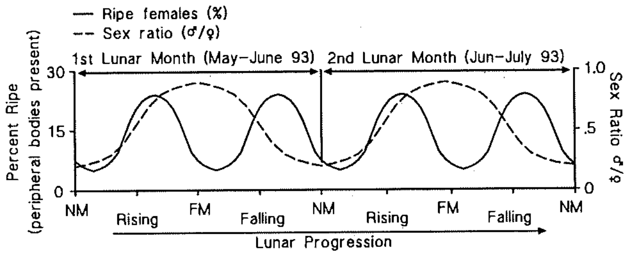

Figure 1. Trends in sex ratio and percentage mature in transect samples from deepwater eastern king prawn trawl fishing grounds.

A high percentage of the females, ranging from about 94 to 98%, were inseminated throughout the two lunar cycles. There was no apparent trend in the percent inseminated. Results from ANOVA indicated that there was a significant difference in ovary weight for some size classes (45.0-50.0mm CL and 50.0-55.0mm CL). Generally, ovary weight was low at or around new and full moon phases, and high around the half moon phases (falling and rising). These results were supported by histological condition of the ovaries. The percentage of females with ripe ovaries (those with peripheral bodies present) differed significantly with lunar phase. The percentage was generally low (< 14%) around the timing of the new and full moon phases and high (> 20%) during the half moon phases.

A preliminary model of the changes in sex ratio and the percentage of mature females is presented graphically in Fig. 1. In terms of quantifying and monitoring spawning stock levels in the eastern king prawn fishery, the results suggest that both the abundance (CPUE) and stage of maturity in adult females are partly dependent upon the lunar phase when they are sampled. Thus, if catches from either the commercial fleet or from research sampling are used to define suitable indices of spawning stock, consideration should be given to the time in the lunar cycle at which the samples are attained.

References

Racek, A.A. (1959). Prawn investigations in eastern Australia. *Res. Bull. State. Fish. NSW.* **6**:57 p.

Questions and discussion following Mr. McGilvray's presentation.

Glaister: Interest by commercial fishers initiated this work. They were considering short term lunar-based closures to minimise impacts on spawning females. The incidence of spawning, on an annual basis, suggests that you'd have to have it every month. There's no discrete period in the year where you'd focus on.

Penn: The fleet also move into deeper water on the full moon in Western Australia, but not because the prawns are more abundant on the full moon in the deep water. It's because the catchability is *lower* in the shallow water. The entire fleet moves offshore to avoid the low catchability problem in the shallows. In the deep it's not as pronounced. If you had the same sampling regimes you'd find that the catchability is still lower on the full moon in the deep water, just not as bad as the depression that occurs in the shallow.

Hill: In other prawns the female ovary maturation cycle occurs in a moult cycle. The moult cycle is affected by temperature, and also by size. Thus, small females are moulting more frequently and the large females slightly less frequently. I don't see how that ties into the lunar cycle.

McGilvray: Moulting frequency was independent of the lunar phases.

Courtney: We had about 3-4% of females moulting throughout the experimental period and there were no marked peaks. We thought moulting would display a lunar phase pattern because we detected increases in male catch rates at certain lunar phases and therefore, thought this was due to the males inseminating recently-moulted females at that time. There was no significant increase or decrease in the frequency of females moulting.

Crocos: That's consistent with the moult cycle relationship because you've got a range of sizes in the population and they're all turning over at a different intermoult period. So you get that consistent level of moulting all through the lunar month. Given that is tied in with the maturation of ovaries, it's hard to understand how you get two peaks within a month with the king prawn.

Courtney: There may be some maturation and resorption going on which is not directly influenced by the moult stage.

Die: You also have to remember that the percent of spawning females in any of those peaks doesn't exceed 20%. About 25% at a maximum. So it could be very different groups of animals spawning in those two peaks not necessarily the same animals.

Crocos: So those two peaks could in fact be an artefact of the particular size composition and therefore intermoult periods that you've got in that sample.

Die: I don't know.

Courtney: The histology results were from pooled animals in a database of over 4000 females ranging from < 40mm CL to > 65mm CL.

Penn: Interesting, there are two peaks which are seemingly right on the neap tides. So the model that you are drawing shows the animals are waiting for a particular level of tidal activity before spawning takes place. The neaps are running a few days behind the moon phase so if your two bumps are real, they are related to neaps.

Staples: Does anybody know what the moulting cycle duration is for *P. plebejus*?

Penn: Most likely well in excess of a month at that size. Typically, there are co-ordinated cycles at the time when the moult frequency is one month. As they grow older the moult cycle gets longer, the co-ordination breaks down and the variation in moult frequency with lunar cycle is not obvious.

Hill: At one stage, there was some data from the Gulf that was very clear on that. The moult frequencies were very lunar and then they broke up.

Penn: That occurs when the intermoult period starts to extend beyond a month.

Koslow: Do you have an explanation of why the male cycle is out of phase with the female cycle?

McGilvray: We can't suggest a reason for that yet. Female numbers stayed relatively constant and the change in sex ratio was a result of males increasing relative to females. Male abundance was much more variable than female abundance. It may be due to differences in *catchability* of males throughout the lunar month or due to them leaving the area.

Courtney: We tried to see if there was a relationship between male abundance and moulting in females, and there wasn't. We then looked to see if it had anything to do with insemination of females and it wasn't. About 94-98% of females were inseminated throughout the experimental period, so it wasn't as though they were coming out to inseminate the females at certain times.

DISCUSSION SESSION - DAY 2

Following the day's presentations, participants were again separated into groups to discuss two questions based upon the day's presentations:

(1) What sort of environmental data should be collected for stock-recruitment?

(2) How relevant are spawning stock indices based solely on CPUE?

Group 1. (Knuckey). Question 1. Environmental factors identified included juvenile habitat and habitat surrounding the fishery. Long-term time-series of environmental factors were deemed important, some of which (rainfall, temperature) are available from the meteorological bureau. Others included cyclones, turbidity, currents and salinities. Some of which are difficult to quantify and a proxy, such as rainfall, may be used. Biological parameters, such as predation, trophic levels and nutrition were considered important but are often very difficult to quantify.

Question 2: Two assumptions with CPUE are that 1) it represents the biomass of the spawning stock, and 2) it is related to recruitment or effective recruitment. Catchability varies and fishing practices change, both of which, influence CPUE. CPUE doesn't necessarily provide a good estimate of abundance or spawning biomass. Increased fish aggregating behaviour can increase CPUE when actual spawning biomass remains unchanged. Levels of recruitment may not necessarily be related to the spawning index to any detectable or measurable degree. When CPUE data are the sole estimate of spawning output, the data should be viewed very cautiously. Fishery-independent data should also be used whenever possible.

Group 2. (Koslow). Environmental data that are readily available include rainfall, sea level data which is indicative of the major currents, temperature data at the sea surface and at depth, salinity and wind data. The relevant environmental variables are likely to differ between species. In some cases it may be possible to identify the dominant environmental processes related to recruitment patterns. Biological studies should integrate oceanographers, and other researchers in the physical sciences. El Nino southern oscillation (ENSO) events should be monitored. Satellite data may be useful and isn't being accessed to any great extent at present. Habitats, and habitat health should also be considered (i.e. the effects of cyclones on seagrass beds).

Global Ocean Observation Systems (GOOS) were considered, currents should be monitored, and data loggers (temperature, depth and salinity) should be used at various depths. Biologists should have input into the types of data they would like to have if observation systems are developed and where they would want them to be. Some palaeo-data sets, such as those from corals, may also provide suitable environmental data, particularly for inter-decadal shift analyses and other long-term studies. Physical oceanographers should be involved in fisheries research.

Question 2: It is important to understand fleet dynamics in order to understand the CPUE data set. Applying temporal and spatial dimensions to interpreting CPUE, and learning new technology used by fishers, are important for determining what CPUE actually represents. CPUEs should be calibrated using fishery independent surveys which may be funded by setting aside quota for charter.

Group 3. (Buckworth) With regard to question 1, other environmental factors include river flow, rainfall as a predictor of habitat extent, sea height data as a description of habitat available, nursery habitat changes, periodic mapping of seagrasses, seasonal blooms of algae and chemical monitoring.

Question 2: CPUE data is often the only measure available and should be enhanced with other data. Identifying and quantifying spawners is difficult. It's possible that what is considered as the banana prawn spawning stock in the northern prawn fishery (now thought to be reduced to 1% of its virgin spawning biomass), may not actually be the spawning stock responsible for recruitment. The spawning stock may not be being measured adequately.

Penn: We need to consider how this environmental data should be co-ordinated and possibly put forward a collaborative program designed to collect it, collate it and make it available.

Courtney: Residential developments are mushrooming on the southeast Queensland coast. There is a lot of change imposed upon drainage basins in the region and the effects of those changes on stocks are currently not assessed.

Penn: Seagrasses at Seven Mile Beach in Western Australia appear to come and go and are affected by rainfall from the winter storms.

Loneragan: Bill Dennison's group at the University of Queensland have been mapping seagrass along depth transects and there is a strong relationship with environmental conditions. At higher turbidity seagrass stops at a lower depth. They are also working on developing bio-indicators within Moreton Bay for measuring environmental stress.

Penn: It is difficult to consider that type of data in relatively simple models of the stock. Similarly with satellite data.

Crocos: I'd like to bring attention to the term "effective spawning". Spawners may produce eggs throughout space and time, but only some spawning stock appears to affect recruitment levels.

End of Day 2.

Day 3. Mathematical and Statistical Limitations and Biases in SRRs.
(Chaired by Dr. Tony Koslow)

Biases in Stock-Recruitment Relationships[1]

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([1]Some of the text and figures have been reproduced from Caputi (1993) *Aust. J. Mar. Freshwater Res.*)

Abstract

Determining the spawning stock recruitment relationship (SRR) for marine species, and in particular crustaceans, involves making many biological and statistical assumptions. These assumptions have not always been considered thoroughly and in some cases have led to biased SRRs. This study examines some of the problems that have to be addressed in modelling SRRs to avoid the biases that can occur. SRRs of Western Australian (W.A.) fisheries such as western rock lobster, tiger and king prawns, and scallops are used as examples to illustrate some points.

Introduction

The determination of the spawning stock recruitment relationship (SRR) involves many biological and statistical assumptions. Some of these assumptions have not always been considered thoroughly in some studies and have led to many spurious or biased SRRs in the literature. Also, the large 'random' variation which typically occurs about the SRR and the subsequent difficulty in obtaining a statistically 'significant' relationship has raised some doubts about the importance of these studies.

This study looks at some of problems which have to be tackled in modelling SRRs to avoid or minimise the biases that can occur. These include: the effect of environmental conditions and stochastic variation in general; measurement errors and biases in the spawning stock, recruitment and environment indices; autocorrelation in stock, recruitment and environmental time-series; lack of independence between recruitment and subsequent spawning index; lack of stationarity in the time-series over the period of study. The effect of multiple life history stages, multi-stock fisheries and multi-species fisheries on SRRs are also examined.

Unit stock

A basic understanding of the life cycle and the definition of the unit stock is, of course, fundamental to understanding the SRR. This aspect is covered in more detail by other papers in this volume and only some points will be discussed in this study.

The better the temporal and spatial distribution of spawning stock and recruitment are defined the better the abundance estimates will be. However, even when the spawning area is precisely defined, it could be that only spawners from a certain area and certain time of year may be generally responsible for the recruitment (Paulik 1973). For example, when assessing the decline in western rock lobster puerulus settlement at the Abrolhos Is. (Caputi *et al.* 1995b), a number of hypotheses could be considered on which part of the spawning stock was contributing to the

Abrolhos puerulus settlement. Firstly, the Abrolhos stock could be treated as a separate unit stock. However, this is unlikely in view of the long larval life (9-11 months) and the mixing of the oceanic waters offshore where the larvae occur. Secondly, the spawning stock from all areas could be assumed to be contributing on average equally to the puerulus settlement in all areas. This suggests that larvae are completely mixed each year. It is a conservative hypothesis since it emphasises the importance of the spawning stock in all areas and has been adopted by Caputi *et al.* (1995b). Thirdly, while there is a level of mixing occurring it is possible that spawning from some regions, e.g., near the Abrolhos, contribute proportionally more than other regions. These hypotheses require an understanding of larval movement between regions to enable a more precise assessment of the relative contribution to the puerulus settlement from the spawning stock in different areas.

Abundance estimates of spawning stock and recruitment

In recent years, performance indicators are being developed in all aspects of Government and Industry to evaluate the success of organisations. For fisheries departments, the monitoring of stock and recruitment should be an integral part of the performance indicators being used to evaluate the management of fisheries. Biological reference points, such as spawner per recruit, are being increasingly required as part of the management plans of many U.S.A. fisheries (Mace and Sissenwine 1993).

Standardised research surveys usually provide the best way to obtain annual indices of abundance. While these surveys are not often possible with the research resources that are available, with the co-operation of the fishers it may be possible to organise these surveys for minimal costs. This has been done for W.A.'s prawn fisheries for a number of years and has also started for the rock lobster fishery. When developing management plans for fisheries, plans should be made for the ongoing monitoring of the spawning and recruitment abundance. This may be made by way of a levy on licences or by using part of the annual quota to pay for surveys. In some cases fishery independent estimates from surveys of eggs, larvae or from some post-larval stage such as the puerulus settlement provide an estimate which is independent of the influences of fishing.

In general, the most common way of obtaining indices of abundance is by the use of the fishers' logbook data. In most of the major fisheries in Australia good catch and effort information is now being collected. However, while they may be suitable for providing estimates of total catch and nominal effort, a review of these data is required to examine whether they are sufficient to provide good spawning and recruitment abundance indices. If deemed necessary monitoring programs should be started to ensure that the basic data for the time-series of these abundance indices is being collected for all the major fisheries, especially those vulnerable to recruitment overfishing.

Such data should be collected with sufficient spatial and temporal resolution to enable reasonably precise indices of abundance to be calculated. However, fishers' data may provide estimates relevant to only part of the stock. These time-series data are not only restricted by closed seasons and areas but also by changes in management regulations over time. In the Exmouth Gulf tiger prawn fisheries, for example, when there was a major decline in recruitment (Penn and Caputi 1986), fishing in the recruitment area was restricted and also banned during the spawning season. This meant that the long time-series of spawning and recruitment indices could not be continued in the same manner at a time when it was most critical to monitor the stock. This resulted in research surveys being used to estimate the spawning stock index and adjustments to the catch and effort data on recruits to correct for changes in the fishing pattern. Hall and Andrews (this volume) examine a modelling approach for dealing with this problem.

Increases in efficiency of fishing gear and vessels over time may result in catch rates in recent years which overestimate indices of abundance relative to past years. Catch rates and effort may need to be standardised to take into account these increases in efficiency e.g., Hall and Penn (1979) used the method of Gulland (1956), and Brown *et al.* (in press) used the analysis of variance approach of Gavaris (1980) and Kimura (1981) to examine the effect of satellite navigation GPS and colour echo sounders on rock lobster catch rates.

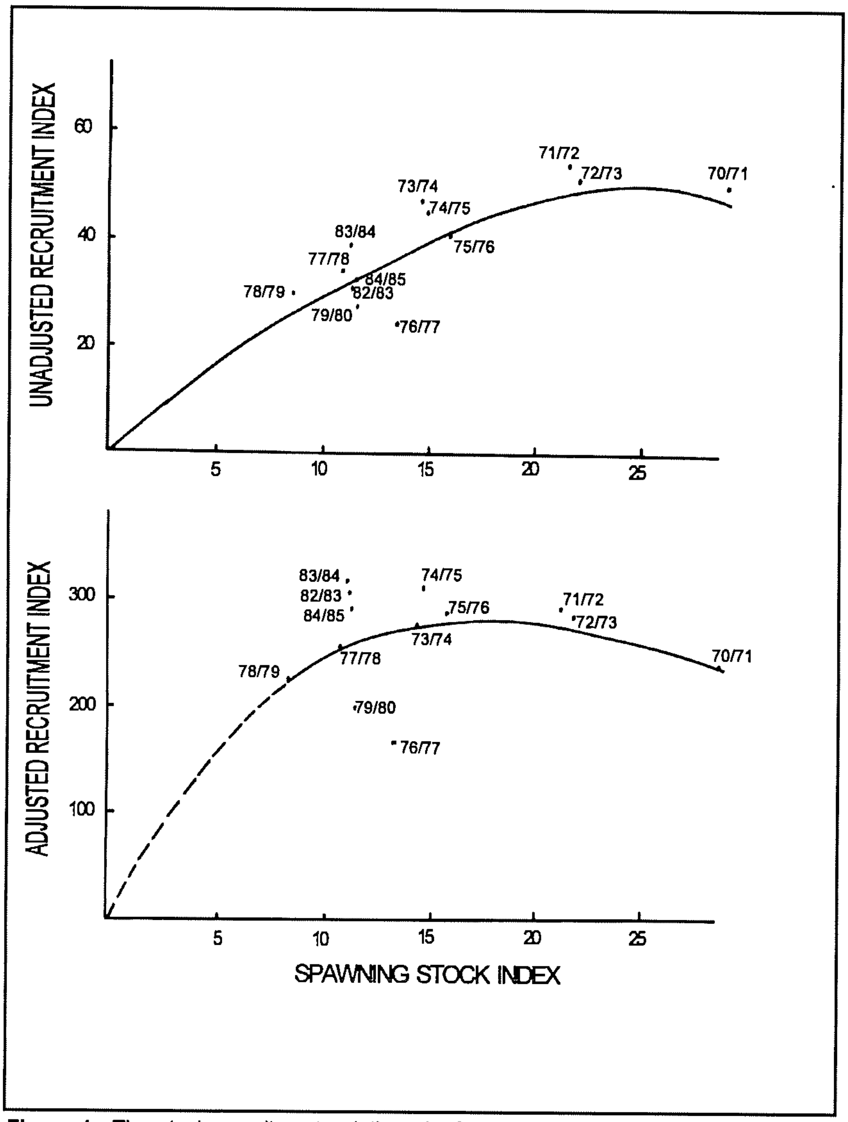

Figure 1. The stock-recruitment relationship for the king prawn fishery of Shark Bay, Western Australia, using the unadjusted (raw catch rate) and adjusted recruitment index (reproduced from Caputi 1992).

The amount and distribution of fishing effort may also affect the indices of abundance. For example, Caputi (1989) highlighted a bias in the recruitment index for the king prawn fishery in Shark Bay which would have (wrongly) led to a conclusion of recruitment overfishing if raw catch rate information had been used (Fig. 1). This was caused by an increase in the number of boats and days fishing on a confined fishing ground resulting in an overall decrease in catch rate since the catch is shared by more boats. Estimates of natural mortality and catchability were used to adjust the catch rates to reflect more accurately the recruit abundance (Fig. 1). Alternatively, real decreases in abundance may be hidden by the fleet moving onto new fishing grounds to maintain their catch rates as older grounds are overfished (Hilborn and Walters 1987).

Fitting stock-recruit models

Statistical inference based on a SRR model, such as the Ricker and Beverton and Holt relationships, requires some assumptions about the distribution of the measure of recruitment abundance. Most often a log-normal distribution is assumed because of the skewness of the recruitment abundance distribution. The Ricker curve ($R = aSe^{-bS}$), for example, is fitted using a logarithmic transformation and linear regression on the following relationship:

$$\log(R/S) = \log(a) - b\,S + W$$

where R and S are the recruit and spawning indices, W is a normally distributed random variable, and a and b are parameters.

When fitting the Ricker model using this equation, the proportion of variation of log(R/S) that is explained is routinely output by statistical packages and many studies quote this as an indication of the goodness-of-fit of the Ricker SRR to the data. However, it is the proportion of variation of log(R) that is explained (coefficient of determination) that is a measure of the goodness-of-fit. This can be obtained by dividing the residual sum of squares obtained in the fitting of the above equation by the total sum of squares of log(R), SS(log(R), and subtracting it from 1,

$$\{1 - \Sigma W^2 / \Sigma SS(\log(R))\}$$

Modelling SRRs using a logarithmic transformation results in an estimate of the geometric mean recruitment for a given spawning stock. If an estimate of the arithmetic mean recruitment is required then an approximate correction may be made using the residual mean square (s^2) from the logarithmically transformed regression as follows (Beauchamp and Olsen 1973, Ricker 1975):

$$R = aS \exp(-bS + 0.5 s^2)$$

Time-series and measurement error bias

Walters and Ludwig (1981) warn that errors in the measurement of spawning stock make it difficult to obtain a reliable model of the SRR. This can often result in the conclusion that recruitment is independent of spawning stock and so lead to over-exploitation of a stock. They suggest that managers should be wary of such conclusions, unless spawning stock is measured accurately, e.g., within 30 percent.

This bias in the parameter estimates of the SRR model due to measurement error in spawning stock estimates may be reduced by the use of an instrumental variable (Johnston 1972). An instrumental variable is one that is correlated with the explanatory variable in a regression analysis (e.g., the spawning stock in a SRR), but is not correlated with the error term (W). Caputi (1989) indicates that a second estimate of the spawning stock index can be used as an instrumental variable in the SRR. The second estimate of the spawning stock can be obtained by splitting the sample size used to obtain the spawning stock abundance into two, thus obtaining two separate spawning stock estimates, one of which can act as an instrumental variable.

The time-series nature of the stock and recruitment indices results in a number of problems in studying SRRs. An error in modelling the SRR may arise from a serial correlation in the recruitment index where recruitment is affected by a long term environmental factor such as an ongoing destruction of nursery ground habitat (Garcia 1983). In this situation the resultant spawning stock would also be decreasing as a result of decreasing recruitment. Since both stock and recruitment indices are serially correlated, as a result of the environmental factor, a model of the SRR would appear to give a good fit but would describe a spurious relationship. These stock and recruitment data are an example of 'lack of stationarity' in time-series data where the SRR has changed from the time period when the habitat was unchanged to where it is now with the reduced habitat area. In this case the habitat area could be used as the environmental variable in the SRR or a separate SRR should be developed using data relevant for the habitat area currently available.

The serial correlation in recruitment will result in a significant autocorrelation among residuals of the SRR. The Durbin-Watson statistic can be used to test the significance of autocorrelation. Trends in residuals can also help identify environmental variables which significantly affect recruitment. However, if a significant autocorrelation is found, but the factor responsible for it cannot be determined, then the fit of the model can be improved by incorporating the autocorrelation into the model. This can be achieved using a two-stage regression procedure (Johnston 1972) involving the spawning stock and recruitment variables from the previous year. Alternatively, the autocorrelation structure of both the recruitment and spawning stock time-series can be taken into account using transfer function models in a time-series approach to modelling the SRR (Noakes *et al.* 1987).

Bias in the parameter estimates of the model of the SRR also occurs when deviations arising from random fluctuations in recruitment indices are correlated with the subsequent level of spawning stock (Walters 1985). This time-series bias would be evident in most fisheries, since if an above (or below) average recruitment occurs, then the resultant spawning stock is also likely to be above (or below) average. The extent of the bias is dependent on the level of variation about the SRR. Using Monte Carlo simulations, Caputi (1988) showed that this bias can be reduced by incorporating an environmental factor in the SRR model which significantly reduces unexplained variation.

The effect of measurement error on the time-series bias in the parameter estimates of the model of the SRR also needs to be taken into account. Caputi (1988) shows how simulating the effect of measurement error and random variation about the mean SRR indicates that there is an interaction between the level of measurement error and random variation about the SRR on its effect on the bias of the estimators of the parameters of the SRR (Fig. 2). This suggests that the effects of the time-series bias and the measurement error bias need to be investigated simultaneously. Once the level of the bias has been determined an approximate correction to the fitted equation can be made. Walters (1990) suggests an analytical bias correction term for the parameter estimates of the Ricker model.

The effect of both measurement error bias and time-series bias is to flatten the SRR (Fig. 3) and hence (falsely) show that the recruitment is independent of the stock for part of the curve when it is not true (Walters 1985, Walters and Ludwig 1981).

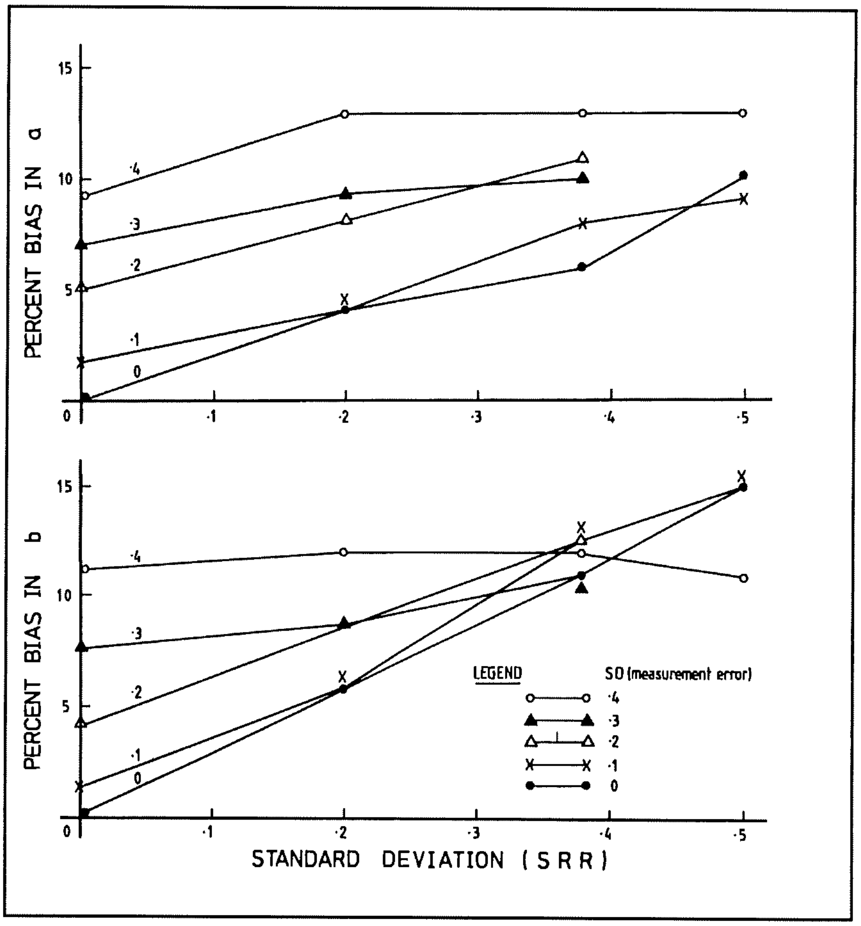

Figure 2. The percentage bias in the estimators of the parameters (a,b) of the Exmouth Gulf tiger prawn Ricker SRR over a range of standard deviations on the SRR (log transformed) and for measurement error on stock and recruitment estimates (indicated on the lines).

Contrast In Spawning Stock

Lack of contrast in the abundance of spawning stock results in unreliable estimates of the productive potential of the stock (Ludwig and Hilborn 1983); this is often due to lack of reliable data from the development stage of the fishery. In fact, Monte Carlo simulations showed that the initial historical data can be a more important factor in management performance than biases associated with measurement errors (Walters and Ludwig 1981). In some situations it may therefore be worthwhile to manipulate fishing policies (active adaptive management) to obtain a contrast in spawning stock (Walters 1986). For some species such as scallops, environmental effects on recruitment are often sufficient to provide large variations in recruitment and hence in spawning stock which provide adequate contrast. In the Shark Bay scallop fishery the recruitment index in 1990 was almost four times higher than the previous record index (Joll, in press) and the subsequent spawning indices in 1991 and 1992 were eight times higher than the previous highest. This has provided some useful information on the level of recruitment at very high levels of spawning stock.

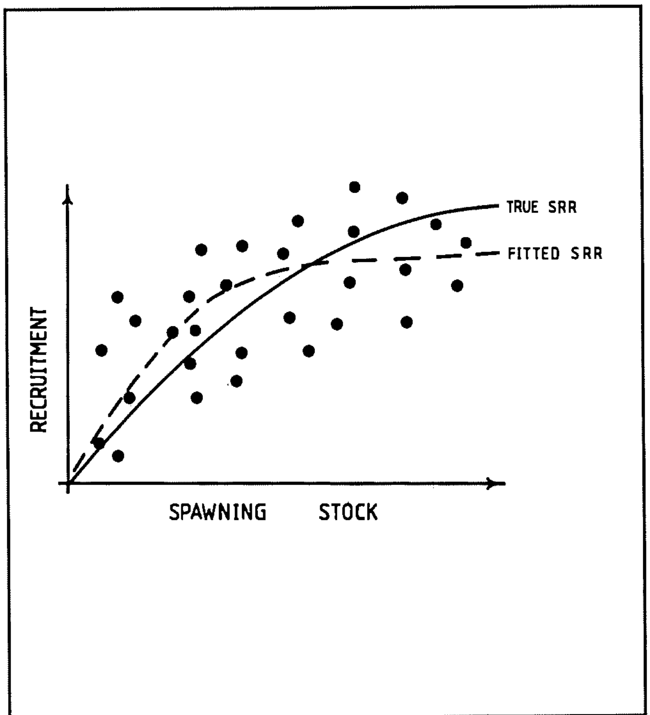

Figure 3. A typical scatter of points in a SRR with fitted and "true" relationships shown.

Table 1 shows the effects of the starting stock on the bias of the parameter estimates of the Exmouth Gulf tiger prawn SRR. The larger the stock at the start of the simulations the less the bias, i.e., the more historical data you have then the greater is the spread of stocks you have. Similarly heavy fishing pressure reduces the stock to the low levels quicker and results in a greater bias, particularly in the density dependent parameter.

Table 1. Percentage bias in the estimators of the parameters (a,b) of the Exmouth Gulf tiger prawn SRR over a range of different fishing efforts and initial spawning stocks.

	Starting Stock							
FISHING EFFORT	6		12		18		24	
	a	b	a	b	a	b	a	b
30	8	8	6	7	6	5		
45	15	27	9	13				
60	20	64	10	27	5	12		
Actual	13	21	12	17	9	13	5	8

Environmental effects

If there are some environmental effects which clearly affect recruitment, then these variables should be incorporated into the SRR model as the significance of the spawning stock effect may be difficult to detect when variations in recruitment are mainly due to environmental effects which have not been taken into account (Goodyear and Christensen 1984). The shape of the SRR may be greatly influenced by the environmental effects.

Because of the large number of environmental variables which may be tested for correlation with recruitment, the risk of a significant spurious correlation is high (Botsford 1987, Walters and Collie 1988). This problem is exacerbated if the recruitment and environmental time-series being correlated are significantly autocorrelated as is usually the case. For this situation, Bayley and Hammersley (1946) suggest determining the effective number of independent observations when evaluating the significance of the correlation between time-series. Thus, before assessing the statistical significance of the correlation between two time-series, the autocorrelations of each of the time-series should be examined to assess the independence of the time-series of observations. The autocorrelations can then be used to determine the effective number of independent observations (N^*) using the following equation:

$$1/N^* = 1/N + (2/N^2)\, \Sigma_j\, (N-j)\, p_j^2$$

where N is the actual number of observations and p_j is the autocorrelation at lag j. Thus if the autocorrelations of time-series are high then each observation is generally dependent on previous observations and the effective number of independent observations would be greatly reduced from the actual number of observations. For statistical inference on the correlation among two time-series, Sutcliffe *et al.* (1976) used the lower of the two effective numbers of independent observations.

Thus environmental variables should be thoroughly assessed before being included in the SRR. Caputi (1989) examines the advantages and disadvantages in the use of environmental variables in SRRs and considers cases when the observed environmental effect is real and when it is spurious. He shows that omitting an environmental variable from the SRR when it is affecting recruitment results in estimators of the parameters of the SRR model being biased if the environmental variable is correlated to the spawning stock. The extent of this bias is illustrated by the SRR of the western rock lobster (Morgan *et al.* 1982) which showed a strong negative relationship between spawning stock and recruitment (puerulus settlement at Dongara). However, after identifying an environmental effect which appears to affect the puerulus stage (Pearce and Phillips 1988; Caputi and Brown 1993), the spawning stock did not significantly affect the level of puerulus settlement (Caputi *et al.* 1995b).

If an environmental variable is added to the SRR as a result of a spurious correlation with recruitment, then this does not cause the estimators of the parameters of the SRR to be biased (Weisberg 1980), though the variances of parameter estimates are increased (Seber 1966). Also, the error variance of the SRR with environmental effects is artificially reduced giving an overly optimistic estimate of the accuracy where recruitment can be estimated.

The confidence we have in an environmental variable depends on (a) how it was chosen, (b) how thoroughly it was tested, and (c) the biological evidence for the effect of the variable. For example, if an environmental variable, which is known to affect the survival of recruits for a given species, is then examined for a similar (or same) species in another area and it was found to be significantly correlated, it would be unlikely that the correlation was spurious. This correlation could be further tested as more years of data become available. On the other hand, if the environmental variable was chosen after correlating a large number of variables with recruitment and finding one that is significant, then there is a good chance that it could be spurious. In this latter situation, the significance level chosen to test the environmental variables should be much stricter (e.g., the 0.01 level rather than 0.05 level). Also, when a significant variable is found, it should result in the setting up of an hypothesis to test the relationship with future samples.

Multi-stage life histories

Information on intermediate stages of the life history between spawning and recruitment to the fishery can greatly aid the development of a SRR. Most species undergo a number of distinct life history stages between spawning and recruitment and, in general, each stage is likely to be affected by different environmental factors and density-dependent effects. Usually all of this information is summarised by a single SRR model with a considerable scatter of points. The SRR is often obscured due to the accumulation of the variations resulting from a number of different density dependent and environmental effects. Estimates of the abundance of intermediate stages help to identify the nature of density dependence which is occurring as well as pin-pointing the environmental effects which are influencing the abundance.

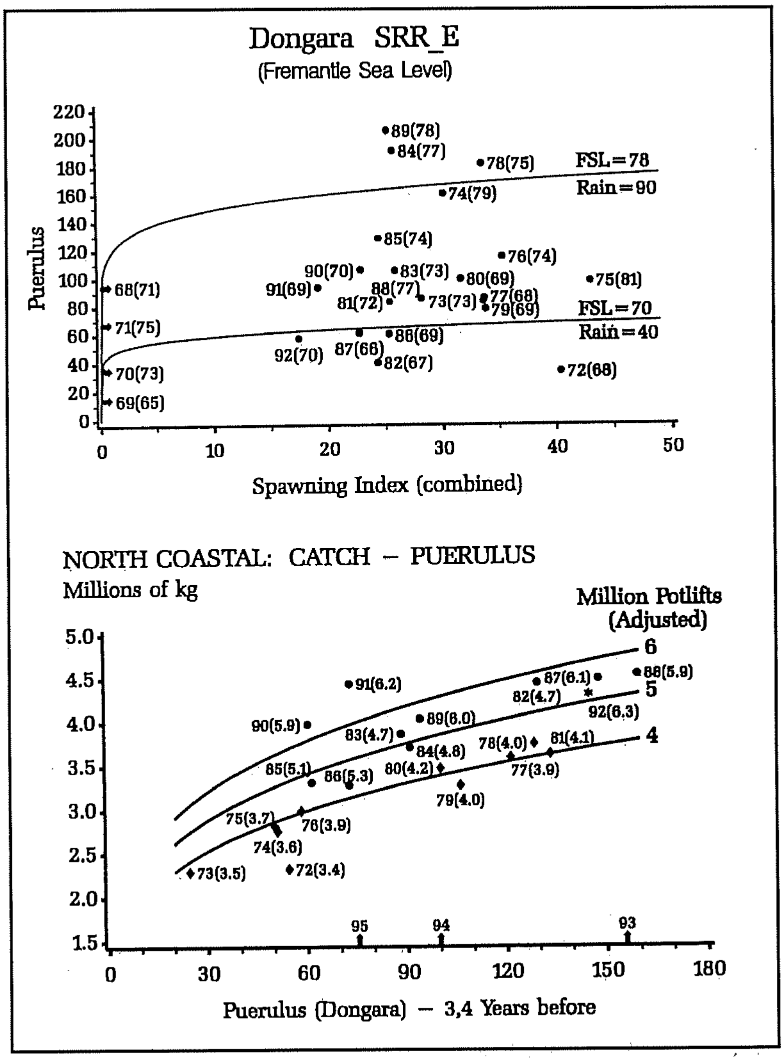

Figure 4. The stock-recruitment (puerulus)-environment relationship for the western rock lobster fishery in Western Australia with the year of puerulus settlement shown and the Fremantle sea level in brackets (reproduced from Caputi *et al.* 1994b). The catch-effort-puerulus relationship for the north coastal region with the year of fishing shown and the fishing effort in brackets (reproduced from Caputi *et al.* 1994a).

The western rock lobster provides a good example of this, where the abundance of the puerulus stage (the first post larval stage, 9-11 months) has proved useful in determining the environmental factors which affect the larval phase (Fig. 4) (Pearce and Phillips 1988, Caputi *et al.* 1995b). The relationship of puerulus to recruitment to the fishery (Caputi *et al.* 1995a) shows a density-dependent relationship though not to the same extent as the spawning to puerulus stage (Fig. 4). If the abundance of the recruits to the fishery (mainly 4-5 year olds) was used to examine the significance of this environmental effect which affects the larval stage then the SRR with environmental effects may have been masked by a number of additional factors which have also affected the recruit abundance over this longer period.

Mousalli and Hilborn (1986) show how survival rate and habitat capacity parameters of a number of life history stages can be combined into an aggregate SRR model. They consider the effect of increasing survival rates and increasing habitat capacity on optimal harvest rates and optimal stock size. They conclude that as a better understanding of survival and habitat capacity is achieved, harvest rates and stock size should be adjusted as the environment changes.

Multi-stock Fisheries

When a fishery is based on a number of discrete stocks then this can present some advantages by allowing for some variation in management policy to examine the response of stocks to different management measures, e.g., different levels of fishing pressure. This can be illustrated using the tiger prawn fisheries of Exmouth Gulf and Shark Bay in Western Australia. The recruitment of both these fisheries was severely reduced in the early 1980s due to recruitment overfishing (Fig. 5) (Penn and Caputi 1986, Penn *et al.* in press). In Exmouth Gulf the tiger prawn spawning stock and recruitment level have recovered in recent years as a result of significant decreases in fishing effort. In contrast, as the tiger prawn was not the major species being caught in Shark Bay as it was in Exmouth Gulf, there was not the urgency for an immediate reduction in effort and no recovery was evident in the stock and recruitment levels during the same period.

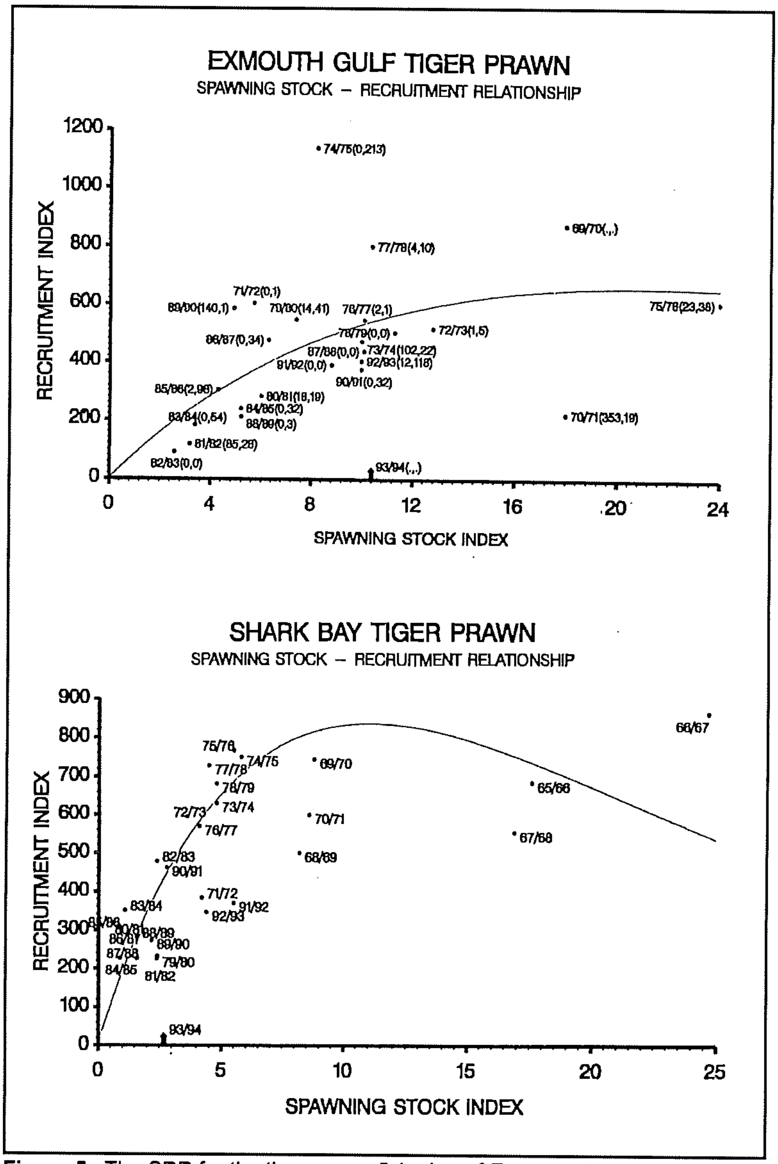

Figure 5. The SRR for the tiger prawn fisheries of Exmouth Gulf (updated from Penn et al. in press) and Shark Bay.

If the management measures had been similar in both fisheries and both had recovered over the same time period, it could have been argued that the collapse and recovery in both fisheries was due to a change in some unknown environmental variable. This contrast in response of the two stocks to the different management measures provides supporting evidence that recruitment overfishing was the reason for the decline in recruitment in these two fisheries. This can be regarded as a fortuitous example of the actively adaptive management policies for replicated systems advocated by Walters (1986).

If a fishery is operating on stocks with different productivities and the stocks are not discrete then the total maximum sustainable catch is less than when each can be fished separately at its optimum level (Ricker 1958). Paulik *et al.* (1967) analytically determined the common rate of exploitation that maximised total sustainable catch from a mixed stock fishery using the Ricker SRR.

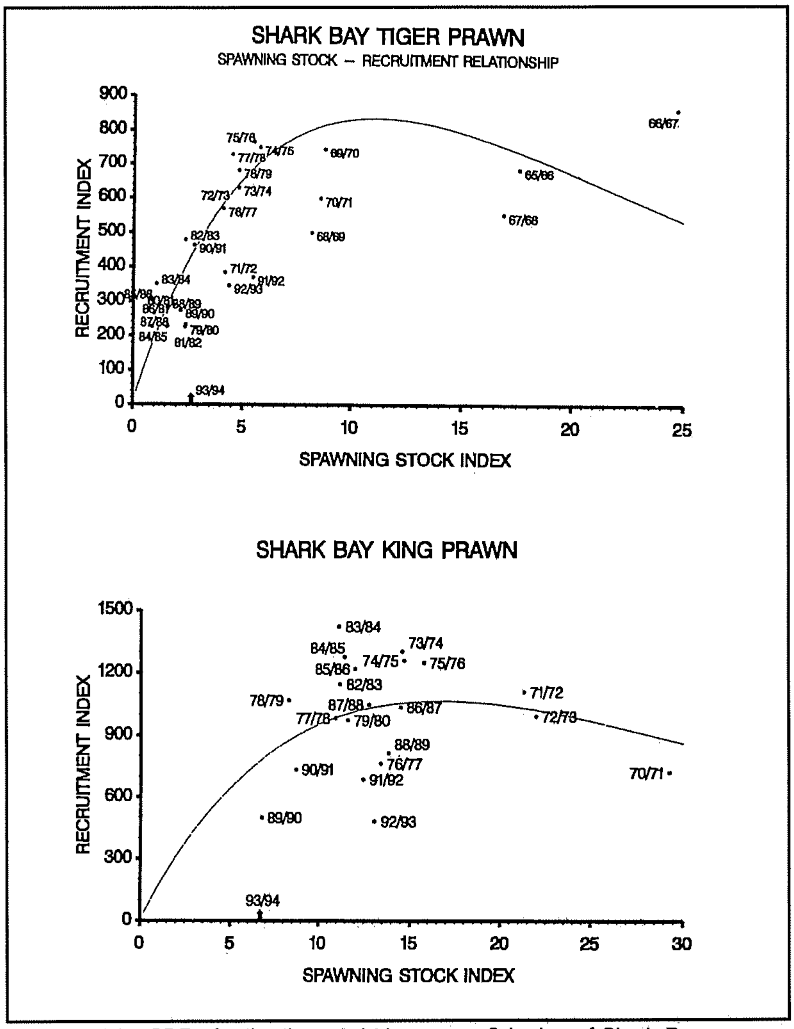

Figure 6. The SRRs for the tiger and king prawn fisheries of Shark Bay.

In the Exmouth Gulf fishery there is little overlap in the king and tiger prawn stocks so that both may be fished to their maximum capacity. However in Shark Bay there is a much greater overlap in the fishing grounds of the two species so that it is much more difficult to manage the two stocks separately. In this fishery the level of fishing in the early 1980s has caused recruitment overfishing in the tiger prawn fishery (Fig. 5) but not in the king prawn fishery (Fig. 6). Thus to optimise the catch in this fishery a compromise between the optimum catch for each fishery separately has to be reached. However the advent of GPS in recent years has enabled fishers to target the species more precisely and this may allow a greater separation of the effort allowed on each of the species. This would allow the catches of each species to be optimised separately.

In the above analyses on mixed stock fisheries, SRRs for the different stocks were known. Hilborn (1985 a and b) looks at the problem when only the SRR of the combined stocks is known. He concludes that stock-recruitment analyses will usually underestimate the optimum spawning stock and overestimate the optimum harvest rate (Hilborn 1985a). Hilborn (1985b) shows that if the stocks have uncorrelated natural variation, the best harvest rate policy will be like a constant harvest rate policy rather than a constant spawning stock policy. But when natural variation is correlated between stocks, the reverse is true.

Summary & Conclusions

SRRs need to be assessed for any possible biases which may be present as a result of the errors and biases in the measurement of spawning stock and recruitment abundance, the time-series nature of the data including the effects of autocorrelation, contrast in spawning stock, stationarity of the time-series data, etc.

Greater emphasis needs to be given to the development of long-term databases to enable the effect of fishing effort on the spawning stock, and the effect of environment and spawning stock on recruitment and catch to be determined. The characteristics of the species being studied such as its life history details and whether there are multiple discrete stocks or whether it is part of a multi-species fishery influences the study of SRRs.

Thus the study of SRRs requires the assessment of problems of a multi-disciplinary nature which includes the fields of biology, environment, economics, population dynamics and statistics.

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Questions and discussion following Dr. Caputi's presentation.

Montgomery: In your Western Australian Rock Lobster database, how long did it take to detect the influence from environmental parameters, such as currents?

Caputi: The ENSO is the most important one and it has a cycle of three to seven years. It's not a regular cycle but that is the type of time frame that should be looked for. The data require continual review, depending on the environmental factor. It can be a decadal variation similar to what was discussed yesterday or larger shifts 10-20 years apart.

Rothlisberg: I thought the rule of thumb was three times the period of the cycle that you have. If it was seven years you might need 21 years of data.

Caputi: In some cases you might not know if you're looking at a cycle of 5, 7 or 10 years.

Courtney: The environmental indices that have been incorporated into SRR's always seem to be associated with recruitment. Do you think we should be looking at environmental indices or influences on the spawning stock much more than we do?

Caputi: Most of the time the dominant effect of the environmental variables will be upon the larval phase. The effects of the environment after that seem to be more related to changes in catchability. Moon phase and swell affect the catchability of juvenile lobsters. Water temperature influences growth of juvenile prawns. Environmental effects may influence egg production, but they are of lesser importance than the environment effects during the larval life.

Wang: The SRR is variable and is therefore, analogous to an "average relationship". It's density dependent. It's based upon average conditions and therefore should be treated with caution. When considering the effects from environmental variables, you require contrasting conditions. The influence of high spawning stock levels upon recruitment will vary with different environmental conditions. The effects of such environmental variables, such as rainfall are largely unknown and may be proportional, additive or multiplicative.

Caputi: Contrast, in terms of the environment and the spawning stock, is important. In a 'natural experiment', you can't control conditions and therefore you don't necessarily get the opportunity to measure recruitment from high spawning stock levels operating under both good and bad environmental conditions. Similarly, you can't measure recruitment from low spawning stock levels operating under both good and bad environmental conditions. You've just got to rely on the natural fluctuation, which can be quite dangerous in not having enough contrast.

Wang: If it was random then you could conclude the relationship is OK.

Die: You mentioned the lack of independence in the spawning stock estimates through time as one of the things that may create biases. Is that a problem with short lived species too?

Caputi: Yes, the scallops get very high recruitment in one year, then you'll get very high spawning stock in the following years. It's a problem in both short and long lived species.

Die: You spoke about the lack of independence between spawning stocks in successive years.

Caputi: No, that will be dependent on the spawning stock and recruitment in the previous year.

Koslow: If you have one set of SR points which suggest a steep decline, and another set which suggest a deteriorating environment, how do you tell them apart and how do you separate them?

Caputi: The only way you can do that is to get a contrast for the spawning stock under the different environmental conditions that you're at now. With degradation, it gives low spawning stock and low recruitment values. In some situations you may be able to reduce effort on the spawning stock, build it up and then measure recruitment under the same environmental conditions. That would provide contrast.

Wang: The important thing is that you have both errors in x and y (for stock and recruitment). With regard to the recruitment indices, you should sample at a specific time each year and note any change in mean size and/or abundance. You should determine if it's the same each year. Recruitment may be delayed by a couple of weeks and that will result in relatively big errors (around 20%). In two weeks mortality could be very high and so that could result in a large error. You should bear it in mind and always check whether the average size or age of the recruits varies or stays the same.

Caputi: Yes, that's part of the discussion we had yesterday.

Wang: You shouldn't rely on the data obtained from only one point in time.

Isolating Tropical Penaeid Recruitment Patterns

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Abstract

One of the essential steps in examining spawning stock and recruitment relationships is the identification of which animals are new recruits. Recruitment patterns can range from the classical, single, homogenous pulse assumed in many fisheries models, to complex patterns of continuous recruitment. The type of recruitment pattern is a major factor in determining the success of seasonal and spatial closures for managing growth over-fishing in tropical penaeid fisheries. Techniques for isolating new recruits range from simple size limits to more complex methods which examine changes in size or age frequency through time.

Length-frequency data with simulated recruitment patterns were used to test the effectiveness of a range of computer techniques available in the simulation model Simsys. We also attempted to extract recruitment patterns from data for two tropical penaeid fisheries which were known to differ in their complexity of recruitment from ancillary data.

Questions and discussion following Dr. Watson's presentation.

Die: What was the effect of total mortality on the results of the model?

Watson: When we used a lower total mortality rate the pulses were better than when we had an inflated rate. Initially the defaults in the program were allowing for total mortality. When we did the simulations and tried to extract the information our total mortality was too high and when we changed it, it made the signal much better, particularly for the age cohort method. It didn't have that much influence on that length cohort method. Those are the only two methods we had that incorporated mortality in the process of trying to get the recruitment pattern out.

Somers: We've experienced similar problems in trying to accommodate larger animals recruiting later on. We couldn't disassociate recruitment of larger animals and changes in catchability of larger animals. How did you approach that problem in your simulation?

Watson: As opposed to selectivity?

Somers: Yes, just changes in catchability.

Watson: We haven't been able to address that completely. In the simulation, the catchability is associated with age and we don't have any changes, we just have selectivity. I don't know whether you can deal with it completely. The problem we had, is that we know that there are large animals recruiting, as you probably did through your tagging studies. We also know that when we're assessing spatial closures, which are near the reef, we're not simply protecting large numbers of small or sub-optimum size animals. There are times of the year when large animals are in that area and the fishers want access. We haven't been able to resolve the changes in catchability because we don't have information on changes in catchability through the different ages.

Koslow: Did you (Somers) obtain information on changes in catchability?

Somers: Yes, but only in the laboratory from the effects of temperature on activity patterns of tiger prawns. In our recent work we've tried to accommodate those results by assuming a seasonal change in the catchability coefficient in accordance with the temperature regimes.

Watson: And with age as well?

Somers: No, not with age, but in terms of the way your cohort analysis identifies recruitment, they could equally be the larger animals which become more catchable.

Watson: No, we didn't put that in the simulation.

Somers: It's just something else to consider when you're looking at it, it may not be an issue.

Watson: In Torres Strait we know that small prawns typically recruit into the fishery and at times pulses of large prawns also recruit. This has made it difficult to come up with a good management regime. Most of these methods don't work as well as I had hoped. One of the things being looked at is an optimisation routine between recruitment patterns and catch patterns. There may be some benefit in taking that approach but it is returning to methods that people handed me a long time ago.

Die: Your tagging data also suggested that larger, older animals enter the fishery. It is not only reflected in the size-class frequencies of the catch.

Watson: You refer to the Turtle Group of Islands' fishery. I expected to be able to track the smaller animals entering the fishery. The length frequencies are from an area which is usually a spatial closure and are close to the seagrass areas *P. esculentus* migrate from. The length frequencies, however, revealed big pulses of large prawns entering the fishery. This is the very thing that annoys fishers. They dislike closing those areas because they know the large prawns will experience the mortality rates before they get fished. We had a good seasonal closure regime, but then due to the changes in timing or the relative strengths of those larger recruiting animals and the smaller ones, the industry decided they didn't like it any more because there was evidence they were losing a lot of product. We could refine the way we look at seasonal closures by tracking patterns of recruits coming in. I don't know if it would be cost effective.

Wang: It's a very tough problem and whatever approach you use, others will always find something imperfect.

Watson: There's optimisation ways of approaching the problem which we will be looking at. It may seem trivial to people who don't have to come up with seasonal and spatial closures, but it isn't. The recruitment pattern is the big signal that the fishery is giving you, the fleet responds to it and the managers interfere with the recruitment pattern-fishing relationship. It has information in it. It's dangerous to ignore it and make assumptions that the prawns all recruit at a particular age and at a particular time of year.

Wang: Do you have a single pulse in recruitment?

Watson: That's just a result from growth. There is a variance involved. I adopted an approach that Terry Quinn and Clive Turnbull were using. I'm not sure how it evolved, presumably because it mimics length frequency data.

Wang: You are saying they have the same age, but have different growth rates?

Watson: Yes.

Wang: What kind of a criteria do you use to select the correct recruitment pattern? Do you use chi-square or the maximum likelihood?

Watson: It depends on which is more important - the pattern or the amplitude. You have to consider what part of the signal is more important in terms of making an effective spatial or seasonal closure. It's probably the relative strengths of the pulses and the age or the size of them. With a chi-square approach you end up with many zeros and small numbers. I haven't been brave enough to come up with any particular approach to it yet, but there are always ways of quantifying which ones work best.

Wang: Different criteria lead to different answers in my experience.

Buckworth: Do you think this could be used to test for multiple pulses or late entry?

Watson: It might allow you a way of determining better recruitment indices for the SRR's. I don't know if it sheds any light on which recruits contribute to which stock. The "which one matches to which" type problem. The method is about trying to do objectively, what everyone has been doing by eye. We had to find some way of dealing with length frequency data.

Genetic Analyses of Crustacean Stock Structure and Stock Size

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Abstract

Methods of genetic analysis of populations have advanced considerably in recent years, both in terms of laboratory techniques for detecting genetic variation and in statistical analysis of the data. It is now possible to give far more accurate answers to many population biology questions. Of most relevance to stock-recruitment relationships are questions regarding (1) identifying and defining discrete stocks and estimating levels of migration between them, and (2) estimating the effective population size (number of spawners), and changes in this size over time.

An estimate of the number of spawners is an essential component for understanding the dynamics of a stock-recruitment relationship. The use of recent genetic methods for the direct estimation of effective population size in prawn populations would be an uncomplicated exercise because of their yearly life cycle (non-overlapping generations). Previously, many crustacean species were not amenable to such types of analysis due to the low genetic variability detected by allozyme electrophoresis, but new DNA techniques are revealing a wealth of genetic variation in prawns.

The discrimination of prawn stocks, the basic unit of management, has also been greatly assisted by our current development of more sensitive genetic techniques. Penaeid-specific population markers are currently being developed, and are being applied to three of the most valuable commercial prawns (*P. esculentus*, *P. merguiensis* and *P. plebejus*). Greater interaction between population geneticists, other crustacean biologists and fisheries managers will considerably assist the management of our crustacean resources.

The following summary covers three topics in the genetic analyses of crustacean stocks. The first is a fairly broad review of what genetic studies have to offer in understanding stocks, the second is a very brief history of genetic studies of prawn stocks, and the third is a summary of the current research on stock discrimination in penaeid prawns being undertaken at the Queensland Agricultural Biotechnology Centre.

Potential of Genetic Studies of Crustacean Stocks

The study of population genetics provides fisheries managers with essential information on stock structure, which is often unattainable by other research methods. Most, if not all, species occur as groups of related yet distinct populations, rather than as single randomly mating units. These genetically distinct groups, or stocks, have diverged from other such groups as a result of temporal, spatial or behavioural separation. Thus the *stock*, rather than the species as a whole, needs to be considered the operational unit for management. The use of genetic techniques to study naturally occurring genetic variation allows the quantification of the degree of gene flow and stock subdivision within a species. By contrast, most other methods of stock discrimination (e.g., including tagging, morphometrics, parasite load, otolith microchemistry, etc.) can only provide information on the post-larval history of the species. Knowledge of stock structure and gene flow is essential information for the sustainable management of the natural species resource.

This is an exciting time in the field of population genetics. Genetic methods have advanced enormously in recent years, both in the laboratory techniques and in the statistical analyses now available, and further advances are continuing to be made at a great rate. It is now possible to give far more accurate answers to many population biology questions using genetic techniques than ever before. The genetic techniques of most relevance to stock-recruitment relationships fall into the three areas of stock structure, stock recruitment and stock size.

When examining stock-recruitment relationships, it is essential to have at least some understanding of what constitutes the stock under consideration. Are there one or more distinct unit stocks being examined? What are the geographic ranges of each stock? Do the recruits come from a local spawning stock, or do they migrate from more distant locations? What proportions of the recruits in a location have come from local versus distant stocks? Potentially, all these questions can be answered using genetic markers. By examining the genetic composition of individuals collected from different areas at different times, it is possible to identify if genetically discrete stocks exist, define the boundaries to those stocks, determine how discrete they are, and estimate the rates of migration between them.

Furthermore, the use of genetic techniques to examine these questions is considerably more robust and cost-effective than other techniques, such as tag-recapture, parasite faunas and micro-chemical composition. However, it is undoubtedly true that the best understanding of stock structure, which must include information on dispersal of larvae and subsequent movement of recruits, comes from combining the results from different scientific approaches. Due largely to the increased capacity for artificially rearing marine organisms, there is now enormous potential for directly examining recruitment processes using genetic techniques. By culturing prawn postlarvae or juveniles from spawners with known rare naturally-occurring genetic markers, and then restocking areas with these individuals, it is then a simple process to screen the adult prawn catch for those markers. This method can be used to answer many different questions, such as, to what extent does restocking contribute to increased harvest, where do recruits move to and at what times, and which habitats prove most productive in rearing recruits?

Estimates of effective population size

Another area that has not yet received a great deal of attention is the estimation of breeding stock size, a crucial parameter in understanding any stock-recruitment relationship. As this application is less widely known, and as there have been some recent developments in this field, it will be discussed in more detail here. The effective breeding stock size (N_e) can be regarded as the number of spawners successfully contributing to the next generation. There are a number of methods to estimate N_e, not all of which are necessarily appropriate in the present context, as they estimate the long-term, average N_e rather than the current N_e. However, some recent methods are proving more useful in estimating current N_e, and although they have so far been used mainly in aquaculture stocks, they may also be applicable to wild stocks.

Long-term estimates of N_e have traditionally been estimated using various measures of either heterozygosity or nucleotide diversity. There is a strong, almost linear, relationship (Fig. 1) between the effective population size and either of these two measures, so that it is reasonably straight-forward, given an estimate of mutation rate, to estimate long-term N_e using either of them. A more useful approach for monitoring the breeding stock size of populations is to estimate the current N_e, and two methods have been devised to do this. The first, and most promising, is to use temporal changes in allele frequencies (Waples 1989, Hedgecock and Sly 1990, Hedgecock *et al.* 1992). Assuming that allele frequency changes over time are due to random genetic drift from one generation to the next (due to the random selection of successful gametes in each generation), the magnitude of these changes is inversely related to the effective size of the population, N_e, and can be used to estimate N_e after accounting for sampling variance. A second method (Bartley *et al.*

1992) uses measures of linkage disequilibrium, which are a negative function of effective population size, to estimate N_e. Particularly attractive properties of both these estimators are that confidence intervals can be calculated for both, indicating the precision of the estimates, and that the two estimators are largely uncorrelated, meaning that they provide basically independent estimates of N_e. As commercial prawn species have predominantly non-overlapping yearly generations, the application of these methods to these species is a much simpler process than applying the technique to a longer-lived species with overlapping generations.

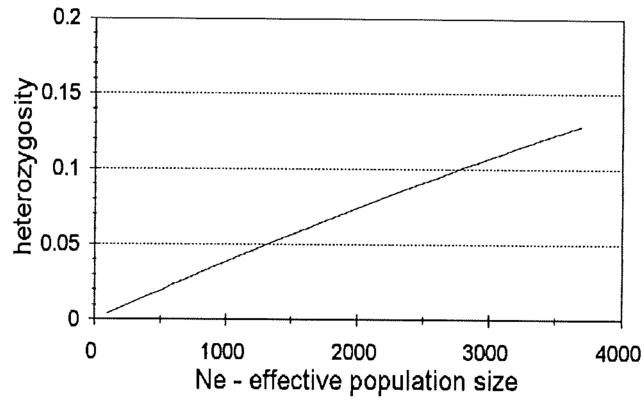

Figure 1. Relationship between effective population size and heterozygosity (for mutation rate of 10^{-5}).

Previously, prawns have not really been amenable to this type of analysis because of the very low levels of genetic variation detected using allozyme electrophoresis. However, new techniques that examine DNA variation directly have revealed a wealth of variation (see below). These two methods of estimating N_e are most accurate for smaller population sizes. However increasing the sample size, the number of populations sampled and the number of loci sampled, greatly improves accuracy. Considering the importance of an estimate of the number of spawning adults to understanding stock recruitment processes, it may be worthwhile to undertake a relatively intensive sampling and genetic analysis program in order to provide some estimates of the effective breeding size, N_e. To determine the feasibility of this in penaeid prawn stocks, some initial computer modelling needs to be conducted. It is necessary to simulate the genetic composition of prawn stocks of various designated sizes over a number of generations and calculate the two estimates of current effective population size (from temporal allele frequency changes and linkage disequilibrium). This would provide a clear indication of the reliability of using these estimates of N_e.

Estimates of N_e can be applied directly in a number of ways. Although attaining highly accurate quantitative estimates would certainly be the ideal for understanding stock-recruitment relationships, other less stringent uses may also be extremely useful to understanding critical biological factors important in fisheries management. It may be possible to determine if N_e falls below a critical level (e.g., that required for recruitment success), and to examine the relative changes in the N_e of a population over time. It may also prove extremely useful to compare the current estimates of N_e with the long-term estimates. Furthermore, the approximate ratio between the effective breeding size, N_e, and the total census population size, N, would be very informative about recruitment success in a stock. Further work is undoubtedly required to determine just how useful genetic estimates of the effective breeding size are likely to be in penaeid prawn population studies, but it does appear that even rough estimates may prove very useful, particularly as there are few other feasible means of determining this crucial value.

History of Genetic Studies of Prawn Stocks

It is unfortunate that the early allozyme studies of prawns (e.g., Mulley and Latter 1981a,b) have been interpreted in much of the literature (e.g., Dall 1985) as showing that (1) there was little genetic variation *per se* in prawns, and (2) there was little, if any, stock structure in prawns. Like any scientific study, the null hypothesis i.e., that there is no genetic differentiation between populations, cannot be demonstrated statistically unless sample sizes are extremely large. These early studies did show that; (1) some small estuarine Metapenaeids exhibited considerable stock structure, and (2) allozymes are fairly insensitive population genetic markers in prawns. The latter finding is, in retrospect, not surprising, as it is now clear that very little of the genetic variation in prawns is exhibited in allozymes. Among the invertebrates (average heterozygosity, $H = 0.075$), crustaceans in general show relatively low levels of allozyme heterozygosity ($H = 0.05$), and decapods in particular display very little allozyme heterozygosity ($H = 0.018$) (Lavery and Fielder 1993).

Recently, Benzie *et al.* (1992) have shown that with a relatively large sampling program, allozymes revealed significant stock structure in *Penaeus monodon* in Australian waters. Subsequently, they have shown (Benzie *et al.* 1993) that the same pattern was revealed using a very simple mitochondrial DNA analysis that examined only a handful of individuals. Sunden and Davis (1991, and unpublished data) have recently examined *P. vannamei* and *P. stylirostris* from Mexico, Panama and Equador using allozyme, mitochondrial DNA (mtDNA) and RAPD (random amplified polymorphic DNA) markers. The allozymes revealed no stock differentiation, while both types of DNA markers exhibited highly significant differentiation. Thus it appears that, by using more sensitive DNA markers, it will be possible to get a much clearer understanding of the stock structure of Australian penaeid species than before.

Current Research

The current research on prawn population genetics at the QDPI Agricultural Biotechnology Centre has two basic aims. The first is to develop a suite of highly sensitive DNA population markers that will be applicable to a range of penaeids, while the second is to use these markers in examining the stock structure of three of the most important commercial species in Australian waters: *Penaeus esculentus*, *P. merguiensis* and *P. plebejus*. Two types of markers are being used. Mitochondrial DNA (mtDNA) is particularly suited to population genetic analysis because of its relatively high rate of evolution and its uniparental inheritance. The segments of the mitochondrial genome that are being targeted are portions of the large subunit ribosomal RNA (16s rRNA) gene, the cytochrome oxidase subunit I (COI) gene, and the non-coding control region. These regions are being examined using a combination of PCR (polymerase chain reaction) amplification, DNA sequencing of a small number of individuals and routine screening using diagnostic restriction fragment analysis. Promising results have so far been obtained for both the 16s and COI genes. The second type of marker being developed (in collaboration with Dr S. Moore, CSIRO Molecular Animal Genetics) are microsatellite DNA markers. These are arrays of short (typically 2-3 base pair) tandem repeats of DNA bases. Different forms (alleles) of the one microsatellite vary in the number of repeats in the array, and can thus be easily identified by simply determining their total length. These microsatellites are found in large numbers throughout the nuclear genome, and each one appears to be highly variable among individuals. Their high rate of evolution and ease of analysis (once initially identified) make them very promising for population studies. So far, a dozen microsatellites have been identified from *P. esculentus*, and two of these have been examined in a number of individuals, revealing considerable useful genetic variation.

Prawn sampling is being carried out throughout the Australian range of the distributions of each of the three species. Preliminary results are now available from the mtDNA analyses for a small number of individuals (3-5) from the extremes of the distribution for each species.

In *P. esculentus*, three haplotypes (alleles) of COI have so far been found, with a small number of base changes between those haplotypes (Fig. 2). One haplotype (C) was found only in Western Australia (Shark Bay) and is highly diverged from the haplotypes found on the east coast (A and B). There is a suggestion from the preliminary data that there may be haplotype frequency differences between *P. esculentus* from Cairns and Moreton Bay, however, it is obvious that more samples will need to be analysed. The diagnostic difference between east and west coast individuals has been confirmed in ten animals from each location using restriction fragment analysis.

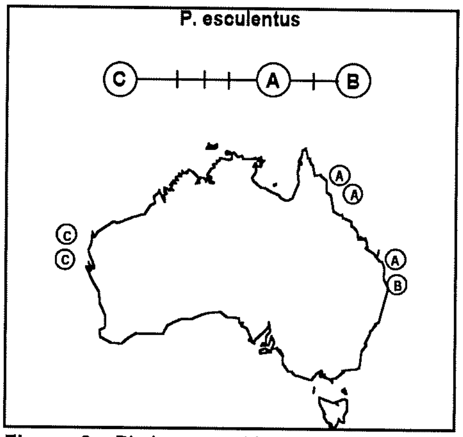

Figure 2. Phylogeographic pattern of mtDNA haplotypes for *P. esculentus*. Each cross bar of upper diagram indicates one DNA base difference.

Similarly, the banana prawn, *P. merguiensis* exhibits a very large genetic difference between individuals from the west and east coasts (Fig. 3). The apparent genetic divergence is likely to have arisen over a very long period of complete isolation of stocks from each of those regions.

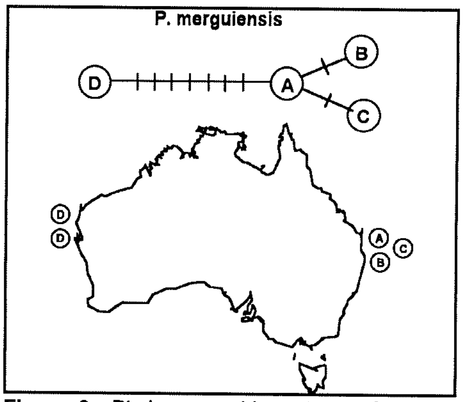

Figure 3. Phylogeographic pattern of mtDNA haplotypes in *P. merguiensis*, based on COI sequences.

As may have been expected in the most highly migratory penaeid species, the preliminary data from *P. plebejus* do not reveal a clear pattern of genetic differentiation from only a few individuals (Fig. 4). It is apparent that there is a high level of genetic variation within the species, with eight mtDNA haplotypes observed among ten individuals. Unlike the other species, there is no clear relationship between the phylogeny of haplotypes and the geographic distribution of those haplotypes. However, there may be significant geographic structuring in the species which will become evident only after more individuals have been examined, and the haplotype frequencies of the different locations compared.

Although these results are very preliminary, a number of conclusions can already be made from the data. Firstly, the DNA markers being used in this study appear to be far more appropriate than previous techniques for analysing stock structure in penaeid prawns. Secondly, from only a few individuals there is now far more information on stock structure in these species than was previously available. Thirdly, there can be considerable confidence that the true genetic stock structure of these species will be revealed using these techniques.

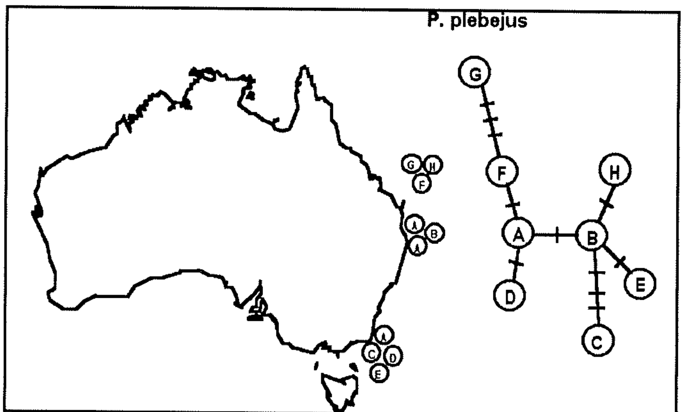

Figure 4. Phylogeographic pattern of mtDNA haplotypes in *P. plebejus*, based on COI and 16s sequences.

In conclusion, a few general points can be made about genetic studies of stock structure in crustaceans. The most benefit from genetic studies will be obtained when they are coordinated with other biological studies of the species, and in this regard Australian marine research is somewhat lagging. It appears to be time for some greater interaction between population geneticists, population dynamicists, crustacean biologists and fisheries managers. In the past each group has tended to approach stock questions from their own perspective. It is only through the pooling of our resources that we will come to a better understanding of our crustacean stocks.

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Questions and discussion following Dr. Lavery's presentation.

Penn: How steady are these break-ups going to be. In the eastern king prawn you have potential for a burst of recruitment from one particular sector of the stock, perhaps in Victoria in one year, and then from a slightly different part of the stock in another year, another burst of recruitment. How likely is it that your markers are going to be steady from year to year?

Lavery: There has to be some temporal sampling going on and I'm planning to do that over a period of years. If they are stable and there are discrete differences, it might give us more confidence that they are temporally stable stocks. In the best possible situation, if there is enough variation there, it might even be possible to detect where these pulses are coming from. That would be an ideal situation.

Rothlisberg: Is it too early to conclude from the preliminary diagram you had that the Mallacoota (Victoria) stock was quite unique but shared one marker with Moreton Bay (Queensland)? Can you conclude that a portion of the stock you measured that year was derived from Moreton Bay but the rest of it was not?

Lavery: It's too early to tell from this data. The level of individual variation I picked up was quite high. This is unlike the situation in the other species, where there are very discrete phylogenetic separation of the genotypes which have been occurring over a long period of evolutionary time. The only things we'll be looking at in the eastern king prawn population are the more short term changes which are reflected in genotype frequency differences. It's only by looking at large numbers of individuals that we'll get any idea of that.

Staples: The questions you put forward have been around for a long time and I'm surprised that they have come up again. You are suggesting that you can show all this, but we have got to work out what it means. What does it mean to you? What is a stock? How much mixing will make it *not* a stock? Those questions haven't been progressed at this stage.

Lavery: The historical level of communication between the groups has been poor. Secondly, population biologists and managers aren't making the most of the genetic techniques available these days. They haven't been defining questions in a way that geneticists can look at quite discretely. There are two sides to what is going on. Population biologists aren't realising the possibilities of what they can do with genetic data and they haven't thought about how to go about asking particular questions that genetics might be able to answer, and vice versa.

Hall: With regard to "N_e" do you have the precision to find confidence levels to give an indication of what the effective number is? What is that precision in terms of the relative error that is associated with the estimate and how many animals do you need to look at?

Lavery: That's the big question. What sort of precision can you get? For the work that Clive Keenan is commencing, it is important to do some modelling exercises before spending large amounts of money. We can achieve much from modelling and determine the accuracy we can get for prawns. With regard to those questions I put up at the end of my presentation, I'm interested to get some good feedback from other prawn biologists. Some of those questions pertaining to the precision would be useful. The precision will be greater when population sizes are smaller. That could be of use when population sizes are declining. Rather than always finding a specific number for N_e, it may be more important to find out when N_e is falling below a certain value. You could also look at how it may be changing over time. Irrespective of the precision, we may be able to pick up changes or declines over time. Also, the ratio between *effective* population size and the *true* population size may be informative. This ratio is probably going to give us some ideas about recruitment in each of the species.

Hall: I was interested to hear that it might be used as an ancillary piece of information to supplement other information. It does help in understanding the SRR.

Koslow: You're looking at rates of change. Do you think these rates of change vary from year to year, and from one species to another?

Lavery: Not necessarily. That variation is going to be random and dependent on the population size itself irrespective of the species.

Koslow: Is the degree of random variability a function of species?

Lavery: It shouldn't be. No.

Die: Could you clarify that spawning stock estimate you have. Is it a value which represents a number of years or is it a point in time?

Lavery: It's the estimate of the number of breeders that have effectively contributed to the next generation.

Die: So it is for a single generation?

Lavery: Yes.

Hill: Looking at that graph you needed about 10 years data to see that variation.

Lavery: No, not necessarily at all.

Hill: Surely, that would depend on the population. If you had Moreton Bay tiger prawns which were genetically very diverse and only a small part of the population contributing to the following generation, you would get a diverse population every year. I thought it was a case of looking at that on a relative basis to find out whether we have a small part of the population contributing or a large part of the population contributing.

Lavery: It is not the allele frequencies themselves that are important, but rather the changes from year to year. Firstly, the longer the time span you have, the more accurate the data you'll get, but a lot of the applications of these theories have been operating on just two or three years data and getting some reasonably accurate estimates from that. Secondly, we're looking at using a number of individual markers for each population. The accuracy can be increased by using more markers and larger sample sizes. (End of tape)

Hill: Can you get an answer in two or three years?

Lavery: Yes, you could, but how accurate that estimate will be ...

Hill: If you say to us that you can get an answer in two or three years that's good, but if you don't have a lot of confidence in it and it's going to take 10 years to get slightly better confidence, then I don't see that you're going to have a lot of support. At the end of the day if you want to embark on a 10 year sampling program in order to get a reasonable confidence estimate it's going to be difficult to get support for that type of work.

Lavery: That's why we're doing the modelling, to determine what the levels of confidence will be over what periods of time.

Hill: I want to come back to you having a shot at the biological community for not using your data. Allozyme work has not been particularly helpful and in the case of penaeid prawns, has not been helpful *at all*. So you're starting from scratch. You've got to start again to convince the community that this is a useful line of research and you've got to be very careful because for example, if you told Jim Penn that Shark Bay and Exmouth Gulf are different, what would he do with that information? What would he do if you've said they're different and what would he do if you said they were the same? That's what you've got to be careful about. You can find differences, but there are only a few cases where that data is useful. Eastern king prawns is an exceptional case but in all the others it doesn't matter.

Glaister: I disagree. Significant differences between brown tigers (*P. esculentus*) along the east coast would have a dramatic impact on our managers approach to managing that fishery. If differences exist and they are sustainable differences then it could mean that you would seriously consider zoning.

Hill: Really, John? If somebody found a difference between Moreton Bay and your next stock of brown tigers, do you think it's going to make any difference? Given the politics associated with these fisheries, the management in Moreton Bay would not be affected by genetic difference or similarity with the next stock of brown tigers along the coast.

Glaister: Managers, the political system not withstanding, would be interested if there were differences along the east coast for a particular species.

Hill: As an example, take Barramundi. You have shown that every river is different. In the Gulf of Carpentaria's coast you have issued one entitlement for all the rivers. You do not issue an entitlement for the Gilbert River and then another for the Mitchell, and so on.

Lavery: We all know socio-political and geographic factors can quite often override any biological factors in determining management. However, if we're trying to manage these species, we must have some idea of the structure within or between management regions. Managers must want to know whether they have multiple stocks within a region being managed.

Dredge: Clive (Keenan) has been able to demonstrate that the stock of *Amusium* spp. (scallops) which is fished on the east coast of Queensland is genetically uniform despite the fact that there are very substantial variations in colour and growth parameters in that stock. Fishers have argued on the basis of observed variation that there should be different management regimes for different parts of the stock. The genetic data has been useful and will be useful in the future to refute the concept that we should zone that fishery into different management zones.

Keenan: To get back to your first point, N_e is a function of heterozygosity. When you have high heterozygosity levels you get a better estimate of N_e and the DNA data is far more heterozygous than the allozyme data ever was, which is why we can use this to apply the technique. The fact that Shane is finding a lot of heterozygosity within Moreton Bay would allow comparisons between years in Moreton Bay to be reasonably successful, but as he says, there needs to be a lot more modelling.

Lavery: You've got to get this in perspective. These techniques are now available and it's worthwhile chasing them up to see how useful they may be. We are yet to see how precise those estimates will be.

Staples: We've seen a lot of people putting dots on the graph between spawning stock and recruitment with the assumption that they are linking the right spawning stock to the right recruitment. This mtDNA work is essential to determine which dots you put on that graph.

Hilborn: One of the things that can happen with stock recruitment curves is that if you have *stock structure* you can determine whether the depletion is localised (randomly depleting some of the stock) or not. One of the theories regarding tigers in the northern prawn fishery is that some of the stocks have been hammered down quite low. The genetics will tell you if they're completely homogeneous and if you can completely reject that or not. However, if there are differences from stream to stream or bay to bay, then you've got to start worrying about those things. This would be very useful to know that.

Rothlisberg: In those three graphs you showed for the three species, you spoke of units of divergence (the cross hatches). Are those comparable across species?

Lavery: In this particular case, no. I've looked at more sites in the recent data that I've got for the eastern king prawns so these particular graphs are not comparable but eventually they will be.

Hilborn: In those same graphs, are each of those things you've called A,B,C and D effectively genotypes?

Lavery: Yes.

Hilborn: So it's mitochondria DNA and would you deal with those as allele frequencies to determine if populations are different?

Lavery: In terms of the frequency differences, yes.

General discussion on the morning's presentations.

Koslow: One thing that has been suggested is the question of utility versus the risk of carrying out adaptive management to try to tease out what these SRRs are. Is there any discussion that anyone wants to get into on these matters? For example, what are the most fruitful approaches for looking at some of these prawn stocks and looking at SRRs? I assume one needs *at least* 10 - 15 years of data before you can do anything that is very fruitful at all with SRRs.

Hilborn: We tend to get obsessed with the number of data points. As someone mentioned earlier, it's the *contrast* that matters. Four data points - if there's two low ones and two high ones - are a lot more useful than 50 data points if the contrast isn't there. I can't help thinking that with prawn data you have such a lousy measure of spawning stock. The errors and variables would seem to have the potential to really dominate the ability to see the real relationship. Most of the kinds of biases that Caputi spoke of would in general, make you less likely to detect a SRR than to make you see one that wasn't really there, although there are some biases that would.

Caputi: It depends on the distribution of the spawning stock. In some cases the spawning stock is quite discrete, as is the case in Exmouth Gulf and it is likely to be measurable. In some cases where the spawning stock is distributed over a large area, it may be very difficult to measure and maybe ±30-40% in which case the SRR will be much more difficult to tease out. Thus, not all prawn stocks should be lumped into one group. The rock lobster fishery spawning stock is probably difficult to estimate because it is spread out over such a large area. When you get a bay situation like Shark Bay or Exmouth, a concentration of the spawning stock is probably readily measurable to ±10%.

Hilborn: Surely not if you're using commercial catch per effort data?

Caputi: No, we are using trawl surveys.

Hilborn: Again, that's probably unusual relative to the other cases we've heard about.

Caputi: It also depends on the time period as well as the space. The time period is relatively concentrated and it's more readily measurable than if it's spread out throughout the year.

Die: In regard to Derek Staples and the PREP program, where different seasonal patterns of recruitment occur, several cohorts may enter the fishery but only one may survive to spawn. What should be measured in terms of recruitment indices? Should we consider the dominant cohort, both cohorts or develop a SRR for each cohort?

Staples: Separate the cohorts and generate a SRR for each. You're going to get some contrast in those two cohorts and it's going to tell you a lot about what's going on in the population. Most of the examples we have here in Australia could be used effectively. The environmental effects are going to affect those two cohorts quite differently and you get more contrast when using the two cohorts.

Penn: We had a suspicion with the Exmouth Gulf data, that there were two cohorts. It's evident in the length frequency data. The suspicion was that the collapse occurred in *one* of the cohorts and the fishery then operated at a lower level and was dependent on the *other* cohort which wasn't being jeopardised by fishing to the same extent. The Shark Bay data had the same appearance, based on data from the large spawning stock and large recruitment, it came down and remained on a plateau which could have been the second SRR maintaining the level of recruitment underneath.

Staples: With regard to the PREP experiment, at the moment the data isn't at a level where you can start teasing SRRs apart.

Day 3. Recruitment Overfishing and Management. (Chaired by Mr. Norm Hall)

Recruitment Overfishing and Management of Penaeid Fisheries: Research and Management Strategies Developed for the Recovery of the Western Australian Tiger Prawn Stocks

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Abstract

The protection of spawning stocks in penaeid fisheries prior to the 1980s was not considered a priority in fisheries management planning. The decline in production from the two major Western Australian tiger prawn stocks through recruitment overfishing (Penn *et al* 1989) in the 1980s therefore required the development of new management practices to control and maintain exploitation at sustainable levels. A review and update of the spawning stock-recruitment relationships developed for the W.A. stocks in Exmouth Gulf and Shark Bay has shown that spawning stock levels have recovered and recruitment/catches have responded to effort reduction.

The history of the W.A. penaeid fisheries and the development of vessel technology has been reviewed to identify factors which led to increased effective fishing effort and recruitment overfishing of the tiger prawn stocks. The resulting evolution of research and management programs to facilitate the recovery of the stocks has been documented. A system of research surveys to complement commercial data for the Exmouth Gulf fishery, developed to support the ongoing assessment of both spawning stock and recruitment levels is described.

The success of the different management arrangements, implemented in the Exmouth Gulf and Shark Bay fisheries in reducing effective effort and allowing stocks to recover, are compared. The ongoing management strategies used to maintain spawning stock levels above thresholds developed from stock-recruitment models are discussed, and compared with other alternative management approaches.

(This presentation ran overtime and questions to Dr. Penn were delayed until the end of the session.)

Management of the East Coast Penaeid Prawn Fishery - Is Stock-Recruitment a Consideration?

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Abstract

Historically, the Queensland East Coast penaeid prawn and scallop trawl fishery was an open entry fishery. As with all Australian penaeid prawn fisheries, management for this fishery has been a relatively recent phenomenon with significant exploitation and subsequent management measures only occurring during the last twenty-five years. The only constraint on initial participation in the fishery was the possession of a Queensland Fishing Licence.

Following rapid expansion of the Northern Prawn Fishery (due to a combination of an expansionary boat replacement policy and a boat building incentive promoted by the Commonwealth) there was a proliferation of older vessels displaced from the Gulf to the east coast. This was exacerbated by speculative investment in second-hand vessels. A freeze on further entry to the Queensland east coast was imposed in September 1979. Thereafter, the east coast trawl fishery has been managed through restrictions on effort (input controls). Such measures have sought to limit the incidence of growth overfishing (the capture of suboptimally sized prawns or scallops), to thus maximise the value of trawl catches to the Queensland industry and to minimise the likelihood of recruitment overfishing (the capture of spawning, adult prawns or scallops in such numbers as to impact the biological success of future spawnings).

This latter objective has been frequently stated but little data have been available to quantify whether it has been achieved. In this paper we highlight information needs of managers and in particular, concerns as to the possibility of stock-recruitment problems.

Questions and discussion following Dr. Glaister's presentation.

Caputi: How did the number of boats increase with limited entry? Were fishers forewarned about it and given some time to come in?

Glaister: People argued that they had already begun construction or that they were going to suffer hardship.

Hill: There was also an expectation and the price of boats was increasing. You could make money simply by building a boat, not using it and then selling after a couple of years because inflation was pushing prices through the roof. When they announced the limited entry there were a number of existing vessels, and an incredible number of boats that were contracted for. Management froze the number of licences on a particular date, but there were many appeals and so the number of boats participating continued to increase. It took another year or two for that to stop.

Glaister: It had a flow on effect, a domino effect down the coast where the price of boats in New South Wales sky-rocketed. At the time you couldn't buy a boat in New South Wales because speculators were buying them and bringing them up to Queensland in an attempt to establish a fishing history before the boom was closed.

Hill: There was great resistance to limited entry. Fishers resisted it. Even the paint industry lobbied the government and argued that the limited entry was not needed. The limited entry alternative wasn't an easy task to stick to. There was tremendous resistance to it.

Poiner: These boats are all getting to be 15 - 18 years old. Where did the assumption come from that these hulls are going to start falling apart at 18 - 20 years of age?

Glaister: It's probably less to do with the boat sinking than people needing to avoid taxation.

Eliason: Insurance companies will not insure certain vessels that are very old.

Glaister: Yes, that's an element as well. There are many reasons why the fishery is so diverse and they include the range of markets, the multi-species nature of the fishery and the distribution of the fishery along the coast. Management of Queensland's fisheries is in a pretty exciting phase now. In the past, the fishing industry has resisted adopting any sort of change. Now they are talking about where it goes from here and it's a bit unknown.

Pre-spawning Closures in the Northern Prawn Fishery

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Abstract

Since 1987, the fishing year in the northern prawn fishery (NPF) has been divided into two separate fishing seasons. The rationale for the biannual seasonal closure regime stems from a combination of biological, economic and social factors. The northern prawn fishery is a multi-species fishery, with banana and tiger prawns the main target species. A single seasonal closure during the late summer months has long been employed as a means of managing the size composition of banana prawn catches for yield per recruit considerations. However, concerns of recruitment overfishing of tiger prawn stocks in the mid-1980s led fishery managers to search for additional constraints on fishing effort. The result was a package of effort restrictions which included a second seasonal closure (following the banana prawn season but prior to the main spawning season for tiger prawns). This presentation will describe the basis for the bioeconomic advice to managers, the influence of social factors in formulating the regulations, and the effect of the effort constraints on subsequent recruitment to the fishery.

Questions and discussion following Mr. Somers' presentation.

Courtney: You modelled the fishery on value per recruit previously and you're probably going to do a modelling exercise on egg per recruit to look at the effects of the closure on egg production. If you do that and find that a closure one week later, or one month earlier, would produce significantly more eggs, would you then put that to the industry and suggest to them that you can increase egg production more by changing it?

Somers: That was done as part of the analysis in 1986. It was based on egg per recruit, value per recruit and the combination of the two and it told us *not* to put the closure during the spawning season. That is difficult to comprehend by many, including fishers who see many gravid females in their catches at certain times of the year. The analysis was based upon the best revenue per recruit for a given egg per recruit and the closure we came up with was to occur at the beginning. It relied on escapement and we were measuring escapement up until spawning. The whole analysis on closure modelling has gone way beyond that. It now considers the interaction between closure modelling and SRRs, and the cost of having a mid-year closure in the short term. We don't know the long term benefits of the closure or how to include it in the SRR. It is being managed on the basis that no more than 4000 - 6000 days of effort go into the tiger prawn stock prior to the 1st August. Based on the uncertainty in parameter values, we've costed that to be between cost-neutral and a maximum of five million dollars in the worst case scenario in net operating revenue. That's the best we can give our industry at the moment.

Glaister: So the spawning closure protects the prawns immediately before spawning?

Somers: It's not meant to protect them immediately before spawning, but rather *sometime* before spawning. You choose whatever time you want. If you do the simple algebra, the monthly mortality coefficients are just additive and it doesn't matter when you put it in.

Glaister: If that was the theory for the closure, are you confident that the boats don't put in extra effort to compensate for the closed period?

Somers: You're right. Recruitment hasn't bounced back and another explanation that shouldn't be dismissed is that effort hasn't dropped dramatically from 1986. In fact it's increased and shifted in time. It's starting to drop now with restructuring. Many of the dual endorsed boats that may or may not have come to the fishery to fish tigers would now come because there was a guaranteed target on 1st August. Thus, effort during the spawning season is at record levels. That's a by-product which should have been predictable.

Glaister: But you've done the calculations in terms of eggs.

Somers: No. That's a job to be done.

Questions and discussion following this session.

Staples: (To Penn) You closed the Exmouth Gulf season on the basis of allowing a certain amount of recruitment to give a constant escapement to the spawning stock. Is that correct?

Penn: Yes.

Staples: How is there a rebuilding of spawning stock if there is constant escapement of spawners every year?

Penn: In the initial stage we shut the fishery for an extended period each season but still couldn't get back to the optimal spawning stock levels.

Staples: How many years was that?

Penn: Four or five.

Staples: And now you're holding it steady?

Penn: Yes, we now have industry agreement and that ability, but prior to 1986 we had a debate every year which went on until the breeding stock ended up low again, but not quite as low as it might have been.

Caputi: (To Somers). The spawning stock in the Gulf of Carpentaria tiger prawn fishery didn't seem to recover after the closure. The points, even the spawning stock points, appeared to be at that lower end. Is that correct?

Somers: They have increased by 20 - 30% but 20 - 30% of nothing is still nothing. That's why the spawning stock it still at that bottom end of the range.

Koslow: You didn't mention environment.

Somers: I meant to in my notes and apologise. We've looked long and hard for an environmental variable to explain the changes that we've seen. That was our first option because we were a bit reluctant to pursue the stock-recruitment route. We could find many environmental factors but none that were consistent across regions. We haven't given up the search and there's a lot more work that can be done. With all of the process work that CSIRO has been doing in the north, we have identified many factors which control those populations. As a result of that work, we would have expected to see the decline reflected at *all of the stages*. However, since the mid 1980s, Derek Staples' juvenile prawn results indicate no decline and this led us to question whether the juvenile abundances were being measured properly. Now we've had six years of intensive work in Albatross Bay and although there may be a problem of lack of contrast in that data we don't see low spawning stock, low larval abundance or low juveniles. There are links between one stage and another, but in others you see dramatic differences, which we refer to as mismatches.

Glaister: (To Caputi) When you were talking about your harvest strategy. What did you settle on?

Caputi: We initially assumed constant effort in Exmouth, using limited fixed entry. The option being used now is to vary the effort, year by year, and have closures to prevent spawning stock falling below a certain level. The spawning stock is closed to fishing once the abundance goes below a certain level.

Wang: When you look at the harvest you look at different fishing intensities and you get a variation in the different fishing intensities. How do you quantify that variation?

Caputi: We look at the SRR, put in a level of variation that has been observed, follow it through the simulations and repeat them a number of times. It is basically a Monte Carlo simulation.

Wang: Are the variations caused by the environmental factors?

Caputi: Basically yes.

Staples: (To Penn) You introduced boats in a very controlled fashion over the years and monitored effort. You obviously overshot. What would you now monitor to actually get the right number of vessels as you develop the fishery?

Penn: At the time we allowed the additional vessels in, we did not overshoot. The difficulty arose when vessels were replaced and the technology of the fleet improved, allowing them to increase effective effort. Any overshot was within the boundaries of being able to bring effort back. A buy-back scheme was effective and reduced the fleet by 20%. The northern prawn fishery's buy back scheme had to take out more than half the boats and created a huge amount of pain convincing half the people they would not be there next year. We in fact had quite good support. The people were happy to leave and the people that stayed in were happy to pay the money. It worked because we were not seeking a radical reduction in fleet size.

Staples: But do you have to overshoot?

Penn: It's inevitable. In any management system you're going to be adjusting the vessel numbers back and you have a quota or effort system, technology improves and the effort goes up. You have to make the adjustment because fisherman are always trying to increase their catch, and are reluctant to face the music until a crisis develops.

Eliason: (To Penn) I'm interested in measuring effective effort. When the W.A. fishers introduced propeller nozzles and large boards, this would have effectively increased their headline length, thus increasing the swept area. Given that headline length was maintained, did you take account of this?

Penn: What you're describing is the theoretical situation. What the skippers then did was redesign their nets, redesigned the boards, and put huge chains on so they were effectively turning otter trawls into dredges with a square mouth.

Eliason: Yes, I agree that adding a nozzle gives more power and the gear is towed at greater speed, all of which increase effort. However, you can put on much larger boards, given a limited headline length. I would be interested to see the type of nets they're using or talk to someone who was in that area at some stage.

Penn: They use fairly standard nets and the gear wasn't operating more efficiently. They were probably reducing the efficiency of the gear but increasing the area covered by increasing the trawl speed. There was a balance between the two. On the one hand you try to control the capacity of the fleet, and on the other you allow them to try to increase catch. They were probably using a lot more fuel, however the marginal increase in individual catch was still profitable.

Die: You use the closing date of your season to control the catch rate of the spawners to ensure escapement. Do you have some estimates on how successful you are in terms of ensuring escapement? How many times have you over run it? Have you over-run it at all?

Penn: Initially we over-ran it every year and ended up in a political argument. Recently it hasn't been a problem. We've set a very conservative cut-off time which is effectively 140 kgs/night for an average size vessel. The fishers are conservative and if we get it wrong we allow them back in between our surveys to do a mopping up exercise. We've done that twice and it was very interesting. For every kilogram decline in catch rate between the two surveys, the catch is reduced by about 10 tonnes from that specific area. Thus, it's starting to give us an idea of the total spawning biomass.

More recently, a few large tiger prawns are crossing the boundary line of the closure late in the season into an open area and fishers are catching them (mostly large females under 15 count) in October/November whilst fishing for king prawns. Thus, they are still harvesting tigers later in the year after spawning has taken place and these prawns are a very valuable product. The fishers now don't mind if we get the CPUE of the spawning stock levels wrong because it results in an increase in the number of large female tigers crossing the boundary line late in the season. Thus, there are many market interactions going on. We're in a situation now where we want fishers to go in for research reasons and deplete the tiger prawn stock, but at the same time the king prawn catch rates are better. In order for this to occur we have to close the king prawn area to force them into the tiger prawn area even for a few nights.

Hall: Based on what has been presented over the last few days on the eastern king prawns, is there any problem in the management of the fishery in two separate management zones (New South Wales and Queensland)?

Montgomery: It concerns me that effort has shifted south and directed at animals of a smaller size. The number of animals in our catch, therefore, must be greater and we don't have good information on that. The economics of the industry concern me more than the biology of the animal at the moment. The animal is looking after itself, but whether we're optimising the economic yield of the resource is another question.

Hall: Is the growing recreational effort going to cause problems in the future? Is management focusing on the complete picture or only at the commercial fleet?

Montgomery: We approached FRDC for funding to try to quantify the recreational fishing component, relative to the commercial fishery in estuaries. From now on it is likely that management decisions will include the recreational fishing sector.

Hall: Any comments from the Queensland side in terms of whether or not there is some difficulty seen in this. It seems that you've got very wide spread spawning going on south of the border as well as north. There's still no real indications, except we have a suggestion from Neil Gribble's work that something may be in decline in Moreton Bay. Are there any issues that come to mind?

Courtney: We need to study changes in the fleet's fishing efficiency much closer. The effects of introducing propeller nozzles, changing engine power and GPS need to be quantified in order to analyse our own data.

Staples: Is the data being collected from both states compatible? Are they collecting the same sort of information that can then go towards the management of this large stock?

Glaister: It would be useful to have a better understanding of the spatial component of the fleet dynamics. It would also be useful to have an index of recruitment, even though the general impression I have is that it doesn't seem to be a significant problem at the moment compared to the West Australian brown tiger situation. It would be extremely useful to have some idea of the catch size information. I should make the point that both New South Wales and Queensland researchers and managers do talk. We are doing joint work in a number of our fisheries so things have evolved quite a bit compared with a few years ago. I'm quite optimistic that that will continue.

Hall: I wasn't inferring that there was any difference of opinion between the two groups. It just seemed that yesterday the workshop spent a considerable amount of time on the eastern king prawn and it didn't get a great deal of mention. We saw the Queensland side, we didn't see much of the south of the border side, so I thought it was worthwhile raising that.

Summary of Workshop by Prof. Ray Hilborn.

I want to summarise much of what I heard and at the same time interject some of my own ideas about some of the problems in detecting and managing SRRs. There were four general areas arising out of the different papers presented.

1) Biology - what we know about the biology of animals in general, of crustaceans, and more specifically of eastern king prawns.
2) Data - understanding and managing for SRR's. Data plays an important part.
3) Analysis - how we actually use the data.
4) Management.

1) Biology. An essential fact of life is that if you don't have any spawners you can't have any recruits. Therefore, on the one hand, any analysis of SRRs should be entered into on the assumption that *it is there*. This is countered, to some extent, by a lot of experience which indicates that it often does not appear to be there. Ten years ago I believed that as methods of measuring stock and recruitment improved, we would see more clear evidence of the relationship. However, I've probably seen more of the opposite. Over time I've become more convinced that in many stocks, there is a very weak, if any SRR. As a biologist, this surprises me but it still appears to be the truth.

In regard to penaeid prawns and specifically whether there is a SRR for the eastern king prawns, there is contradictory evidence. In Exmouth Gulf and other W.A. stocks there is reasonably good evidence that there is a relationship. In a number of other stocks there doesn't appear to be one. It was the first day when Jim Penn presented his analysis of those areas where one might or might not expect to establish the relationship and we can't go too far beyond that at the moment. You don't really know *a priori* what to expect. Generally, if you can't fish a stock very hard, you are unlikely to decrease recruitment. With most of the fisheries we've been talking about it seems that you've the potential for reducing the stocks quite a bit.

Another area about biology which arose from the genetic paper this morning, is stock structure. In the north west of the United States and Canada most of our salmon stocks are harvested at a rate of 50% - 80% per year. That is, 50% - 80% of the returning fish are harvested. The salmon are not multiple spawners, but rather semelparous. They come back, are harvested, spawn and die. Harvesting at 50% - 80% a year means that if you look at salmon habitat, the only place you're going to find fish spawning is a place that is capable of producing intrinsic rates of growth that will sustain a 50% - 80% harvest rate. If you harvest from a small river that offers poorer habitat, then it may only support 1.1 or 1.2 recruits per spawner on average. It can't support 2 or 4 recruits per spawner. Rivers of that low productivity may have had fish in pre-harvesting times but they won't have fish now. If you start doing surveys of habitat in the north west you can potentially identify enormous areas we don't even call Chinook salmon habitat or Koho salmon habitat any more because no one's ever seen fish there since they started doing studies. It's quite possible if you weren't harvesting at all populations could survive there. The current thinking about prawn population structure is not anything like salmon but if it was, it would be quite possible that you could have had some habitats, mangroves, marginal streams that basically were fished out early on and have never been able to recover simply because they can't take that kind of exploitation rate. That would take a level of stock structure and fidelity that goes against most of what's known about prawns, but it's worth considering. Having spent a lot of time working on Orange Roughy in New Zealand, non-sustainable yields are always on my mind. In almost every fishery, non-sustainable yields are considered and yet throughout the last three days, references to declines in catch were largely considered in terms of overfishing. Given the life history of prawns, one does not normally think about non-sustainable yields.

There were many other interesting talks about what actually is a spawner and what is a recruit. That leads us into the next section on data.

2) Data. A recurring theme is that there are two major types of data that can be used to measure abundance; commercial catch data (CPUE) or surveys. Although it's often difficult to get funding, most researchers prefer surveys because they can be designed. CPUE data tends to provide only what the fishery gives you. Over the last few days, most analyses that were based upon CPUE data failed to reveal a SRR, whereas some survey data tended to reveal them. That was the general trend. If you've got to use CPUE data, then standardising it is a very important part of understanding it. These fisheries have been, and will continue to be subjected to the creep of technology, increasing fishing efficiency. Quantifying and calibrating the effects of technological change on CPUE is difficult and may be impossible. You're trying to correct for technological gain in the CPUE data in order to see a pattern in the SRR. That's asking a lot, but suggests what's important in order to maintain an understanding of the fishery's operations. You've got to know what's going on in the fishing fleet.

One of the key lessons in the northern cod story is that none of the stock assessment people were really on top of the changes in fishing efficiency enough to really realise that the fishing fleet had grown in efficiency by a factor of three. For ten years they used CPUE as a measure of abundance and in retrospect discovered it was completely wrong, the stock had not grown at all but had been stable. I was pleased to hear Jim Penn discussing how W.A. monitors change in their fleet's efficiency and quantifies change in CPUE. I've seen it for the northern prawn fishery. Tony Courtney said they don't monitor those types of changes yet in Queensland, but that CPUE is attained through the logbook program.

In order to know what's going on in the fleet in terms of technology, there's no substitute for contact with fishers. Georgina's comments are particularly appropriate there, that as biologists you need to understand what's going on in the fishery in order for the fishers to really be helpful, that is, to complete their forms. They have to know what you want and how you're going to use it. As a general rule, those undertaking stock assessment live and die by data. There's an implicit assumption that as time goes on we'll get more data systems and know more. Ten years ago Queensland did not have a catch monitoring system, now it does. Once you have a good data system it's very easy for it to deteriorate and this assumption that data is always going to improve is not at all a natural one.

The integrity of long term data sources needs to be maintained. It's very easy for the reliability of data to decline or for it to become totally unusable. For long term databases that are based upon CPUE, much of that maintenance depends on commercial fishers knowing what the data will be used for, and that it is in their interests to supply it and get some feedback. If all they're doing is filling out books and sending them off with no feedback the thing will fall apart. You need to have people who are in touch with the fishers, going fishing with them, and knowing how the equipment is being used. Jim Penn mentioned that radar was used for a long time, but it wasn't for 6 or 7 years before they actually started using it in a way that really meant a technological change.

3) Analysis. Nick Caputi gave a good summary of the myriad of problems associated with detecting the SRR. SRRs are likely to be difficult to see, even when they are present. There are many reasons, including environmental noise, why you don't see them. The main point is that if low spawning stocks produce low recruitment, then you're going to see it a lot faster than if low spawning stocks only sometimes produce low recruitment. Thus, the more important the SRR is (the more sensitive recruitment is to spawning stock), the more likely you are to detect it. Frequently however, what you're trying to do is detect a relationship between a poorly measured X-variable (spawning stock which is often CPUE with some calibration for changing gear efficiency) and a Y-variable (recruits). In general, recruits are measured more reliably than spawning stock.

On top of the relationship is all of the environmental noise. Thus, the chances of detecting the relationship, unless it's really strong, are not that high.

4) Management. This leads us to the last area and the most interesting one which is management. Ian Somers mentioned an approach similar to the one I'm suggesting. That is, that the simplest scenario is that there are two alternative hypotheses about the state of nature (Table 1). The first is that there is a SRR; smaller spawning stocks will produce fewer recruits. The second is that there is no SRR.

Table 1. Simplified range of options for the state of nature within the fishery and possible management alternatives.

	State of nature	
Management actions	Yes, there is a SRR	No, there is no SRR
No change (keep fishing as if a YPR problem)	1	3
Reduce effort	2	4

When using this simple scenario there are two management alternatives. One is that there's no change; fishing continues and the problem is treated as one of yield per recruit. The other management alternative is that you reduce effort. It is important to state that fisheries management is a decision problem and not a scientific one. There are scientific aspects to it, but it's not an estimation problem. The problem of fisheries management isn't to determine which of the 4 options in Table 1 above is true, but rather to decide what to do.

Option 1 represents the situation where a SRR exists but no change in management is introduced. Managers have to decide what the cost would be if no changes were made and there was a SRR. Conversely, they have to decide what the costs to the fishery would be if there was no SRR and effort was reduced (option 4). Most of the potential benefits and losses to the fishery will be associated with options 1 and 4.

Fundamentally, the purpose of fisheries is to make money. There are social and economic objectives as well, but in the long term we're trying to make the most money out of a fishery. For prawns, conservation as an objective in itself, doesn't seem to be a large component of management. Penaeids have high rates of recovery and in this respect they are not like an old growth forest. The population dynamics are fast enough for stocks to feed back and recover very quickly. If no changes are made and there is a SRR (option 1), then the stock's likely to decline until it is no longer economically viable, or it becomes apparent that there is a SRR. When evaluating the consequences of doing this, it should be done largely on the basis of expected economic cost, rather than, as in the United States, where consideration is given to the endangered species act.

Penaeid prawns are relatively short lived. The population dynamics are such that they tend to recover relatively quickly. You should not have to consider their conservation status. If the fishery gets over-exploited then the fishers will end up catching less and that's really what you need to worry about. I might get some disagreement on that. If you do reduce effort and there is no SRR (option 4) then there is going to be some cost in forgone effort, but most of these fisheries often already have excess effort. Thus, there's very little cost to reducing effort if it's in a yield per recruit situation.

Congratulations to David Die for doing an excellent job on presenting Serge Garcia's paper. However, I don't see a lot of need for what Dr. Garcia called "limit reference points". You don't need to have the reference points because they would fall quite naturally out of this analysis. In a yield per recruit fishery there is usually very little benefit to be gained from going to really high effort levels. The curves are usually very flat. If you're starting a new fishery and effort is low, there's no point in putting forward a limit reference point because you get very, very diminishing marginal returns. In a new fishery there's no point in pushing to the limit reference point because it is not one you would want to get to. You wouldn't naturally push the fishery if you were starting off fresh. If you're already at low stock levels, then I would argue that it's largely irrelevant because then what you'd be concerned about is the recovery phase and you're probably below the limit reference point to begin with anyway.

This then leads to some consideration of the precautionary principle. Care should be taken with how the precautionary principle is applied because there's two fundamental aspects of managing a fish stock. On one hand is the long term conservation objective, and on the other is the purpose of the fishery, which is to make money and employ people. Thus, the principle must be considered both ways. Caution is required with respect to destroying the existing commercial fishery and with respect to causing long term damage to the biological resource. The precautionary principle is usually only applied to the biological conservation aspect.

Option 1 above, could be referred to as the "biological bad end". Here, a SRR is present but no change in management has the potential to lead to a decline in stock (recruitment overfishing). For penaeid prawn fisheries I believe that this has little chance of occurring. Option 4 could be considered a "commercially bad end" - no SRR exists but effort is reduced, lowering catch and value. You have to weigh the probabilities of these two scenarios and determine how much risk you're willing to take to the *fishery* and how much you're willing to take to the *fish*? I don't see any suitable blanket-approach which always selects one or the other.

In many fisheries unless the fishery is already over-exploited, the limit reference points alternative should not be taken. In fisheries where effort is controlled, it is unlikely that management would choose to operate the fishery at levels which push catch rates down towards the lower extremes. The only time this would occur is when overfishing has already occurred, usually through lack of control of effort in the early stages. The real precautionary principle would be to shut the fishery down if it was thought to be over-exploited. In almost every case, that would lead to bankruptcy and it's not the way the real world works. It's important to give advice which considers both the uncertainty and the economic social reality.

Another aspect I was interested in was the technical analysis of the yield per recruit issues. For eastern king prawns, for example, you could undertake yield per recruit analysis with and without stock recruitment. You need to do this to figure out what the cost of the different cell options (Table 1) were.

Finally, I'd like to focus the discussion on three major areas; 1) the kind of data that should be collected, 2) the data that is being collected now, and 3) what should be collected in the future. It may be more beneficial to do routine monitoring, rather than research. If research is done what type of research should be done? The findings should be interfaced with users and managers to determine the kind of options that should be evaluated.

Koslow: For fish, it's the large fisheries which are based on the short lived species (anchovy, sardines and herring) that show the classic examples of severe depletion. Some of them have never come back. The California sardine fishery was one where the industry did not accept being shut down and the entire fishery collapsed. I would therefore be more cautious about option 1. There are many penaeid prawn fisheries within Australia and Asia. Are there case histories where the economics of these fisheries have been allowed to takeover? What has happened to the stocks under such conditions?

Penn: The difficulty is that in most third world countries the stock levels are depressed and it's difficult to determine whether they have been left to be driven by economics. In most of the multi-species fisheries the data is not that reliable. Tony Koslow is correct in that although penaeids are short lived, most fishing occurs prior to spawning. They are therefore, not in the safest category.

Hilborn: Do they tend to school?

Penn: Yes, there are some schooling species. In some species, such as banana prawns which are likely to have a steep stock recruitment curve, there is a rapid recovery (within one year). Is it possible that the cycles we see stocks going through are imposed by the fishery, rather than the environment?

Hilborn: That didn't answer Tony Koslow's question.

Penn: There is a lot around you can be suspicious about but getting data is very hard.

Glaister: Many of those fish species are very strongly aggregating. You can't conclude they are analogous to the prawn situation.

Staples: My experience from Asia is that it is very hard to find any evidence of recruitment overfishing. Discussions with the fishers suggest that there has been little change in prawn size or catch weight over long periods, and yet the fisheries' departments are concluding that the stocks are over-exploited. They are over-exploited in an economic and social sense (there's far too many fishers) but it's very hard to find quantitative evidence of recruitment overfishing.

Penn: The fisheries that I have written about in the past that have experienced trouble were on the geographic limits of their distributions.

Hilborn: Can you think of any particular one?

Penn: South Australia had problems with a couple of their stocks. There are three stocks of banana prawns on the west coast, two of which are virtually non-existent. The species is still there but the fishery doesn't exist.

Staples: The tiger prawn stocks in Kuwait are similar.

Penn: Yes, the Kuwait stock is pretty well on the limit of it's range.

Rothlisberg: The fishers in southeast Asia represent the 100th generation that's been fishing those stocks. Pre-exploitation levels are unknown.

Staples: The catches from Asia are tens of thousands of tonnes.

Rothlisberg: In Australia all of our major penaeid prawn fisheries have developed since World War II. We've lived through the pre-exploitation.

Hilborn: With regard to long-term data, if data collection in the eastern king prawn fishery stayed the same over the next 15 years would you have a considerably better data set than you have at the moment?

Courtney: It's difficult to say exactly what the total biomass coming out of the fishery is now, so if that continues for the next 15 years we still won't know what the total biomass was.

Hilborn: Where is the catch data coming from now? Is it from the logbook data?

Courtney: We've got CPUE for the entire fishery in Queensland. Two areas in particular can be identified as major recruitment areas and the CPUEs from those two areas allow us to monitor recruitment.

Hilborn: How's that data being collected?

Courtney: Through a compulsory logbook program.

Hilborn: That data could be analysed on a spatially stratified basis to get around concentration profiles. Can you look at offshore and inshore CPUE?

Courtney: Yes

Hilborn: What other kinds of data are you collecting now, continuous as it is?

Courtney: From the logbook we can assess individual boat movements, as well as movements by the fleet. However, there must be shifts in space and time which are likely to be very important.

Hilborn: It gets important in order to really understand CPUE. If the fishers move around a lot then you would expect that the CPUE will be determined by the cost of fishing in an area and not by the abundance in the area, which is a concern. You generally have to keep track of that. Do you monitor vessel power and changes in technology?

Trainor: At the moment we have some very basic gear sheets from the vessels.

Hilborn: Is there anyone out with the fishers, finding out how they're using it?

Trainor: Only in an ad hoc manner.

Hilborn: What's your experience in Western Australia? Are you monitoring changes in technology or do you have to catch up?

Penn: We have the data handled by the research team involved in the particular fishery. Occasionally there are events which we miss and we then retrace our steps. One example involved difficulty separating scallop-targeted effort and prawn-targeted effort. We were allocating effort to scallops when in fact we should have been allocating it to prawn effort. There are occurrences similar to that which keep arising and you've got to be close to the fishery to understand it.

Chubb: The commercial monitoring program for the western rock lobster fishery has technical staff out on the boats two weeks out of every month of the season. They are involved in talking with the skippers, determining where they fish and where they move. When there are improvements in technology, the technicians learn how to use it at the same time the fishers do. Thus, we are reasonably close to having a feel for what goes on with the changes in gear technology.

Staples: Do both Queensland and New South Wales have logbook programs covering the eastern king prawn fishery throughout its whole range?

Montgomery: New South Wales monitors catch through a monthly return system. We don't get much information on a spatial scale. CPUE is also measured from our fisher's co-operative records.

Hilborn: Any individual vessel movement data?

Montgomery: No.

Hilborn: Do you monitor any changes in the gear used by the fleet?

Montgomery: No, any changes that are noted come from our observations when we're in the field.

Glaister: There have been research programs that collected precise information.

Hilborn: Are these ongoing research programs?

Glaister: They usually last 3 - 5 years. Neil Trainor is collating historical data from the fishery. He's looking at very old records from individual fisher's personal diaries?

Eliason: I have a good idea of what they use.

Hilborn: Just from the logbook program?

Eliason: Yes and also from having worked in the industry. I'm quite interested in discussing it with them and have actually collected some records.

Hilborn: Does that go into any permanent form of record?

Eliason: I have a lot of records that I've collected through a more explicit gear sheet that I sent off, but I haven't entered it all.

Hilborn: So there's no form of systematic surveys.

Montgomery: Does Queensland collect size composition data?

Eliason: You could get that information through buyers.

Courtney: We don't collect it. It has been collected during short term research projects.

Hilborn: In 15 years from now would you have a consistent series of size composition data?

Montgomery: We don't collect size class composition data in New South Wales under the current system.

Trainor: There is one other source of effort data. That is the UDV (under deck volumes) which includes length and breadth for the boats.

Hilborn: Is that for both states?

Montgomery: Yes, that's on our monthly returns.

Staples: What about boat characteristics?

Montgomery: Yes

Eliason: That also includes power as well.

Begg: Is it important to be able to quantify the recreational component? There may be areas where it isn't a commercial fishery but there is a significant recreational component.

Courtney: There is no recreational component of the eastern king prawn fishery in Queensland.

Montgomery: We've just completed a three-year survey of the recreational fishery in New South Wales but it won't be ongoing.

Hilborn: How big is it compared to the commercial catch?

Montgomery: It's 15% of that taken by commercial fishers in estuaries.

Die: Only in the estuaries? What is the commercial estuarine catch?

Montgomery: 100 tonne a year.

Hilborn: How much of the total catch comes from estuaries?

Montgomery: About 25%.

Hilborn: So overall it's about probably 5% of total catch and probably not an important factor, although 15 years from now it might be different.

Staples: There is a need to collect environmental and meteorological data along the coast, as well as catch and effort.

Hilborn: In this case it's not so much a matter of collecting it but *collating* it. Why is it that they do surveys in Western Australia but not in Queensland or New South Wales?

Courtney: We seek funding for research on specific research objectives. We don't have long term research or monitoring programs. Everything's based on a maximum of three years.

Hall: It's also the size and the extent of the fishery. They're fairly manageable in Western Australia. The rock lobster is wide spread but it's got money to compensate.

Hilborn: How big are Shark Bay and Exmouth Gulf?

Hall: 60 x 30 mile for Shark Bay.

Hilborn: So they're really small areas compared with the east coast here?

Koslow: If all the catch is coming out of the logbooks, how much ongoing effort is there to validate it? Are there any funds to cross-check the data?

Trainor: There is currently a landing return through the buyers which is being used to validate the average catch per vessel. Catch is reasonably under control but the area the catch was taken is still not verified.

Somers: I'd like to raise a point about schooling species, non-schooling species and the data you need to collect for each. We understand you need to collect different types of effort data. There is a big searching component in schooling fisheries. Tiger prawns aggregate more than we expect them to and the northern prawn fishery fishers use GPS to home in on these aggregations. The CPUE data doesn't reflect how much these animals aggregate. The fishers catch a high percentage of the product in a very small area. In a single trawl 70-80% of the catch is taken in a very small section of the trawl and GPS is allowing them to deplete that little hot spot, which is minute in the eyes of the fishers.

Hilborn: Are you talking in tens of metres?

Somers: Yes tens of metres. What that means is that you might go to all of this trouble for the next 15 years and collect information that is far too coarse. The same sort of phenomena may occur in the eastern king prawn fishery. GPS is becoming very common in dealing with the fishery offshore, where in some respects, they were amateurs before they had GPS.

Hilborn: The big concern about using CPUE data with anything that schools is it may be impossible to collect data on a fine enough resolution to give a very reliable measure of abundance.

Penn: It's always dangerous where you've got a global system that's trying to collect everything from every species. The problem Ian Somers has just raised is very specific. A global logbook monitoring program is never going to provide that detail. You don't need every trawler on the east coast filling in a research logbook to find out the calibration factors to deal with the particular problem of GPS. You need to consider a subset situation with a research logbook if you've got those sorts of concerns. If the management agency is genuinely interested in managing the stocks in the long term, then that's where they have to put some money into specific research as well as for the global system.

Somers: There are two lessons to be learnt. Firstly you have to make sure you aren't playing catch up. You have to know how to interpret that coarse data and be aware of its deficiencies. Secondly, there is no substitute for fishery independent data at some stage or on a periodic basis.

Hilborn: Although the eastern king prawn fishery extends over 2000 kilometres along the east coast, is there any chance of doing surveys on a smaller scale which would be useful? Someone was showing today that there seemed to be three hot spots in all of Queensland and maybe it would be possible to set up some survey systems in those areas.

Montgomery: We're considering that approach in New South Wales to monitor abundance of eastern king prawns. We recently completed a three-year stratified random survey along the coast and we're considering repeating that for the eastern king prawn in the year after next.

Trainor: Industry is using this technology now. It's time for management to start looking seriously at satellite tracking of the fleet and for data-logging. It not only provides good locational data, but you get the good catch and effort data from that location.

Hilborn: You may need to approach the fishery's managers with the prospect that, with the current monitoring system in place, you won't be able to provide them with any more information in 15 years than you can now. That would really make the point with them because we assume that, although the data may be a little uncertain now, in a few more years it will be very much clearer. That might be the stimulus needed to get improved data collection.

Dredge: That's a hell of a risk for Queensland because it took 3 - 5 years to induce the cultural change needed for data acquisition to be seen as an essential part of any fisheries management or monitoring. To tell them now that the system isn't good enough could risk losing what we have achieved.

Caputi: The system is probably good enough for obtaining estimates of total catch and total effort, but it may be of little value in obtaining recruitment indices and abundance estimates. It's not totally useless and therefore it's a matter of approaching management and requesting to improve it, in terms of positioning. Industry surveys may also be useful and don't have to cost a lot. Industry pay for it and concessions could be given to those who participate to do certain things. We always think survey work has to come from consolidated revenue and that's very expensive. Research vessel surveys are also expensive and it's almost impossible to cover that whole area. With the co-operation of the industry it is possible and doesn't have to be that expensive.

Trainor: Funding is made available for specific research projects with finite life spans. Often such funding is very much "flavour of the month" oriented. It is difficult to maintain funding for the long-term, ongoing projects that we are talking about.

Hilborn: It may take a major crisis, such as recruitment overfishing, to mobilise the resources. That's not an uncommon experience.

Penn: You're more likely to get the industry behind you for such things as surveys, if they think the researchers and managers provide useful information. With respect to closures designed to protect small prawns, you can usually get someone to survey inside at no cost. You can use that information to forecast catch, and in doing so, generate something that the industry wants. They then get behind you.

Glaister: Theoretically, that's fine, but because of the size of the coast here, enforcement is a real consideration in the closure system.

Penn: If the large areas are a problem you could focus on hot spots. Industry could run surveys for you and you could have your own people on board.

Glaister: Even the hot spots, such as Princess Charlotte Bay, are large areas.

Penn: You'd be surprised once you got some data. The industry are usually pretty keen to help.

Glaister: They're sampling the closures for us right now!

Die: In Western Australia you use research surveys to forecast seasonal closures. Have you managed to use those surveys to obtain recruitment indices, which you would otherwise not have obtained?

Penn: The survey data are used for many purposes, including the calibration of the commercial data base. The recruitment surveys are used to give an indication of how long the season will last. We have 10 years of data now. When I first set them up I didn't think they would remain in place for more than two years. Now we have matching recruitment and spawning stock survey data for at least 10 years and we can start to construct a specific stock-recruitment data base using that. Norm Hall uses the spawning stock survey as the end product of the year class to then back calculate what the recruitment was using a VPA type approach.

Glaister: We are gathering that kind of information in Princess Charlotte Bay but unfortunately it's a short term project. We're evaluating the area closure there. I agree with you that using commercial vessels to obtain closure catch rate and size-class frequency data, rather than research projects, would be an excellent way of getting support from industry. Industry here are concerned that unscrupulous fishers go into the closures when they shouldn't. They're also concerned that the closures may not be economically beneficial.

Hilborn: What research should be undertaken?

Die: We're waiting for Shane Lavery to give us some results from his genetic work.

Dredge: It would be helpful to do some genetic work on effective population size and compare those results with a population that you could measure. That might involve finding an isolated prawn population which can be estimated.

Hilborn: Like Exmouth or Shark Bay?

Dredge: The tiger prawn stocks in Hervey Bay or Moreton Bay may be suitable. This workshop has been very much focused on prawns and rock lobsters. We have very substantial fisheries for other species of crustaceans. In Queensland we catch almost 3000 tonnes of crabs of three species a year. Although they may be more difficult to work on, they haven't been mentioned and appear to attract less research attention in this country.

Arreguín-Sánchez: Catchability was deemed to be an important factor influencing the likelihood of recruitment overfishing. This could be one area of research.

Hilborn: What kind of a research project would you do to look at catchability. That is fundamental to changing gear efficiency.

Hall: Depletion experiments could be considered. They may need to be repeated to see what temporal patterns occur with catchability.

Hilborn: In the northern prawn fishery you have an experiment with that closure on. You could measure Z (total mortality) before the closure goes on and then afterwards. This would give an idea of catchability and F (fishing mortality). Is there any monitoring during the closed period?

Somers: No, we have used the logbook CPUE data during the depletion time of the spawning season to estimate Z, F and M (natural mortality).

Hilborn: Does it work very well, is it consistent?

Wang: We used weekly total catch to estimate the mortality, catchability and the total number of recruits. I intended to work on some of the simulations and it worked very well with real data but was unreliable. We then tried using VPA but it turned out to be a nightmare.

Hilborn: It usually does.

Glaister: As far as the east coast king prawns go, the data that Neil Gribble presented suggests that there is a problem with catches having changed in Moreton Bay. Secondly, fishing effort from the New South Wales fleet has expanded and they're now taking some of the prawns that would have moved north, to Queensland waters. Routine monitoring of recruitment could be undertaken, via logbook analysis, sampling, or both. It is likely to be routine monitoring rather than a research project.

Dredge: There's much information being put forward about eastern king prawns and it would help if there was synthesis of the current and future research.

Staples: That's my impression as well.

Die: Do the Western Australians or the northern prawn fishery use market categories for their assessments?

Somers: We found market categories to be unreliable. We couldn't afford to put our own personnel on board and so we got fishers trained to do it. Processor information on size composition was unreliable, even if we did it ourselves. This is because the product was not always available to us, or only available at specific times when they were doing export assessments. Also you can't be sure where the prawns have come from because it's so far removed from the fishery these days that a lot of mis-labelling goes on.

Wang: We still don't have reliable estimates of natural mortality and therefore should do more work on it.

Penn: Many people have attempted to measure it. We had one attempt which was partially successful with a closed population of king prawns in a protected area. It used two vessels and we tagged thousands of prawns. Our estimates of natural mortality were low compared to most of the literature. Estimating in the rest of the fishery is extremely difficult. A better approach is to use an estimate of catchability and then estimate natural mortality, if you've got fishing mortality and a reasonable measure of catchability.

Hilborn: So nobody wants to apply for money for a tagging program?

Somers: Tagging programs have been tried and tested and always found failing. The experiment Penn described was a special case with Coburn Sound and the tagging was not the classical tagging. It was a mark/recapture on three occasions to estimate stock size. Normally when you try to measure natural mortality directly, or natural mortality/fishing mortality from tag/recapture studies of prawns, initial mortality and ongoing tag mortality make it un-quantifiable.

Hilborn: Has anyone tried coded wire tags on prawns?

Somers: Derek Staples did. Tell him about your coded wire tags.

Staples: Yes you can tag them but the problem is recovering them? We attempted to recover them by scanning recaptured prawns over conveyer belts.

Dredge: We've tried using sequential tag releases in sedentary or near sedentary populations of prawns to get estimates of M. It gives reasonable estimates (M = approx. 0.05 per week).

Hilborn: Has anybody tried the new embedded visible tags? They're a little bit bigger than coded wire tags. You inject them in transparent tissue.

Montgomery: I tried some in lobsters but haven't tried them in prawns. They tend to move around in the body.

Hilborn: And get lost?

Penn: Yes, we tried them, or their forerunners, in prawns. Scar tissue is generated, wraps around the tag and it comes off at the next moult.

Buckworth: The future resolution of some of these problems would be genetic tagging. It would give you a direct link between some of these population units that we currently don't have.

Hilborn: Could you use that to get M (natural mortality)?

Buckworth: Not to get M, but it would resolve a lot.

Montgomery: The most important issue pertaining to eastern king prawns is the biological optimisation of yield per recruit.

Hilborn: OK, let's move from research to analysis.

Staples: There needs to be both research and improved monitoring for the eastern king prawn fishery. There also needs to be a balance between the two. Some of the resources put towards research may be able to be put towards monitoring, if that's what is required.

Hall: You could develop research exercises to validate some of the logbook data and any monitoring programs. You could also study the technological approaches, such as those Neil Trainor mentioned to get improved catch and effort data. That's a short term research project which would be worthwhile. It would also be worthwhile using tagging to examine the rates of prawn movements between areas within the fishery.

Courtney: Since 1990 we've tagged about 9,000 eastern king prawns around Moreton Bay and in the Fraser Island area. That was largely a repeat of work that has was done in the 1970s and it showed similar results to the earlier work. Basically, there was a movement of prawns northward.

Trainor: Could Derek Staples comment on the value of scientific observers on the foreign fishing vessels?

Staples: We have a program in the southeast fish trawl for observers on a trial basis. They are collecting very good information but the cost-benefit needs to be looked at.

Hall: It would be a good idea to determine what oceanographic factors are important for the fishery. Queensland is also susceptible to much coastal development and you may also benefit from seagrass and other nursery habitat maps to understand the effects of development.

Die: Catchability of eastern king prawns is likely to differ between Moreton Bay and offshore. It is also likely to vary considerably between different offshore areas. The fleet operates differently in different offshore areas. It is a major stumbling block in the way we're going to be able to use CPUE data. It is also likely to be different again in New South Wales.

Courtney: We did a depletion experiment to estimate catchability on eastern king prawns but it is compounded because of the highly migratory nature of the animal. They don't remain stationary and move out of the area very rapidly. Earlier work by Lucas in Moreton Bay concluded that the population in Moreton Bay is reduced by 50% every two to three weeks. They move out very rapidly and this makes it difficult to get a grasp of catchability, even in the inshore areas.

Trainor: Tony Courtney's point is a valid one. There are not only spatial factors influencing catchability, but temporal factors a well. If you look at an area, plot the catch by day, and then sort it, it is highly skewed because most of the catch occurs on only 10% of the days fished.

Hall: If these are the problems that you face understanding your data, then you've got to put in time, effort and extra research to make sure you understand what your catch and effort data is all about. Otherwise you've got a massive amount of data but it means very little to you.

Staples: We need a good model of the eastern king prawn fishery. Steve Montgomery has developed a spatial model. Does that need to be stepped up and used in this?

Montgomery: Yes, it's what I meant by optimising yield per recruit. We do have a model which should be published by now. It's based on a simple departmental yield per recruit model based upon tagging studies in New South Wales over the last couple of years. It shows quite clearly that yield varies between times.

Staples: That model can form the basis of a larger one and can provide some research priorities as well.

Montgomery: We've come to the conclusion that to go any further with it, it would take a large research project. It requires a lot more variables which aren't there at the moment.

Hall: There are a variety of models that are possible. You may be able to include the Queensland fishery in the model and consider the stock in its entirety. You may get quite a lot of mileage from that. One of the benefits of it is that you will start being able to use the logbook data and explore the deficiencies in it.

Hilborn: It sounds like there's quite a lot of room for analysis both for modelling and for data analysis.

Final Session. Identifying Future Research Priorities in Relation to SRRs.

Participants were again separated into groups, which were based upon major fisheries and those involved in the research and management of them. Each group was asked to list four priority areas that need to be examined with regard to studying the SRRs within their fishery.

Penn: In our fisheries the priority for management is to maintain an understanding of the spawning stocks. We judge the performance of the Fisheries Department on a number of factors. These include whether we're able to undertake stock assessment of each fishery we're responsible for each year. We produce an annual report to parliament on how successful we are. We try to determine whether breeding stocks in each of the major fisheries is being maintained. These are our priorities from a department management point of view. The four priorities are therefore; 1) undertaking yearly stock assessment on each major fishery, 2) determining whether the breeding stock is being maintained, 3) forecasting next year's catch and 4) modelling.

If you're doing stock assessment work then you should be able to provide an indication of what the catch is going to be, the range it's going to have, and some explanation for it. Fundamentally we're here to make sure the stocks survive and therefore it's prudent to determine the condition of the breeding stocks, even if they're not related to recruitment. If you know what the recruitment is you can forecast catch.

We have yearly stock assessments and a breeding stock monitoring program which may simply be to determine that recruitment is being maintained and there's no evidence the stock is in trouble. Then we try to predict what the catch is going to be and what range it's going to be in next year. For breeding stocks, particularly for our major fisheries (lobsters and prawns), we have monitoring programs which are using commercial data. These are validated, in one way or another, by surveys to ensure that we have good measures of breeding stock and recruitment. We also collect environmental data as well. We can tell the difference when the two (CPUE and research surveys) are varying. Our top priority for all our programs is to put those things together. Then we have a modelling approach to determine what the predicted catch may be sensitive to. If necessary we go back and add more biological data when we can see there is some variation we don't understand.

Hall: One of the fundamental things is to get good catch and effort data sets and a fishery database. That really is the essential ingredient right at the beginning. A huge amount of our effort is devoted to that and the continuing assessment.

Penn: I'm disheartened when people separate the biologically orientated research from the (logbook) database maintenance. The database is a measure of what the fishers are up to and the catch is what the stock is doing. It's as much research (to research the fishers in the context of their behaviour), as it is to undertake biological research. We've integrated our database management into the research division and it's considered as a research program - not something that is done by somebody else. That is a priority and if it's there you get feedback to the fishers and all the rest of it starts to work better.

Courtney: Now a representative from the northern prawn fishery will list their priorities.

Somers: Firstly in the northern prawn fishery we need to define the effective effort going into the fishery. We've been able to partially answer that with the help of Rick Buckworth and the Northern Territory, but it was a preliminary assessment, based on head rope length and it only went to the mid 1980s. From then on effective effort continued to increase without the head rope length increasing. We know that for a fact. Secondly, we have been searching for it like the holy grail, that is the influence of the environment on tiger prawn recruitment. We have an environmental database at CSIRO, albeit a couple of years out of date now and we intend upgrading it in the near future. That environmental database is not that comprehensive. It is meteorological data and it relates to all of the recording stations in the north. Thirdly, we need to determine the effective spawning stocks. Peter Crocos mentioned that yesterday. They need to be defined if we want to know the relationship between the spawning stock index and the recruitment index, irrespective of what we do from the modelling point of view. Fourthly, as Yougan Wang said before, we need to estimate M and q (natural mortality and catchability) and we've made substantial progress in that in the last months. We've actually been trying to do that for the last decade.

Staples: With regard to the effective spawning stock, if it is only a portion of the spawning stock and that portion stays the same every year you don't have a problem.

Somers: That's right.

Staples: So it's really the variability in effective spawning stock.

Somers: No. It's a bit like measuring the wrong thing. What's the unit stock? Once that's defined you may not need to do anything again except use the commercial fishery data. The trouble is the way it was described you need a lot more than just commercial catch and effort data. You need to know what the stock structure was, what the size composition was and the age structure.

Courtney: Reg Watson, would you put forward your four priorities for the Torres Strait?

Watson: I'm speaking for a whole range of fisheries. There's a lot of correlation with the previous work. We're facing a situation where we're going to have very little use of research vessels in the future. That's my appraisal and we're going to have to make greater reliance on logbook data. Thus, the first priority is to do what research we can now to find out which are the best and most useful indices for recruitment and spawning stock from the logbook data. I want to do some research looking at PFI's (population fecundity indices) and also recruitment patterns to determine what part of the logbook information we can use in the future to keep gathering information on stock and recruitment. We can't plan on doing that in the future by research surveys.

The second priority, based on what the Western Australians do, is to make it possible for us to offer the incentives for industry to assist us in doing surveys. I don't know a way in the system, as it currently operates, for me to offer an operator a chance to go into a closure and survey it for us under our control. I don't think that's possible and it's a weakness in our ability to get data in the future, particularly because we will have less sea-time with research vessels. This would include Papua New Guinea. We have very little information about what happens to the same stock just north of the border. They're not collecting information in that country. In the Torres Strait context, we have to find out more if we're looking at recruitment processes and changes in habitat.

The third one is depletion experiments for stock size and catchability estimates. The fourth priority is to monitor changes in habitat and fishing behaviour, but particularly changes in critical habitats such as seagrass areas. We have done surveys and we know where they are but there's no program for us to collect the correlating environmental information, except for the meteorological data.

Glaister: With regard to eastern king prawns, the first priority is understanding the fishery as a whole, rather than in two parts (New South Wales and Queensland). This means collecting information throughout the extent of the fishery and maintaining continuity and the standardisation of the database.

Die: The second priority is to develop indices of stock and recruitment on the basis of that standardised database.

Courtney: How about trying to get hold of the ever-increasing technological changes?

Glaister: That's implied in number one.

Penn: It's implied in number two, also.

Milton: What about defining stock structure?

Die: Yes, definitely.

Courtney: Do you mean in the sense of determining if it is one or more than one unit stock?

Die: Yes, what is it? This is relevant to tiger prawn stocks along the coast and endeavour prawns, as well as the eastern king prawns.

Glaister: Red spot prawns too. With the fishery becoming more search-oriented, technology and GPS are changing the CPUE dramatically. In certain cases, such as when fishing red spot king prawns, you're able to go up against the reef. Five years ago you couldn't have done that. Identifying those kinds of changes could be a priority.

Loneragan: That's so important. It's almost worth making it explicit even though it's implicit in some of the other priorities.

Chubb: It could be included as fleet dynamics and efficiency.

Courtney: Dr. Gracia would you like to identify research priorities for the fisheries in the Gulf of Mexico?

Gracia: I'm going to focus mainly on the white shrimp, *P. setiferus* in the southern Gulf of Mexico. I have to acknowledge that overfishing has already occurred and that a re-building of the stock is taking place. First of all we have to measure the real effort and estimate the effective effort on the spawning stock. This includes both the trawl and artisanal fisheries. One of the other things is to assess the spawning stock. This involves determining the distribution pattern of the spawning stock in the area and determining the minimum stock size. Another priority is to determine whether the area of nursery grounds has been damaged or destroyed. The resilience of this fishery also needs to be restored because recruitment overfishing has already occurred. We need to determine how such populations can recover under such situations. The fourth priority is modelling so that this problem can be managed and prevented from happening in the future.

Die: That was from the southeast of the Gulf of Mexico and now from the north.

Arreguín-Sánchez: We have three different fishing grounds in Gulf of Mexico. Adolfo Gracia was talking about the white shrimp fishery in the southern ground. I was talking about the brown shrimp in the more northern fishing ground. There is another area where there is a combination of these and other species. We also have another shrimp, the pink spotted shrimp and the situation of this fishery is quite different. We've had an expansion of the fishery over the last seven years. In the beginning, the fishery was very successful, but with expansion, the population dynamics and stock-recruitment situation have changed. The brown shrimp fishery was growing, but now it is stabilising. As far as SRRs are concerned, the relationship is best described and understood for white shrimp. The pink shrimp fishery has many problems and is the only one in the Gulf of Mexico with decreasing yields - almost ten thousand pounds in the last decade. One of the problems is one area was closed to trawling. Before the area was closed it was a well established fishing ground and the fleet targeted species depending on the season. They worked on the pink shrimp and when that population decreased they turned to brown shrimp. Currently, because the area is closed, pink shrimp have been overfished. Also, the fishing effort on pink shrimp in the coastal waters has increased significantly and the yields decreased significantly. So we have two problems here; recruitment overfishing and growth overfishing. In my opinion, the first priority for future research in the Gulf of Mexico is to identify the SRR in all stocks. The second priority is due to the multi-species nature of the fishery. We need to identify the distribution of the different species. The brown shrimp occurs in different areas of the Gulf of Mexico and we don't know if they are different stocks, or part of a single stock. Thus, the third area of research priority is to identify stock structure.

Without further discussion or identification of other high priority areas for future research, the workshop was brought to a conclusion.

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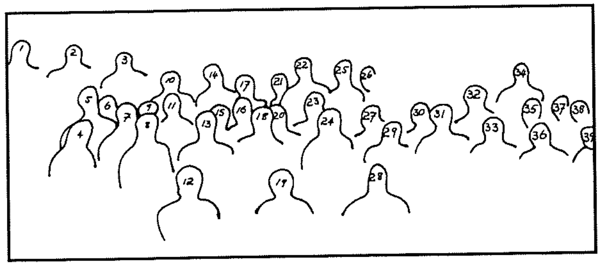

1-Shane Lavery, 2-Clive Keenan, 3-Mike Dredge, 4-Tony Courtney, 5-John Glaister, 6-Chris O'Brien, 7-Peter Rothlisberg, 8-Reg Watson, 9-Steve Montomery, 10-Norm Hall, 11-Ian Somers, 12-Neil Loneragan, 13-Brian Taylor, 14-Neil Trainor, 15-Jim Penn, 16-Clive Turnbull, 17-Neil Gribble, 18-Yougan Wang, 19-Tony Koslow, 20-Rik Buckworth, 21-Georgina Eliason, 22-Ray Hilborn, 23-Ian Knuckey, 24-Francisco Arreguin-Sanchez, 25-David Mayer, 26-Dave Vance, 27-Matthew Sheehy, 28-Derek Staples, 29-Carolyn Robins, 30-Nick Caputi, 31-Adolfo Gracia, 32-Peter Crocos, 33-Kate Yeomans, 34-David Die, 35-Jason McGilvray, 36-Julie Robins, 37-Michael Cosgrove, 38-Gavin Begg, 39-Robin Watts.

Participants not in photogragh: Chris Chubb (Photographer), Burke Hill, Max Beatson, Pat Coutin, Don Heales, Rob Kenyon, Dave Milton, Tony Tucker, Mick Haywood, Mark McLatchey, Kevin Warburton, Ian Poiner, Phil Pond, Simon Prattley.