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Summary of the West Coast Rock Lobster Managed Fishery science and modelling review

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Table of Contents

Executive Summary

An independent peer review of the science and modelling associated with the West Coast Rock Lobster Managed Fishery was undertaken in May/June 2018. The impetus behind this review was two-fold, i) to address industry concerns that stock assessment modelling was not reflecting what was being experienced by fishers on-water, and ii) to increase stakeholders understanding of, and confidence in, the stock assessment process while ensuring that the process was commensurate with contemporary scientific practices. The review was conducted as two separate components, a science review attended by one international reviewer, industry stakeholders and Department of Primary Industries and Regional Development (DPIRD) scientists, and a modelling review which was attended by the same attendees as the science review with the addition of two more international reviewers. Presentations and discussions during the science review resolved a number of existing industry concerns. There were some outstanding issues, both from DPIRD and industry, raised in the science review which then formed the Terms-of-Reference for the subsequent modelling review. From the modelling review, the reviewers considered the current modelling framework and analysis conducted by DPIRD to be robust and fit for use in setting the annual quotas. In addition, the reviewers provided a number of recommendations they considered would add value to the management of the fishery and further improve the stock assessment process. The majority of these recommendations have either already been implemented or are major components of on-going work.

1. Introduction

In early 2018, Western Rock Lobster (WRL) requested to work collaboratively with the Department of Primary Industries and Regional Development (DPIRD) to undertake a formal independent peer review of the science and modelling associated with the West Coast Rock Lobster Managed Fishery (WCRLMF). While the fishery has annual reviews of the stock assessment and associated annual indices as part of their Marine Stewardship Council (MSC) certification and harvest strategy, the last formal review of the stock assessment modelling was conducted just after the change in management from input to output controls in 2011 (de Lestang et al. 2012). Since then, the fishery has settled into its new quota management system and has seen an increase in the legal biomass of lobsters. This increase in biomass has resulted in pressure to raise the total allowable commercial catch (TACC). While the TACC setting was not a part of this independent peer review, the outputs from the stock assessment modelling will ultimately form the basis of these calculations, and confidence in the science and modelling resulting from the peer review will greatly assist in TACC decision making. Therefore, it is important to ensure that the modelling is accurate and that the quality of advice from the modelling is appropriate. This is particularly relevant given concern has been expressed by some commercial fishers that they are observing different catchability and lobster behaviour compared to their historical experiences. In their view, the modelling may be overly optimistic and fishers are concerned by the consequences of overestimating the legal biomass.

In order to review the modelling of the western rock lobster resource, a two-step process was adopted. The first was a science review that outlined the science program for the western rock lobster resource and addressed the concerns of the fishers in data collection and interpretation. This was then followed by a review of the stock assessment modelling, focusing on fisher concerns not adequately addressed during the science review.

2. Science Review

The science review (Appendix 1) consisted of two separate processes: a coastal tour identifying issues with the wider industry; and a one-day workshop which combined science presentations with a question and answer session. The one-day workshop was attended by one international reviewer (Dr. Linnane) who also formed part of the modelling review (see below) for consistency across the two-fold review process. The presentations and discussions during the science review were considered mutually beneficial, and a number of existing concerns were resolved during this process. However, there were some outstanding issues which were decided would form part of the Terms-of-Reference (Appendix 2) for the subsequent modelling review.

2.1 Outcomes of Science Review / Terms of Reference

For more detail see Appendix 2

1. Appropriate levels to set the threshold and limit reference points (MSC definitions)?

    - Threshold: Maximum Sustainable Yield

- Limit: Point of Recruitment Impairment

2. Review and assess the three models and determine their appropriateness.
3. Are three models to assess the fishery necessary or should they be reduced / modified (is there a more efficient process)?
4. What is seen while fishing is not reflective of the growth of biomass in the models. Are the models having difficulty assessing this index?
5. Is spatial variation in recruitment been accurately captured in the model and has it changed temporally?
6. Is the current data collection sufficient for the management of the fishery?

3. Modelling Review

The modelling review consisted of a two-day workshop (Appendix 3) which combined presentations by DPIRD scientists to the reviewers, the collective examination of the data and models by the reviewers and scientists as well as a question and answer session between the reviewers and industry representatives. The reviewers were internationally renowned stock assessment modelers and lobster scientists, Dr. Malcolm Haddon (CSIRO), Dr. John Hoenig (Virginia Institute of Marine Science) and Dr. Adrian Linnane (South Australian Research and Development Institute). The reviewers considered the current modelling framework and analysis conducted by DPIRD to be robust and fit for use in setting the annual quotas. They provided a report (Appendix 4) which contained a number of recommendations they considered could add value to future stock assessments. These specific recommendations are listed below:

3.1 Outcomes of the Modelling Review - Recommendations

These recommendations are simply copied from the body of this review (Appendix 4) and their context and justifications are to be found in their relevant sections.

ToR 1: Appropriate levels to set the threshold and limit reference points (MSC definitions)?

1. In addition to egg production (and any requirements from the MSC), consider adopting a reference point based on puerulus counts.
2. In relation to spatial allocation, consider adopting a dynamic allocation procedure where regional TACCs are based on the current biomass in each region.

ToR 2: Review and assess the three models and determine their appropriateness.

1. Continue to use a living document to report on progress with on-going model changes and updates.
2. For the Integrated Model, consider reducing its complexity but expand the reported outputs and diagnostics.

3. For the Biomass Dynamics Model (BDM), provide explicit and documented comparison of the implied stock dynamics with those from the Integrated Model over the same periods and explore the inclusion of some spatial dynamics.
4. For the Tag Recovery Model, attempt to improve tag recovery rates.

ToR 3: Are all three models necessary?

1. Retain all three models but continue their development as described in TOR 2.

ToR 4: What is seen while fishing is not reflective of the growth of biomass in the model(s).

1. Attempt to obtain data from inshore areas through either expansion of the independent breeding stock survey (IBSS) or the meshed pot sampling program.
2. Investigate alternative CPUE scenarios in relation to time-series of data and changes in catchability.
3. Given observed changes in fishery dynamics, maintain IBSS and possibly expand as per (1).

ToR 5: Is spatial variation in recruitment accurately captured in the model and has it changed temporally?

1. Maintain puerulus sampling at current levels and possibly expand to include areas considered to have lower levels of productivity.
2. Examine alternative projections using the BDM with different settlement rates based specifically on more recent puerulus settlement rates.

ToR 6: Is current data collection sufficient for management of the fishery?

1. Continue to improve documentation of CPUE standardisation and consider alternative CPUE scenarios as per TOR 4.
2. Maintain and possibly extend IBSS as per TOR 4.
3. Expand either fishery-dependent or independent meshed pot sampling into areas considered to be exhibiting lower productivity levels.

4. Actions arising from the review process

A key outcome of the science and modelling reviews was to get a list of suggested modifications / additions / deletions to the data sources and approaches used in the assessment of the Western Rock Lobster fishery. The reviewers' report from the modelling (Appendix 4) contained a number of recommendations, all of which will be adopted by DPIRD. The timing and process for their implementation is outlined below. For full details on the background behind these recommendations, please refer to the reviewer's report (Appendix 4).

ToR 1: Appropriate levels to set the threshold and limit reference points (MSC definitions)?

1.1-In addition to egg production (and any requirements from the MSC), consider adopting a reference point based on puerulus counts.

In the current[1] (and planned) Harvest Strategy the sustainability objective is to "*maintain breeding stock levels above threshold reference levels with 75% certainty, projected out 5 years*". Although this statement does not specifically identify puerulus recruitment levels as suggested by the reviewers, the projection component incorporates puerulus settlement. The modelling projections is essentially based on three main pieces of information, current biomass levels, future projected catches, and the most recent four puerulus settlement levels. Since puerulus settlement levels are one of the main drivers in the future projections of biomass, we consider that they are already incorporated into the sustainability indicator of this fishery. This recommendation is considered adopted.

1.2-In relation to spatial allocation, consider adopting a dynamic allocation procedure where regional TACCs are based on the current biomass in each region.

In the initial management arrangements for the fishery when it transitioned to output controls (TAC), a dynamic allocation of quota between the northern and southern parts of the fishery was implemented. Following advice from WRL, management arrangements were changed, locking in a 50:50 catch ratio north (Zones A & B) and south (Zone C). Adopting some form of spatially-variable allocation has formed a component of the discussion paper of the new Harvest Strategy for this fishery.

ToR 2: Review and assess the three models and determine their appropriateness.

2.1-Continue to use a living document to report on progress with on-going model changes and updates.

A living document outlining model changes and development has been produced for the past four assessments. This document will continue to be produced and will be incorporated in the five-year updates of the Resource Assessment Report for the Western Rock Lobster Resource as an appendix.

2.2-For the Integrated Model, consider reducing its complexity but expand the reported outputs and diagnostics.

DPIRD has already started to undertake this component of work. A simplified model framework from the integrated model (IM) is being developed and an external contractor has been acquired to work with DPIRD staff to develop the new integrated model. The new simplified version of the IM will be developed on a more contemporary platform (TMB). As part of this development the diagnostics and outputs reported will be expanded in line with reviewers' recommendations. It is hoped that this will have been completed in time for its application in the 2020 stock assessment.

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[1] West Coast Rock Lobster Harvest Strategy and Control Rules;2014 – 2019 Published by Department of Fisheries 168 St. Georges Terrace Perth WA 6000 June 2014 ISSN 0819-4327 http://www.fish.wa.gov.au/Documents/management_papers/fmp264.pdf

2.3-For the Biomass Dynamics Model, provide explicit and documented comparison of the implied stock dynamics with those from the Integrated Model over the same periods and explore the inclusion of some spatial dynamics.

DPIRD has already started to undertake this work and it is foreseen that it will be available for the subsequent stock assessment in 2019. The main component of this work is to develop an index from both the IM and BDM that can be presented on the same scale. This index represents all lobsters > 76 mm (not including ovigerous females).

2.4-For the Tag Recovery Model, attempt to improve tag recovery rates.

The current tagging project has finished and so tag reporting rates are no longer a concern. However, in the development of future tagging studies in this fishery extensive work will be conducted to increase tag-return rates. This will require strong support by WRL and the industry more broadly.

ToR 3: Are all three models necessary?

3.1-Retain all three models but continue their development as described in TOR 2.

DPIRD plan to maintain all three models and add an additional simplified version of the current IM by 2020.

ToR 4: What is seen while fishing is not reflective of the growth of biomass in the model(s).

4.1-Attempt to obtain data from inshore areas through either expansion of the IBSS or the meshed pot sampling program.

DPIRD have initiated a new project in conjunction with WRL aimed at producing annual standardised estimates of lobster abundance in shallow water (< 20 m) regions throughout the fishery. It is hoped that this survey will start in May 2019.

4.2-Investigate alternative CPUE scenarios in relation to time-series of data and changes in catchability.

DPIRD have started this analysis. The influence of commercial catch rate data to the biomass projections produced by the BDM has been assessed; commercial catch rate trends since the inception of quota were found to have minimal influence on projections.

A direct examination of the influence on commercial catch rates from commercial fishers changing their reporting of catch and effort from monthly to daily with the change to quotas will be conducted. This analysis will focus on using data from fishers who have filled out volunteer daily log-books that span the period of this changeover. The use of these three data sets per fisher will provide a strong indication as to any changes in the relativity of catch rate information across this time period.

4.3-Given observed changes in fishery dynamics, maintain IBSS and possibly expand as per TOR 4.1.

DPIRD have no plans in reducing the IBSS. Recent discussion with WRL have identified a process by which the IBSS may be expanded (see 4.1).

ToR 5: Is spatial variation in recruitment accurately captured in the model and has it changed temporally?

5.1-Maintain puerulus sampling at current levels and possibly expand to include areas considered to have lower levels of productivity.

Puerulus sampling will be maintained at the current long-term locations (n=8), with the program expanded with additional puerulus collectors located in comparable shallow-water areas within the Cliff Head region which is considered to be an area of atypical low productivity.

5.2-Examine alternative projections using the BDM with different settlement rates based specifically on more recent puerulus settlement rates.

Alternate projections from the BDM using reduced levels of puerulus settlement have been conducted and will be presented to industry at the subsequent Annual Management Meeting.

ToR 6: Is current data collection sufficient for management of the fishery?

6.1-Continue to improve documentation of CPUE standardisation and consider alternative CPUE scenarios as per TOR 4.

A draft CPUE standardization report has been developed for a contemporary fishery (south coast crustaceans). It is planned that this document will be finalized utilizing the input from a range of scientists within DPIRD and will then become a departmental standard document. The processes outlined by this document will be applied to WRL data and reported on in the subsequent publication of the Resource Assessment Report for this fishery.

6.2-Maintain and possibly extend IBSS as per TOR 4.

This has been addressed in TOR 4.1

6.3-Expand either fishery-dependent or independent meshed pot sampling into areas considered to be exhibiting lower productivity levels.

A focused survey has been developed within the low-productivity area surrounding Cliff Head (FRDC 2016-260). This sampling utilizes meshed pots as well as the tagging of lobsters to track their growth and movement. The expansion of the IBSS into shallow waters (see 4.1) will also use meshed pots. This will greatly increase our understanding of the low-productivity areas as well as the broader fishery.

Appendix 1. Report from Science review

Science Review Report

6th April 2018

Simon de Lestang, Jason How, Emma-Jade Tuffley, Matt Taylor and Clare Robinson

GOVERNMENT OF WESTERN AUSTRALIA

Department of Primary Industries and Regional Development

Western Rock Lobster

World leading sustainable fishery

Science Review Process

The process for the science review was broken down into two main phases. A “coastal tour” of major ports within the fishery, conducted by Western Rock Lobster (WRL), to canvas industry's opinions regarding status of the fishery (see Appendix A). This was augmented with a number of emails by fishers posing specific issues they wished to have clarified at the subsequent workshop. Phase 2 was a science review workshop held on 6th April 2018 at the DPIRD offices in Hillarys. The review was organised by DPIRD in collaboration with the WRL. The workshop consisted of presentations by Drs Simon de Lestang and Jason How from DPIRD and Dr Tim Langlois from UWA (Appendix B) and was attended by 33 participants (Appendix C). Questions were allowed throughout the presentations, with additional time provided in the afternoon of the meeting for concerns to be raised by participants. All of the questions, concerns and discussion have been summarized in this report. Outcomes from these discussions informed the terms-of-reference for the modelling review held on 31 May and 1 June 2018.

Science Review Presentations

The science presentations outlined a number of key factors used in the stock assessment. These were:

- Data sources collected and used in the assessment of the fishery
- Atypical observations being reported by fishers
- Factors affecting data sources and causing biases in perception
- An assessment of catch rates throughout each main area of the fishery, focusing on the relationship between puerulus (post-larval) recruitment and subsequent undersize lobster abundance
- A review of the heat wave that impacted the coast in the summer of 2010/11 (and to a lesser extent in 2011/12 and 2012/13)
- A description of the integrated stock assessment model from which the annual assessments are made (as well as a description of two draft models being developed to compare with the integrated model)
- The outcomes of the modelling focusing on where the stock is currently considered to be
- Associated current and future research projects

Questions raised during science presentations

A number of questions or discussion points were raised during the science presentation. These, and the associated responses are outlined below.

What is the relationship between lobster growth rate and temperature?

Density, temperature, sexual maturity and habitat have been shown to affect lobster growth rate. Generally however, juvenile growth rate will increase with temperature, though interplay between the aforementioned factors does make it a more complex issue. A paper on this has recently been accepted for publication (de Lestang 2018).

Could a lack of juveniles in an area affect the settlement of puerulus?

The Department is currently investigating potential cues for puerulus settlement. For example, does noise associated with other lobsters trigger settlement? However, in aquaria, puerulus are often ingested by larger lobsters. This cannibalistic behaviour would suggest that a lack of juvenile lobsters would not result in reduced settlement owing to reduced predation rates. Work overseas has indicated that settlement is triggered by water depth and certain types of algae. Additionally, studies have shown that puerulus and post puerulus lobsters are not gregarious for one to two years after settlement.

Since going to quota and opening the fishery to year round fishing, some fishermen are known to heavily target the IBSS locations right before DPIRD sample. This would not have happened in the past when the fishery was closed over the breeding season. This is likely to affect IBSS catch rates. How do you account for this in the model?

Tag returns show that some IBSS sites are heavily fished. However, these sites are representative of deeper water breeding grounds. There is no reason to assume these sites are being fished any more intensively than the rest of the fishery. Catch rates from the IBSS therefore should be representative of the entire fishery and a good proxy for abundance. However, should the fishing on the IBSS grounds be more intensive than other deep water breeding areas, then the index would be an underestimate of the broader breeding grounds. This could result in a more conservative management of the breeding stock.

Fishers are concerned about the fact that they can now keep setose. Will this have repercussions for the breeding stock?

This is one of the benefits of a quota system and of fishing at relatively low harvest levels. When management regulations result in large number of lobsters being left on the ground, fishers can take more of what's in their pots without risking the state of the breeding stock. The effect of these changes are monitored by the IBSS.

Discussion: The importance of commercial monitoring and the meshed pot program for the assessment of the stock was highlighted and it was noted that it requires considerable industry assistance. This elicited some discussion regarding why some commercial monitoring trips weren't undertaken on some fishers' boats and why meshed pots aren't being recorded to the same level they were previously.

It was noted by a fisher that commercial monitoring staff don't want to go out in bad weather and that is why they are not getting on as many boats to monitor. The same fisher also said that they are now too busy to complete a meshed pot. This was rebuked by another fisher who stated that it doesn't take that much more time and fishers should take a more active role in the collection of data for research. A different fisher mentioned that they go earlier on the days when monitoring staff are out so that they can record the undersize abundances from a greater number of pots than just the single meshed pot. The CEO of the WRL said that they are committed to getting access to more research data from fishers and wanted to explore ways to attain this. A suggestion of extra quota was suggested but was dismissed as neither DPIRD nor WRL had quota to give away in return for research participation.

Fishers in the Jurien Bay area have changed fishing behaviour in recent years, from concentrating on the shallow waters, to now focusing effort in the deep offshore waters and the whites. Could the changes in shallow and deep water total catch and catch rates in Jurien Bay, be reflecting a change in fishing effort location, rather than a change in biomass location, as suggested by the scientists?

This proposed change in fishing location effort will have impacted the total catch in deep and shallow water, and explains why the majority of total catch now comes from deep water. However, catch rates take into account the number of pots fishing in each location. Catch rates have increased across both deep and shallow water, but the increase has been far greater in the deep water. This suggests that biomass in deep water is at a historical high level and that while biomass in both shallow and deep water has increased, this increase has been greatest in deep water.

Discussion: Modelling showed that the Abrolhos Islands were not as impacted as other northern locations after the heat wave. It was suggested that this may be related to the relatively warmer waters of the islands, and that the ecosystem there may be more resilient to heatwaves as a result. However, it was mentioned that the islands have experienced a substantial change in floral habitat after the heatwave, from "cabbage weed" to what has colloquially been termed "scary weed", which is a green filamentous algae.

Could the fact that the model is not predicting the recent downturn catch rates in Kalbarri since the heatwave be a result of later than average winter storms delaying puerulus settlement in this area?

Late winter storms could explain this variation from the model. If this is the case, next year we should see a massive increase in undersize. However, the residual plot suggests the puerulus-undersize model has over estimated undersize catch rates each year since the heatwave, with the exception of one very low catch year.

Fishing efficiency has increased substantially since the fishery began, especially in the 1990's when technological advancements meant technology such as GPS were readily available for use by fishers. Where the model has backdated estimates of catches, what fishing efficiency has been used?

There has historically been extensive amount of research on fishing efficiency with five papers having been published on this subject (see de Lestang et al., 2012 for a review on historical fishing efficiency). Fishing efficiency is estimated by the model and is year and area dependent. The main contrast used by the model to estimate fishing efficiency since the early 1990s is the difference between commercial catch rates and those from fishery-independent surveys in similar areas. For the pre-1990s period the model uses the outcomes from previous analysis to inform fishing efficiency.

Could the poor relationship between puerulus settlement and recruitment of juveniles at the Abrolhos Islands be an indication of the carrying capacity of the species?

Yes, this suggests that carrying capacity impacts juvenile numbers more than levels of puerulus settlement we record.

Where is the significant growth in biomass from 2007 to 2010 coming from? We as fishers are not seeing this level of growth on the ground. We came off a low level of recruitment around this time, so the model is saying the existing biomass doubled in weight over this period. We don't believe this possible.

This growth is a result of a reduction in the number of animals being fished, leaving a larger biomass on the ground, and the growth of this biomass. Yes, catch rates have more than doubled and we are interpreting this as an increase in biomass which is supported by the fishery-independent surveys in deep water.

But the fishery's catch rate only doubled because the fleet halved. 20 years ago you were forced to fish right next to each other, now you rarely see another fisher. We are not seeing this 50% increase in biomass that the model describes.

Catch rates can be affected by a reduction in the fleet but they do not double purely as a result of the fleet halving. This would only happen if pots were fished right next to each other. The relationship between size of the fleet and catch rates is not linear. Catch rates increased because the fleet went from harvesting 70-80% to 30% of legal biomass, leaving behind an additional ~50% to grow and carry over biomass to the following year. Over the time period 2008 - 2013 (five seasons) the fishery caught ~ 14 000 t less lobsters than was predicted from the historic puerulus-catch relationship, this represents a marked increase in biomass being left in the water.

Is weight gain dependent on size?

It is both size and sex dependent. Smaller animals moult more frequently and the weight gain is more dramatic relative to their original weight. Large females do not grow as fast as large males, which moult more regularly.

Where is the Department getting information on undersize catch rates, because there is no longer anywhere to enter it on our catch return forms?

We get this information from meshed pot surveys and commercial catch monitoring. We would like to change reporting procedure so we can capture this information directly from fishers also.

Is high grading affecting growth rates?

The larger biomass could be stunting growth through competition for food, habitat etc. As high grading has become common, we have tracked damaged animals in the IBSS. We haven't seen a marked increase in damage in lobsters captured in the IBSS since the transition to quota management.

Could fish damage be affecting growth rates? We see an increase in damage and moralities from fish in multi day pulls, which have become more popular since going to quota.

We need to look at the post-release mortality of lobsters, especially if there is fish damage, and the effect of multi-day pulls on mortality rates.

Is high grading accounted for in the model?

We do not adjust for size-specific high grading in the model, rather we apply a uniform high grading percentage for the month which is estimated from commercial monitoring data and CDRs. However, the length frequencies from the model and the IBSS match, so we appear to be removing the right proportions of different grades.

A 5 year old animal can be 80 mm in Fremantle, but only 75 mm in the islands, is this due to greater nutrient levels in the cold water?

It's not due to nutrients; it is mainly a result of the effect of temperature on metabolic rate. Lobsters are poikilothermic, i.e. having a body temperature that varies according to the surrounding temperature, therefore their metabolic rate is dependent on the temperature of the water around them. Lobsters in the warmer waters, e.g. the Islands, reach sexual maturity faster, and at a smaller size, due to their increased metabolic rate. Once lobsters reach sexual maturity their growth rate slows. Animals in the colder waters in the south take longer to reach sexual maturity, and therefore have a higher growth rate for longer, resulting in them being larger.

Suggestion from fisher: Instead of using the purpose built casitas to capture juveniles, you could just use a modified pot and pull at night. A pot with meshed up ends, but open side to allow them to enter, produces large catches of undersized lobsters, especially if pulled at night time.

Industry Forum

Rapid Biomass Increase

During the industry forum, concerns were again raised regarding the significant increase in biomass in the model from 2007 to 2010. Fishers felt that this increase was exaggerated and not what they were witnessing on the ground. They believed the model was interpreting their increase in catch rate as an increase in biomass, when in reality their catch rates had only increased due to a reduction in the fleet and increased efficiency. This created a lack of confidence in the models from fishers. DPIRD agreed that the relativity of commercial catch rates has changed over time, due to a range of factors that have either increased (e.g. pot size, less pot competition etc.) or decreased (reduced bait usage, targeting specific grades) catch rates (other than simply biomass). It is important therefore to recognise that the modelling uses information from a range of studies on fishing efficiency as well as the contrast in catch rates from commercial fishing to those from the IBSS. DPIRD further explained that confidence in modelling should also come from the fact that three models, all using different sources of data, were showing the same level of exploitation. Using various models, operating under different assumptions and using different inputs, is a rigorous way to test model outputs. The fact that all three models are telling the same story provides confidence in the results. Industry was not completely convinced by these arguments, and this concern has been expressed in the fourth term of reference (see Terms of Reference).

Low Catch Rate Zone

Industry were especially concerned about biomass in an area of perceived low catch rates, in a shallow water area south of Dongara. This area was considered very good ground for many years, and supported a fleet of approximately 50 boats. However, industry now claims that the area has such low catches no more than one boat ever fishes there, and despite this reduction in pressure, the stock has never come back. Fishers believe that this 'dead zone' is not associated with the 2011 heatwave, as catches have been very low in this area for around 25 years. There was some conjecture among fishers regarding the extent of this 'dead zone', but generally it was thought that inshore catches are extremely low from Green Head to Dongara and below average from Wedge Island to Jurien Bay. The majority of fishers agreed that Lancelin south has a very strong inshore fishery. A second area of low catch rates, in Kalbarri, was also discussed. Industry believes catches in this area decreased dramatically after the 2011 heatwave and is yet to recover. This situation in Kalbarri was supported by data shown by DPIRD. However, concern was expressed that even the areas near the mouth of the Irwin River, an area of presumed historically high puerulus settlement and juvenile recruitment, had not recovered. Industry was concerned that the model can't explain these trends, and it was felt that until this is better understood, the TACC should not be increased. The Department assured industry that their concerns about these low catch zones are being investigated. These areas are the focus of an FRDC funded collaborative project, run by DPIRD and The University of Western Australia. The aims, outcomes, and some preliminary results of this project were presented by Dr Tim Langlois (UWA) during the workshop. The Department was confident that this project will identify the processes underpinning these patterns in catch rates and fishers were generally satisfied with this research.

Industry's lack of confidence in the model outputs led them to question the quality of the input data. Some fishers were concerned that catch data is no longer representative of biomass, as under a quota system fishers are now able to modify their behaviour in response to low catch rates. It was acknowledged by many from industry that catch rates can vary significantly between years and locations. In years and areas of low catches fishers will modify their behaviour and effort to maximise their catch, often by moving to more productive areas. For example, Kalbarri fishers are known to fish Dongara when Kalbarri catch rates are low. The model, therefore, rarely receives data on low catches rates. Industry believes this may result in the model receiving positively biased data. DPIRD responded that this is accounted for in the model as it has a high spatial and temporal complexity (11 areas and 11 time-steps each year). The movement of effort from one area to the next is accounted for and low catch rate areas are taken into account. Furthermore, the model contains information from independent surveys (IBSS), which is standardised for efficiency and occurs whether catch rates are good or not. However, some industry members were unconvinced, and this concern is captured in the sixth term of reference (see Terms of Reference).

Increased Whites Migration Exploitation

In addition to moving along the coast in response to low catch rates, fishers are also known to change their effort between targeting deep water whites and shallow water reds. It was highlighted that in recent years the deep water whites have been particularly targeted. Industry expressed concerns that these kinds of changes in fishing behaviour may not be adequately captured by the model, and questioned what effect concentrating effort on the deep water whites may have for the fishery as a whole. DPIRD explained that variation in fishing effort and location is captured within the model. The model is constructed with two depth zones across its 11 ‘areas’ and effort is apportioned to each of these according to the statutory catch and effort returns (currently catch disposal records; CDRs) received from industry. If the current trend of the industry is greater effort focused on the whites, DPIRD proposed that this could only be positive for overall biomass. The whites migration is very likely the height of a lobster’s juvenile mortality as they march long distances across open sand with little protection from predators. Therefore, taking extra lobsters during this period is likely to have less of an impact on overall biomass than taking resident reds. It was acknowledged that this migration is an important stage in the life cycle of a lobster, and so enough biomass must make it through this migration to ensure the longevity of the stock. However, current migration data indicates that this is not a problem as there is still a large number of lobsters migrating, including undersize lobsters, and these are spreading across the fishery. This is reflected in increased abundance in the fishery-independent survey in deep water.

Modelling of Migration

How the model incorporates migration rate and direction was also questioned by industry. DPIRD explained that the model uses tag data to account of migration. The model tracks the movement patterns of tagged lobsters and uses this to allocate a proportion of migrating animals to each of the 11 model areas. These proportions are updated as additional data becomes available from tag returns. By incorporating fishing effort with recruitment and migration rate from tag returns, the model is able to calculate the net flow of animals, and therefore biomass, in each area. However, industry raised concerns about a possible disconnect between settlement and recruitment into the fishery, and how this would impact the models estimate of migration. Fishers are concerned that there are certain areas within the fishery, for example the ‘dead zone’, where puerulus is high but catch rates are still low. In these areas fishers believe puerulus settlement is not indicative of recruitment into the fishery three to four years later, as the model assumes, due to unknown processes that are not accounted for within the model. As a result, the model would be overestimating migration into the deep water in these areas. DPIRD clarified that if unknown processes are impeding recruitment into the fishery, the model would use these data to derive the “puerulus to recruit” relationship used in the model. Therefore, this pattern would be replicated within the model.

Pot Size Changes

The issues associated with multiple day pulls of mesh pots were mentioned. Industry conceded that many fishers leave their meshed pots for up to a week, and that this probably creates biases within the data obtained. The Department noted that two day pulls did not appear to be a problem, but beyond this it was very likely that the quality of the data would be compromised from animals exiting pots. With more meshed pot data the Department would be able to better measure this reduction in catch rate, however the current low level of participation makes this calculation difficult. Several other issues regarding catch standardisation were also discussed. Industry questioned how the Department was going to control for different pot sizes when interpreting catch rate data, especially in light of the recent changes to pot dimension regulations. The Department agreed that having multiple pot sizes in operation within the fishery does make the interpretation of catch rate data more problematic. The new large 1 x 1 m pots are likely to have a notable effect on catch rates, and ideally the Department would like to calculate a correction factor for these pots compared with the traditional pots. Fishers stressed that in addition to new pots being larger, there are many variations in pot construction that could be impacting the comparability of catch rate data, such as straight sides compared to the traditional sloped sides. However, the Department insisted that calculating any more than one correction factor would be too finer scale, and a lack of replication would diminish confidence in the calculation. One correction factor to adjust catches from large pots would capture an average of the various configurations of these pots, and would ensure the comparability of catches from these pots and traditional-sized pots.

Provision of Research Data

Industry asked the Department whether they were comfortable with the amount of tagging data driving the migration model. Based on both the model outputs and sheer numbers of tags released (approximately 60,000 over the last three years), the Department was happy with the amount of tagging data used in the model. However, the Department did mention that more monitoring data would be beneficial. This type of data is very valuable, as it allows them to see exactly what's coming up in a pot, providing extra detail on lobster sizes, condition, and reproductive state. The importance of the data collected during the IBSS was stressed, as these surveys remove biases associated with commercial catch such as escape gaps and fishing efficiency. The Department would like to see more independent surveys, and even suggested that they could be run by industry, similar to the meshed pot program. However, a lack of industry participation was highlighted. In a recent pot salting trial run by the Department, where commercial fishers' pots were salted with tagged lobsters, less than 10% of fishers notified the Department of the captured tagged lobster. The Department also mentioned a continuing decline in meshed pot data due to very few fishers participating in the program. In a recent request for additional participation in the meshed pot program, the Department received no interest from fishers. Several fishers present at the meeting mentioned that they participate in the program, and encouraged others to do the same, claiming that it really only takes "a couple of extra minutes" and is "easy".

Despite the above stated issues with standardizing catch data from industry, the Department was very happy with the type of data being collected. The move from catch and effort statistics (CAES) to daily CDR has been very beneficial, as the Department now receives daily, rather than monthly, catch information, more regularly and at a finer temporal and spatial scale. While paper CDR forms are still in use, the majority of fishers now use the mobile application FishEye to report CDR. Industry generally thought that FishEye, as well as other Department reporting apps such as the tag return app, work very well. However, some issues were discussed regarding the reporting of catch data and several ways to improve the quality of data reported were suggested. Both industry and DPIRD agreed that including the ability to record information on undersized lobsters, setose, tar spots and spawners would be beneficial to management. The Department indicated that they would have more confidence in these data if it were recorded on a voluntary basis, as if compulsory it was likely that some fishers would not record the lobster condition accurately. It was concluded that the Department would look into adding a voluntary section on lobster condition to the CDR form for next season. Industry also suggested that the Department make the blocks on the CDR forms smaller, to increase the spatial resolution of data. It was acknowledged by both industry and DPIRD that there is an issue with fishers under reporting the number of pot lifts per day, due to re-pulling pots; i.e. they may fish 120 pots, but after the initial pull, they go back and re-pull the first 50, meaning a total of 170 pot lifts not 120 as reported. The Department explained that this would cause the model to increase the fishing efficiency estimate. They explained that there is in fact a “session” feature in the app to address this issue, where fishers can refer to a group of pots as one session, and those pots that are re-pulled can be logged as a second session. The Department agreed that the use of this feature needs to be better explained to fishers. Fishers also brought several issues with the tag return app to the Department's attention. The app only accepts carapace length measurements to the nearest millimetre. Industry would like to see the app modified so that decimal places may be recorded. Additionally, fishers reported issues recording the release of a tagged lobster. While the application has a “release” option, there appears to be an issue with the software, and the program will not accept this input. DPIRD agreed to rectify both of these issues with the tag return app.

Email Questions

A list of questions was emailed to the Council and Department prior to the workshop. These were read aloud and answered as a part of the industry forum.

1. What was the rationale and methodology used in changing the method that the puerulus collection data is now presented, with sites now aggregated.
To stop people focusing too closely at a single site. As it is now, this provides a more general picture for a region. The individual sites are used in the modelling and will be shown at the workshop.

2. Is the puerulus data still available as it was presented in the past and not corrupted with other sites, in particular the Seven Mile and Alkimos collectors?
We record the data individually at the collector level. The main use of the collated data is to show industry.

3. Has the data collected for each year and each statistical block in the fishermen’s returns since output control started been collated?
Yes. This is what we use in the model and will be shown at the workshop.

4.	Has the breeding stock survey work in A and B zone detected a reduction in the proportion of large males? The opening of the season in the spring breeding season has resulted in fishermen targeting areas where males congregate when there is a high price for large-sized lobsters.
No. Since we started taking max-size and setose females the proportion of large males has not declined.

5.	How is the now accepted dead ground areas reflected in the model used to calculate the biomass of lobsters in the fishery?
This is a focus of the workshop.

6.	Has data from other areas of the shallows been collated to determine if other areas are now affected in the shallows?
This is a focus of the workshop

7.	For the last few seasons in the summer fishery, in the A-B zones an increasing percentage of the catch is being taken over the edge of the continental shelf in depths between 80 and 100 fathoms. The past summer saw around 40% of the total AB quota being taken in 6 weeks in this very deep water. In the previous years of input control even with the discovery of the outside Big Bank run fishery, nothing approaching this percentage of the catch was taken. This obviously has greatly reduced the catch required to be taken from mainly the middle ground, as mostly the shallows now produce very little. How has this major alteration in fishing pressure been incorporated into the model?
It is directly taken out of the migrating deep-water not the shallow water. The integrated model replicates this behaviour.

8.	Does the model take into account the summer fishing at the Abrolhos where large amounts of the total island catch is taken in the deep water over the edge?
Yes the integrated model does.

9.	A limited amount of tagging has been carried out over the years by the Department. Has this been collated, and if so can it show the growth rates for each area, and in specific depths?
We have tagged more animals than any other fishery in Australia; over 226 000 lobsters. We have used this for a number of research areas including growth. The results from the latest growth work were presented at the last coastal tour which detailed growth by area and decade.

10.	Has any tagging been conducted on smaller (40-60 mm) animals? If so again has this data been collated to be able to show growth rates for different areas and depths? Also does this show any significant migrations for these small animals?
Yes. See above. Yes significant migrations have been shown. These data were presented at the last coastal tour.

11. What data does the Department use to calculate the abundance of stock on the ground?
Are all available data sources are used in a range of models; Integrated model, biomass dynamics model and tag-recapture model?
Explained at the coastal tour and detailed during the workshop.

12. Does the Department have data on the number of pots used in the fishery and the number of days fished to catch the quota in each area? Has this data been collated to determine if the effort to catch the annual quota has changed since the beginning of output control?
Yes from the CDR. Presented at the coast tour.

13. Does the Department still use catch per pot lift to estimate abundance?
Yes. CPUE from commercial fishers and IBSS are used. These data are standardised to account for biases such as soak time, high grading, escape gaps, etc.

14. How has the model been able to assess the much lower effort on most of the middle ground, particularly in the summer "Whites season"?
The model is separated into shallow and deep (< and >20 fm). It does not specifically separate the middle ground from other areas.

15. How does the model allow for the great increase in technological effort in recent years?
This includes:
i) shared data (existing fishermen purchasing data from retiring fishermen),
ii) a consistent increase in the technology available to fishermen, including sounders running 3D ground plotting data, compensated for pitch, roll and heave,
iii) use of much larger pots with the capacity to catch up to 3 times more than the old standard pot in the very deep water run.
iv) Ability of large capable boats and experienced fishermen to exploit the remote areas in the north of the fishery.
v) use of 2 and 3 pots per rope in the deep water, construction of much larger boats with the ability to operate in very adverse weather, and hold vastly more catch in high quality tanks, which allows fishermen to catch more lobsters per day against the alternative of having to stop pulling when the capacity of the boats tanks is reached.
The use of comparative indices of catch rates between commercial fishers and independent surveys. If commercial fishers are becoming far more efficient in an area then there will be a divergence between catch rates. The model conducts this comparison at 7 different locations. We have just published a paper on this and presented it at the lobster conference in Maine.

The following questions were provided after the workshop and hence were not directly answered during the industry forum. The answers are provided below for completeness in addressing industry concerns.

1. Lack of lobster between Dongara and Wedge Island inside 15 fathoms.
This was a focus of the workshop (see Industry Forum - Low Catch Rate Zone).

2. Edge volume is larger in December, January and February, however there are very few lobsters under 76 mm. There was previously large volume cacker runs through this area.
This was addressed during the workshop (see Slide 27 of Appendix 4 for summary)

3. There are significantly fewer undersized lobster north of Dongara to Flat Rocks.
This was a focus of the workshop (see Industry Forum - Low Catch Rate Zone).

4. Less boats are fishing Fresh Water area since catch numbers have declined in recent years – meaning the lack of lobsters is not due to overfishing.
This was a focus of the workshop (see Industry Forum - Low Catch Rate Zone).

5. There are more pot lifts per vessel, however there are significantly less pots in the water since quota began.
Effort is incorporated into the modelling process (see slides 75, 91 and 96 of Appendix 3 for details)

6. We now have 12 month fishing where previously it was 7.5 months with A Zone boats able to fish A/B Zones at any time of the year. Previously A Zone was only fished 15 March to 30 June. A Zone boats could only fish B Zone 15 November to 14 March. Was there a change in the modelling to reflect these changes?
The integrated model is structured in such as a way as a change to the model structure was not required. The catch and effort from these periods and locations was therefore just ascribed to the existing 11 model areas and 11 time steps.

7. We now fish August/September/October handling spawning female lobster, catching the same females repeatedly. Is this affecting the viability of the spawn and survival rates of the spawning females?
Damage is monitored during the IBSS and no increase in damage has been recorded.

8. High grading of catch means repeatedly catching the same lobster, is this affecting survival rate?
Discard mortality was quantified previously (Brown and Caputi 1983, 1986). This mortality rate is applied to high graded lobsters and hence is accounted for in the model

9. Does model allow for larger pot volumes (1 x 1 m pots) and multiple day pulls?
This was a discussed during the Industry Forum (see Pot Size Changes).

10. Has the model changed to allow for advancement in technology i.e. larger boats, larger holding capacity, 3D mapping, secure communications, 24 hour GPS location and computer plotting systems.

This was a discussed in reference to email questions (#15) during the Industry forum (see above).

11. Lower fishing pressure in November/December (end of quota period) when whites are migrating allow more lobster to get to the edge and move into other zones. This would affect the modelling for each zone. Fishermen have found that A Zone seems to be improving per pot lift whereas B Zone is decreasing.
This was a discussed during the Industry Forum (see Modelling of Migration).

Conclusions

The presentations and discussions during the science review were mutually beneficial, and a number of existing concerns were resolved during this process. However, there were some outstanding issues which industry and the Department request the model review panel to address. These were formulated into a terms of reference (TOR) at the conclusion of the review. These TOR were the focus for the review of the modelling on the Western Rock Lobster Resource.

Terms of Reference

1. Appropriate levels to set the threshold and limit reference points (MSC definitions)?
    - Threshold: Maximum Sustainable Yield
    - Limit: Point of Recruitment Impairment
2. Review and assess the three models and determine their appropriateness
3. Are three models to assess the fishery necessary or should they be reduced / modified (is there a more efficient process)?
4. What is seen while fishing is not reflective of the growth of biomass in the models. Are the models having difficulty assessing this index?
5. Is spatial variation in recruitment been accurately captured in the model and has it changed temporally?
6. Is the current data collection sufficient for the management of the fishery?

Appendix A: Coastal Tour Locations and Dates

Monday 26 March 2018 in DONGARA
3.00pm – 5.00pm
Southerly Tavern, Dongara

Monday 26 March 2018 in GERALDTON
6.30pm – 8.30pm
Sirocco Bar, Ocean Centre Hotel

Tuesday 27 March 2018 in KALBARRI
5.00pm – 7.00pm
Kalbarri Hotel

Wednesday 28 March 2018 in JURIEN BAY
4.00pm – 6.00pm
Sandpiper Tavern & Pizzeria

Thursday 29 March 2018 in LANCELIN
2.30pm – 4.30pm
Lancelin Inn Hotel

Wednesday 4 April 2018 in FREMANTLE
3.30pm - 5.30pm
Fremantle Sailing Club

Appendix B: Agenda

West Coast Rock Lobster Science Review

Workshop 1

8.30 a.m. Friday, 6 April 2018

39 Northside Drive, Hillarys

Meeting Chair - Matt Taylor, WRL CEO

0830	Arrive and Registration
0900	Welcome/Apologies/Introduction/Background/Purpose
0915	Science Presentation
	- Model inputs, assumptions and biases
	Presenter: Dr Simon de Lestang and Dr Jason How
1030 - 1050	Morning Tea
1050	Science Presentation
	- Model inputs, assumptions and biases
	Presenter: Dr Simon de Lestang and Dr Jason How
1230 - 1300	Lunch
1300	UWA Research Presentation
	- Low catch rates in the shallow water areas at the centre of the fishery
	Presenter: Dr Tim Langlois
1400	Industry Forum
1530 - 1545	Afternoon Tea
1545	Formation of Terms of Reference for Model Review (Workshop 2)
1700	Meeting Close

Please note - Questions and comments are encouraged and welcomed during the science presentation sessions throughout the day. In the event that a question cannot be sufficiently answered immediately it will be addressed in the Industry Forum session at 14.00.

Appendix C: Attendees & Apologies

Attendees

No	Name	Organisation
1	Kim Colero	Chair, WRL
2	Terry Lissiman	Deputy Chair, WRL
3	Nic Sofoulis	Director, WRL
4	Clay Bass	Director, WRL
5	Linda Williams	Director, WRL
7	Matt Taylor	CEO, WRL
8	Clare Robinson	Communications & Research Officer, WRL
9	Katherine Chow	Finance & Administration Officer, WRL
10	Simon de Lestang	Scientist, DPIRD
11	Jason How	Scientist, DPIRD
12	Graeme Baudains	Principal Management Officer, DPIRD
13	Carli Telfer	Fisheries Management Officer, DPIRD
14	Laura Orme	Fisheries Management Officer, DPIRD
15	Tim Langlois	Research Fellow, UWA
16	Sam Koncurat	Industry Representative
17	Basil Lenzo	Industry Representative
18	Jim Waters	Industry Representative
19	Peter Stanich	Industry Representative
20	Clinton Moss	Industry Representative
21	Jarred Groom	Industry Representative
22	Mark Ralph	Industry Representative
23	John Fitzhardinge	Industry Representative
24	Roy McVeigh	Industry Representative
25	Fedele Camarda	Industry Representative
26	Greg Cole	Industry Representative
27	Jim Penn	Scientist
28	Mark Rossbach	DPIRD
29	Eric Barker	DPIRD
30	Nick Caputi	Scientist, DPIRD
31	Emma-Jade Tuffley	DPIRD & UWA
32	Michael Brooker	UWA
33	Jessica Kolbusz	UWA

Apologies

Name	Organisation
Robbie Wuillemen	Industry Representative
Peter Prideaux	Industry Representative
James Paratore	Industry Representative
Nino Paratore	Industry Representative
Peter Bailey	Director, WRL
Robbie Glass	Director, WRL
Justin Pirrottina	Industry Representative
Peter Hammond	Director, WRL
Peter Cooke	Independent Director, WRL
Karen Brown	Independent Director, WRL

References

Brown, R. S., and Caputi, N. 1983. Factors affecting the recapture of undersized western rock lobster *Panulirus cygnus* George returned by fishermen to the sea. *Fish. Res*. 2:103–128.

Brown, R. S., and Caputi, N. 1986. Conservation of recruitment of the western rock lobster (*Panulirus cygnus*) by improving survival and growth of undersize rock lobster captured and returned by fishermen to the sea. *Can. J. Fish. Aquat. Sci*. 43:2236–2242

de Lestang, S., Caputi, N., How, J., Melville-Smith, R., Thomson, A. and Stephenson, P. 2012. Stock Assessment for the West Coast Rock Lobster Fishery. *Fisheries Research Report No. 217*. Department of Fisheries, Western Australia. 200pp.

de Lestang, S. 2018. Could warming oceans and increased lobster biomass rates be affecting growth rates in Australia's largest lobster fishery? *Bulletin of Marine Science*. https://doi.org/10.5343/bms.2017.1100

Appendix 2. TORs supplied to reviewers

WEST COAST ROCK LOBSTER MANAGED FISHERY
MODELLING REVIEW
31 May 2018

The terms of reference (TOR) of the West Coast Rock Lobster Managed Fishery modelling review were developed during the science review held on the 6 April 2018 and are listed below. They are followed by a section for each TOR with background information. DPIRD scientists will also provide presentations specific to each TOR during the modelling review on the morning of 31 May 2018.

Terms of Reference

1. Appropriate levels to set the threshold and limit reference points (MSC definitions)?
    - Threshold: Maximum Sustainable Yield
    - Limit: Point of Recruitment Impairment
2. Review and assess the three models and determine their appropriateness
3. Are three models to assess the fishery necessary or should they be reduced / modified (is there a more efficient process)?
4. What is seen while fishing is not reflective of the growth of biomass in the model(s). Are the models having difficulty assessing this index?
5. Is spatial variation in recruitment being accurately captured in the model and has it changed temporally?
6. Is the current data collection sufficient for the management of the fishery?

TOR 1. Appropriate levels to set the threshold and limit reference points.

The limit and threshold reference levels used in the current Harvest Strategy and Decision Rules (HSDR) (http://www.fish.wa.gov.au/Documents/management_papers/fmp264.pdf) for the West Coast Rock Lobster Managed Fishery (WCRLMF) were based on egg production levels prior to a rapid increase in fishing efficiency, associated with the adoption of new technology, which occurred in the early 1990s (Hall and Chubb 2001; de Lestang et al. 2012). The average levels of egg production, as determined from the current integrated stock assessment model, during 1983 – 1985 were subsequently used as threshold reference levels, with limit levels set at 20% below these. This rationale for ascribing reference point was applied to all but one region of the fishery (see below).

Since the model has a fine spatial scale, a region-specific threshold level was determined for four separate areas (breeding stock management areas: BSMA). The BSMAs are based on biological differences as well as management zones. These areas were the southern deep-water (south of 30°S), central deep-water (28 – 30°S), northern deep-water (north of 28°S) and shallow water Abrolhos. It should be noted that Big Bank, which is part of the northern deep-water region, was not as heavily exploited as the rest of the fishery until the 1990s. As such its threshold level was set at an average of the early 1990s breeding stock levels in this region (average of 1993-1995).

The HSDR for the WCRLMF is due for review in 2019 and the fishery will be moved from management under the *Fisheries Resources Management Act* (FRMA) to the *Aquatic Resources Management Act* (ARMA) in early 2019 which will also necessitate a new HSDR in the Aquatic Resource Use Plan (ARUP). It is therefore a prudent time to review threshold and limit reference levels, and align these with more contemporary concepts such as those adopted by the Marine Stewardship Council (MSC) and identified in DPIRDs Fisheries Management Paper 271 http://www.fish.wa.gov.au/Documents/management_papers/fmp271.pdf). Specifically FMP 271 defines these reference levels as:

For thresholds "*Current best practice in fisheries management assumes that where the stock is at a level that produces the maximum sustainable yield (MSY) then MSY should be used as the threshold reference level.*"

For limits "*... as being the stock level 'below' which future recruitment levels arising from this stock is likely to be directly and adversely affected (i.e. recruitment overfished, or in MSC terminology - 'point of recruitment impairment').*"

We are suggesting that the threshold reference levels be set at the egg production levels when the fishery is fishing at an equilibrium level of MSY (or some fraction of this e.g. 0.9MSY). Another modification may be to use egg production for the entire fishery as a primary indicator (with threshold and limit reference points) whilst also having as secondary indicators for each BSMA with only threshold reference levels. The process to determine new threshold level(s) may be:

1. Use the surplus-production model (SP) to determine the catch representing fishing at MSY (e.g. 10,000 t).
2. Use the integrated stock assessment model (IM) to determine the egg production levels in each BSMA when the fishery is consistently fishing to MSY (i.e. taking 10,000 t as determined in 1.)

Similarly, limit reference level(s) could be set at the egg production level just above the point of recruitment impairment as determined from an updated stock-recruitment-environment relationship. The process to determine this is proposed to be:

1. Use the stock-recruitment-environment relationship to determine stock levels (egg production) when recruitment is expected to be impaired (affected) by low stock levels.

2. Use the integrated stock assessment model (IM) to determine the egg production levels in each BSMA when the overall levels of egg production are at this point of recruitment impairment (the model will use a historical spatial distribution for exploitation).

TORs 2 and 3. Review and assess the three models and determine their appropriateness – are all three necessary?

Currently the integrated model (IM) is the only model formally used for the stock assessment of the WCRLMF. Recently the outputs of this model have been compared to those from the draft biomass-dynamic model (BDM) and draft brownie tag-recapture (BTR) model. As all models are currently in general agreement (noting that the two draft models need to be reviewed), this provides an increased level of confidence on the IM outputs.

The development of three models, which all provide a level of assessment of the WCRLMF, provides the opportunity to contrast their various advantages and constraints. This contrast has initiated the process of determining the most appropriate model structure for assessing the fishery into the future.

The IM which has been reviewed previously, incorporates a broad array of data and produces all the outputs required by the current HSDR. However it is extremely complex, slow to run and would be quite difficult to hand over to a new assessment scientist. In its current form the model is possibly overly complex and would benefit from a process of simplification. Dependent on the construction of the new HSDR, this model may not require such a fine spatial or temporal scale. One possibility is to progressively reduce the complexity of this model whilst comparing the required outcomes that are needed for assessment, stopping the simplification once the accuracy of outcomes reduces.

The BDM currently provides a fishery-wide assessment, which is not at the scale required by the current HSDR. However it is far simpler than the IM, which makes its annual update and eventual hand over relatively straight forward. It also benefits from having a “standard” model structure, one that has been published and employed many times. Furthermore, it is the only model of the three which contains variable productivity due to population size, a relationship that may have started to impact the fishery due to its recent run of population growth. It is possible that some minor alterations to this model or a change in the new HSDR would allow this to be used for the annual stock assessment.

The BTR model is not seen as a replacement model for the annual stock assessment. Rather this model’s outputs are a very good cross check to those of the IM or BDM as it uses a very different data source and assumptions. Its main limitation is the requirement to constantly tag and recapture large numbers of lobsters each year. If deemed appropriate it may be something that is implemented on a five – ten year cycle to cross check against the other model(s).

Another option includes the development of a completely new model, one that sits in-between the current IM and BDM in terms of complexity (both spatial resolution and data sources).

TOR 4. What is seen while fishing is not reflective of the growth of biomass in the model(s)

Some fishermen feel that the IM and DBM estimates of the increase in legal lobster biomass (and therefore what the tag-recapture model assumes the current biomass to be) are overly optimistic and are not reflective of what they are seeing in their catches. These models indicate an approximate doubling of the legal biomass from 2008 until 2017.

Empirical data, which is used by the models, shows an increase in legal biomass: these include the legal standardised (for depth/month/location) commercial catch rates and standardised (for swell/month/location) fishery-independent catch rates (IBSS). Both of these indices have doubled over this time period. Additional evidence comes from the reduction in landings during this period (due to effort reductions and then quota). The historical relationship between puerulus recruitment and commercial catches is very good and, due to the high historical exploitation rate, can be used as an indication of what biomass is recruiting into the fishery each season. There is a substantial difference between what has been caught each season and what historical catch predictions indicate would have been available (in the order of 40 000 t "left" in the water over this period). This suggests that the legal biomass should have increased to at least double of its estimated 15,000 – 20,000 t. The fishery historically landed an average catch of ~ 11,000 t, whilst since 2007 it has averaged 6100 t.

TOR 5. Is spatial variation in recruitment accurately captured in the model and has it changed temporally?

Some fishers within industry consider that a shallow water area at the centre of the fishery (Cliff Head) has reduced in its productivity and that this is not accounted for in the assessment. This area is bounded by two puerulus collection sites but does not itself contain a site. Latitude-specific puerulus-undersize catch rate relationships indicate that there have not been any marked changes in these relationships over the past 20-30 years in all locations except for Kalbarri and possibly at Cliff Head (noting that the Cliff Head relationship uses puerulus settlement recorded just south at Jurien Bay).

A marked deviance from the normal relationship is present in Kalbarri (minor deviance at Cliff Head), with its onset occurring just after the fishery experienced a marine heatwave in early 2011 that was centred on the mid-west of WA (http://fish.gov.au/reports/Documents/Pearce_et_al_2011.pdf). The Kalbarri shallow water region, which is relatively large, typically contributes about 3% of the total annual commercial catch, while the Cliff Head region contributes even less catch than this. This deviance may however be due to other factors such as puerulus settling late in the settlement season and therefore having a different contribution (survival) to subsequent biomass or increased natural mortality linked to carrying capacity issues in the shallow water regions (biomass levels have increased in shallow water regions since 2008).

Puerulus recruitment is measured at eight locations throughout the fishery. Much of this information is used by both the IM and BDM models to inform recruitment, however only the IM uses these data on a fine spatial scale. Both models account for inter-annual for variation in catch rates as being partly due to changes in recruitment.

TOR 6. Is current data collection sufficient for management of the fishery?

When the fishery moved from input to output management controls and fishers started to target lobsters based on price and not availability, the pattern of fishing changed dramatically. This has resulted in a break in the relativity of commercial catch rates. Historically the main inter-annual variability in commercial catch rates was puerulus settlement 3-4 years previous and fishing efficiency. Fishing efficiency generally increased each year with more efficient fishers buying up pots off less efficient fishers coupled with knowledge and technology constantly improving. However, with the move to quota and a relaxation in a range of fishing regulations, many fishers have changed their efficiency in far more complex ways that are extremely difficult to measure. Greater amounts of effort are now occurring during times of poorer catchability (e.g. June/July, when the fishery was traditionally closed) as fishers chase higher prices being offered which biases the overall catch rates downwards. More fishers are now also fishing the deep-water whites migration in late January / early February, where they are pulling their pots multiple times within a night and achieving very high catch rates. This is also occurring in the deep-water areas off the Abrolhos Islands, an area previously closed to fishing at this time. Associated with these changes has been the advent of high-grading (return of legal lobsters) which is yet another factor that must be measured and accounted for when comparing commercial catch rates. To account for many of these biases the modelling has had to rely more on the data produced by the Independent Breeding Stock Surveys (IBSS). These only occur over a 10 day period annually in a maximum of seven sites in deep water.

However, IBSS are no longer conducted at all sites (seven) each year due to their cost, with Kalbarri and Fremantle the most commonly missed locations. In 2017 the Jurien site was also missed (total of three sites missed). In addition, staff reductions combined with an extended fishing season has resulted in a decline in the coverage of commercial monitoring. A third source of lobster catch information is the mesh pot program which was initiated at the time of low puerulus settlement: commercial fishers provide catch composition and catch rate information from one standard and one modified (meshed to catch undersize) pot. However, with recent improvements in catch rates (more of a hassle to measure all the lobsters) and profitability in the fishery, fishers have become less inclined to provide this service.

A re-assessment of what data is vital to the assessment of the WCRLMF is required. This should be based on what modelling outputs are required for the stock assessment and what model structure will be employed to derive these. This can then inform on exactly what data sources are needed for the assessments.

Appendix 3. Agenda for Modelling review

WEST COAST ROCK LOBSTER MANAGED FISHERY
MODELLING REVIEW
31st May and 1st JUNE 2018

AGENDA

08.30	Registration	
09:00	Welcome and Introductions	Mr Graeme Baudains (DPIRD WRL Manager)
09:05	Opening remarks from WRL	Mr Matt Taylor (WRL CEO)
Thursday May 31st	**DPIRD Presentations**	
09:10	Presentations on the 5 Terms-of-Reference	Drs Simon de Lestang and Jason How (DPIRD)
10.30	***Morning Tea – 20 minutes***	
	Reviewers to run Meeting	
10:50	Assist reviewers	Drs Simon de Lestang and Jason How (DPIRD)
12:00	***Luncheon Break – 45 minutes***	
14:30	***Afternoon tea – 20 minutes***	
16:30	***Close for the day***	
Friday June 1st	**Reviewers to run Meeting**	
09:10	Assist reviewers	Drs Simon de Lestang and Jason How (DPIRD)
10.30	***Morning Tea – 20 minutes***	
12:00	***Luncheon Break – 45 minutes***	
	Reviewers to present findings	
12:45	Presentation by reviewers	Drs Malcolm Haddon, John Hoenig and Adrian Linnane
13:15	***Questions and Answers with industry***	
16:30	***Close for the day***	

Appendix 4. Reviewers report

Note: DPIRD comments related the to the findings from this report are presented in Appendix 5

Western Rock Lobster Science and Modelling Review

Adrian Linnane[a], Malcolm Haddon[b], and John Hoenig[c]

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31st May – 1st June, 2018
Hillary's Boat Harbour

Table of Contents

Executive Summary

Three models are used in Western Australia to assess the stock status and aid in producing management advice for the West Australian Rock Lobster Fishery. These are the relatively large and complex size-structured Integrated Model (IM), the much simpler Biomass Dynamic Model (BDM), and the more specific Tag-Recovery Model (TRM) that attempts to answer questions concerning biology and abundance. Each has its separate strengths and weaknesses but put together they form an excellent toolkit with which to assess this complex fishery. The IM might benefit from some simplification, which would need to be done carefully and take some time. Conversely the BDM might benefit from some increase in spatial complexity if possible. Issues with the TRM focus more on the availability and representativeness of data to be used with it. Despite these potential improvements this collection of models remains a defensible and capable framework within which to assess and help manage the western rock lobster fishery.

As with all models their outputs can only ever be as good as the data to which they are fitted. The range of fishery dependent and independent data collected is detailed and appropriate. Some recommendations were made concerning further exploration of data from the period when the re-structure occurred in the fishery. This period coincided with a new log-book that required reporting daily instead of monthly, there were large reductions in catch and effort, and many other ways in which the different time-series of fisheries data may have been broken. Especial focus should fall on the IBSS and puerulus counts as providing independent estimates of relative abundance through time.

There remain many spatial issues that influence the dynamics of both the fishery and the stock it is dependent upon. These issues range from the difficulties in obtaining representative samples over such a geographically extensive fishery to management arrangements that seemingly ignore the biological reality of heterogeneity in stock density. Spatially complex fisheries are invariably more difficult to manage and maintain than less spatially heterogeneous fisheries.

While the current modelling and assessment arrangements appear to be fully capable of dealing with the fisheries requirements, the challenges of the recent changes have been recognized. Both the period of change in the fishery and spatial details need special attention in future developments and possible revisions of the assessment modelling frameworks.

Specific Recommendations

These recommendations are simply copied from the body of this review and their context and justifications are to be found in their relevant sections. We place them here as part of the summary.

ToR 1: Appropriate levels to set the threshold and limit reference points (MSC definitions)?

1. In addition to egg production (and any requirements from the MSC), consider adopting a reference point based on puerulus counts.
2. In relation to spatial allocation, consider adopting a dynamic allocation procedure where regional TACCs are based on the current biomass in each region.

ToR 2: Review and assess the three models and determine their appropriateness.

1. Continue to use a living document to report on progress with on-going model changes and updates.
2. For the Integrated Model, consider reducing its complexity but expand the reported outputs and diagnostics.
3. For the Biomass Dynamics Model, provide explicit and documented comparison of the implied stock dynamics with those from the Integrated Model over the same periods and explore the inclusion of some spatial dynamics.
4. For the Tag Recovery Model, attempt to improve tag recovery rates.

ToR 3: Are all three models necessary?

1. Retain all three models but continue their development as described in TOR 2.

ToR 4: What is seen while fishing is not reflective of the growth of biomass in the model(s).

1. Attempt to obtain data from inshore areas through either expansion of the IBSS or the meshed pot sampling program.
2. Investigate alternative CPUE scenarios in relation to time-series of data and changes in catchability.
3. Given observed changes in fishery dynamics, maintain IBSS and possibly expand as per (1).

ToR 5: Is spatial variation in recruitment accurately captured in the model and has it changed temporally?

1. Maintain puerulus sampling at current levels and possibly expand to include areas considered to have lower levels of productivity.
2. Examine alternative projections using the BDM with different settlement rates based specifically on more recent puerulus settlement rates.

ToR 6: Is current data collection sufficient for management of the fishery?

1. Continue to improve documentation of CPUE standardisation and consider alternative CPUE scenarios as per TOR 4.
2. Maintain and possibly extend IBSS as per TOR 4.
3. Expand either fishery-dependent or independent meshed pot sampling into areas considered to be exhibiting lower productivity levels.

Background and Review Activities

Representatives of the Western Rock Lobster (WRL) organisation (Taylor, 2018) wrote to Dr Rick Fletcher in a letter dated 8 February 2018 making a request to work collaboratively with DPIRD to undertake an independent review of the modelling and science used in the assessment of western rock lobster. The last independent review of the stock assessment modelling was made in 2011 (de Lestang, *et al*., 2012) immediately following the transition from input to output controls implemented as a Total Allowable Commercial Catch (TACC) with Individual Transferable Quotas (ITQs).

The primary reasons behind this request were concerns raised by active fishers noting that recent fishing experiences differed from previous or historical experiences but also considered to differ from current model outputs in relation to the status of the fishery. More specifically, the organisation members were stating that compared to historical experiences, there were now fewer undersized lobsters, lobsters were not being found where they used to be found, they were not behaving as they used to behave, and were not as easy to catch as predicted by the assessment models. These perceptions were reported to be stronger the further north in the fishery observations were made.

The WRL recognized that some of these perceptions may be at least partially explained by large changes in fishing practices since quotas were introduced (Taylor, 2018). In particular, it was recognized that moving to fishing in all 12 months, high grading to improve the value of catch, the taking of setose females, the introduction of additional escape gaps, other large changes in fishing behaviour and extreme environmental events may contribute to changing perceptions concerning the fishery and stock status (Taylor, 2018).

A need to have confidence in the fishery science and modelling used in the stock assessments was also emphasized, especially given the possible increase in the Total Allowable Commercial Catch for the 2019/20 season.

The collaborative approach agreed upon led to two workshops being conducted in the first half of 2018. The aims of the first workshop held on 6th April 2018 (de Lestang, *et al*., 2018b) were to discuss and document the issues raised by the fishers, as well as to allow DPIRD scientists the opportunity to explain the possible factors driving these changes. These were then used to design a formal review of the science and modelling used for the western rock lobster stock and develop a set of Terms of Reference (Terms of Reference and Background Information, 2018). The more general objective of the second workshop was to allow the panel to review the stock assessments models as well as discuss industry concerns in more detail with a view towards providing recommendations against the terms of references. This present report contains a description of the outcomes of the second workshop held at the DPIRD offices at Hillary's Boat Harbour over May 31st – Jun 1st 2018.

Review Activities

The face-to-face review period was relatively brief being only two days. In order to ensure sufficient time was made available for presentations from DPIRD staff and subsequent questions from the reviewers only an outline agenda was produced for the workshop. The agenda mentions only five terms of reference because TOR 2 and 3 were considered together:

Outline Agenda

Thursday May 31st DPIRD Presentations

8:30 Registration

9:00 Welcome and Introductions Mr Graeme Baudains (DPIRD WRL Manager) 9:05 Opening remarks from WRL Mr Matt Taylor (WRL CEO)
9:10 Presentations on Terms-of-Reference Drs Simon de Lestang and Jason How (DPIRD)

10:30 Morning Tea – 20 minutes

10:50 Assist reviewers Drs Simon de Lestang and Jason How (DPIRD)

12:00 Luncheon Break – 45 minutes 14:30 Afternoon tea – 20 minutes

16:30 Close for the day

Friday June 1st Reviewers to run meeting

9:10 Assist reviewers Drs Simon de Lestang and Jason How (DPIRD)

10:30 Morning Tea – 20 minutes 12:00 Luncheon Break – 45 minutes

Reviewers to present findings

12:45 Presentation by reviewers Drs Malcolm Haddon, John Hoenig and Adrian Linnane

13:15 Questions and Answers with industry

16:30 Close for the day

After introductions were made there were presentations given that provided details of the issues raised, the models used to assess the stock, the model assumption, and their outputs. Questions were asked freely through the presentations leading to helpful discussions of the issues under examination. The draft agenda assumed the presentation would be completed by morning tea but the discussions raised meant that completing the presentations took until lunch time. The Western Australian scientists were very open with their materials, model code, and discussion, which made for detailed discussions, limited only by the time available. Their responses were invariably rapid and helpful, even during the running of the questions and answers session with Industry members.

On the second day, after lunch, an initial or draft presentation was made by the reviewers, with all reviewers contributing material for the slide show and commentary during the presentation.

That presentation, along with the feedback during the question and answer session with Industry members that followed the presentation, forms the basis of this report.

Terms of Reference

There were six terms of reference detailed in the document - *Terms of Reference and Background Information (2018)*:

1) Appropriate levels to set the threshold and limit reference points (MSC definitions)?
    a. Threshold: Maximum Sustainable Yield
    b. Limit: Point of Recruitment Impairment
2) Review and assess the three models and determine their appropriateness.
3) 3. Are three models to assess the fishery necessary or should they be reduced / modified (is there a more efficient process)?
4) What is seen while fishing is not reflective of the growth of biomass in the model(s). Are the models having difficulty assessing this index?
5) Is spatial variation in recruitment accurately captured in the model and has it changed temporally?
6) Is current data collection sufficient for management of the fishery?

Each of these terms of reference are addressed separately below.

TOR 1:

Appropriate levels to set the threshold and limit reference points (MSC definitions)?

a. Threshold: Maximum Sustainable Yield

b. Limit: Point of Recruitment Impairment

a) Reference points based on maximum sustainable yield (MSY)

The Marine Stewardship Council (MSC) requires that reference points be based on maximum sustainable yield (or a fraction of MSY). We do not think this is necessarily appropriate for the western rock lobster fishery for two reasons.

First, the recruitment and population dynamics of western rock lobster is highly variable, thus basing status determination and consequent management advice relative to a single, fixed equilibrium quantity may not perform well with respect to stability in the fishery.

Second, MSY and related the related parameters B_{MSY} (biomass producing MSY) and F_{MSY} (the fishing mortality rate predicted to bring the population to B_{MSY} and maintain it there in the long term) are difficult to estimate reliably and precisely. In contrast, reference points based on a period of stability believed to reflect known conditions (e.g., biomass was near the unexploited level or biomass was thought to be close to optimal) may be more precisely determined even if it is not known exactly how that level relates to MSY (though a suitable model should be able to determine the state of the stock during a given reference period). Thus, we think the approach of basing reference points on a defined time period (e.g. the 1980s) may have merit and should not be abandoned without good reason. If MSY and B_{MSY} values are still required for MSC certification they can be calculated (for example from the biomass-dynamic model) but extra care would be needed to maintain precautionary advice if they were to be used in active management.

b) Reference points based on egg production and puerulus abundance.

Currently, limit reference points for this fishery are based on egg production. While this is appropriate, one could in addition define a limit reference point based on some selected minimum puerulus settlement. The advantage of using egg production is that it provides the earliest indication of a potential problem (if egg production is not adequate, take immediate action). The disadvantage of the egg production reference point approach is that the ability to forecast future dynamics is not as strong as when puerulus settlement is used. Previously a similar level of egg production has given rise to a wide range of puerulus settlement **(Figure 1**).

The advantage of using puerulus settlement as the basis of a reference point is that it has greater predictive capability of future stock dynamics and catches (three to four years ahead) than simple egg production (**Figure 2**). The disadvantage is that any corrective action based on puerulus counts is a year after the corrective action that could have been taken based on egg production.

In essence, egg production gives one the earliest indication of a potential problem but the predictive power is not great. Puerulus counts provide a way to update (and potentially correct) the perception of stock status and future dynamics, and the puerulus counts provide a more reliable forecast of conditions.

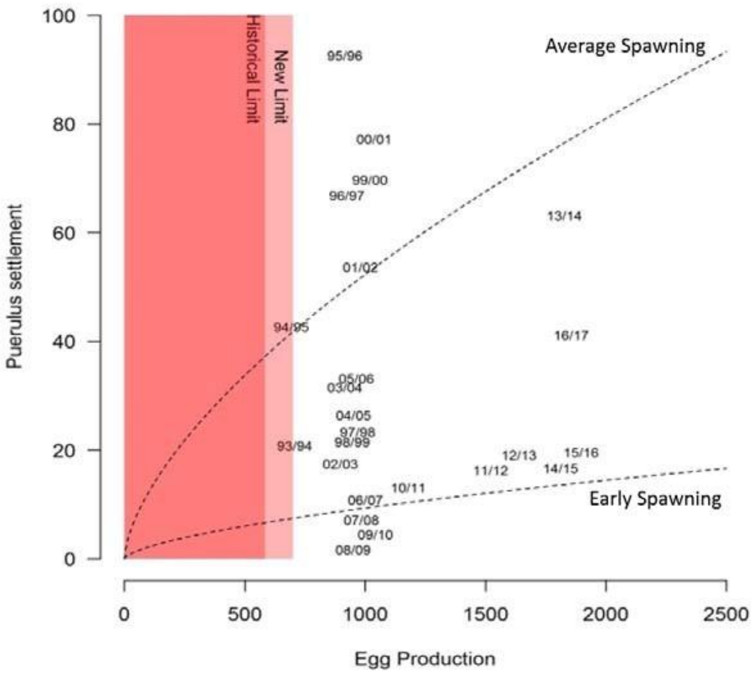

Figure 1. Copied from the presentation made by Dr de Lestang at the WRL Modelling Review on 31st May, 2018.

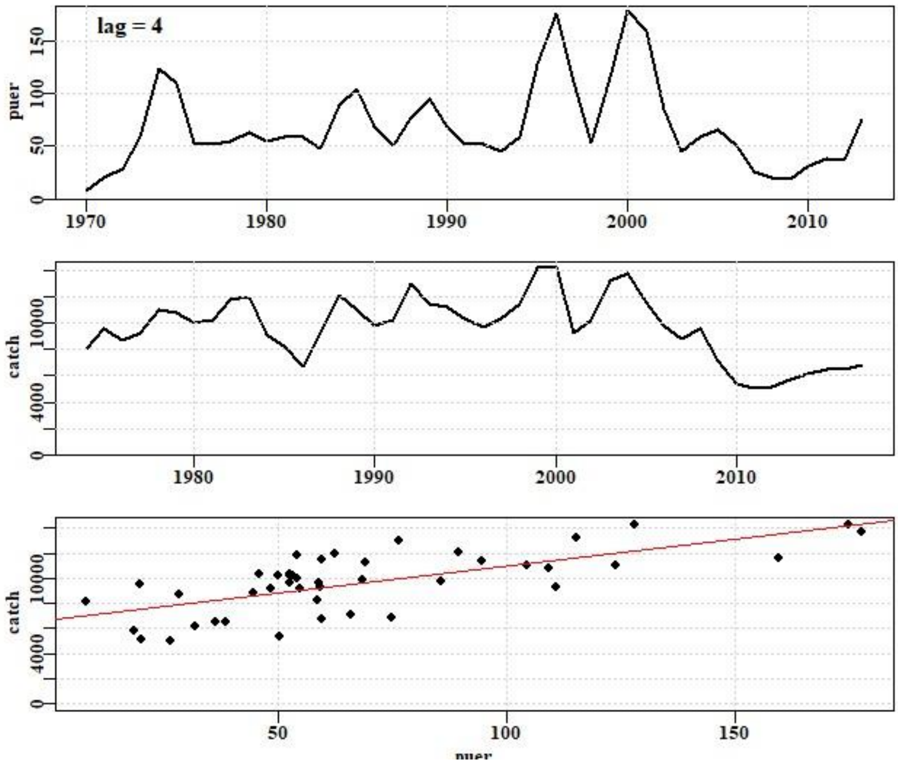

Figure 2. A plot of the puerulus counts from 1970 – 2013 above the total reported catches for the years 1974 – 2017 (a lag of four years. The bottom plot is the lagged values against one another with a linear regression with $P << 0.00001$, and describing 48% of the variation in the data (data only preliminary).

We therefore recommend that consideration should be given to having reference points based on both egg production and puerulus counts. For example, in a given year the egg production might be estimated to be very low, triggering corrective actions. The next year, the puerulus counts may be well above average triggering a reconsideration of stock status and future recruitment to the future, and hence future potential catches.

The potential value of such a puerulus based reference point is suggested by a draft plot of puerulus counts, especially over the last few years (**Figure 3**). Since the unusually low puerulus counts from 2006 – 2012 the geometric mean of the numbers since then remain, on average, below the longer term geometric mean value (**Figure 3**). The expectation would therefore expect to be lower than average catches. Of course the catches though the earlier period were very much greater than those being taken now.

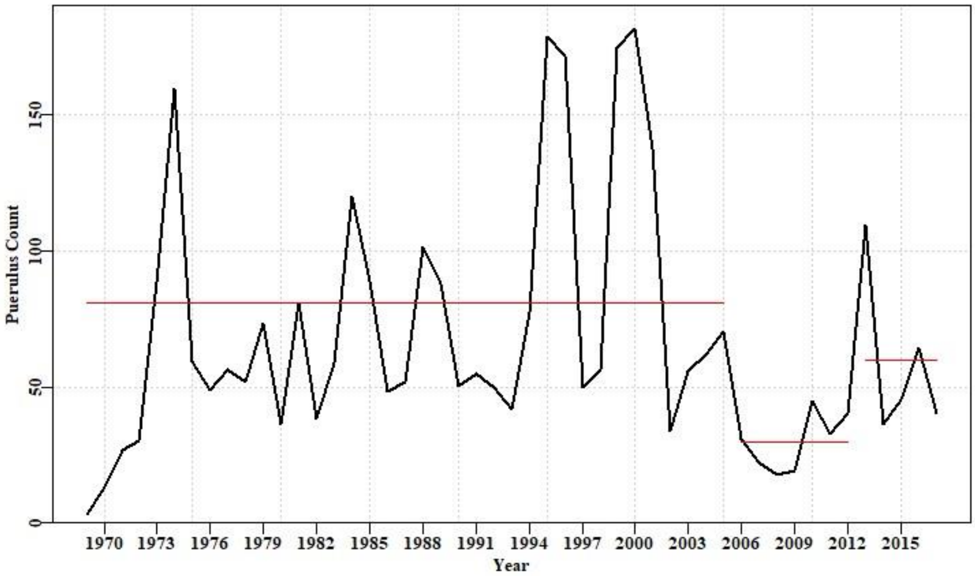

Figure 3. The series of puerulus counts (approximate analysis only; updated draft data using Warnbro, Lancelin and Jurien only, provided by Dr de Lestang) from 1969 – 2017.

Implications of Assessment relative to Reference Points

The reviewers noted that there is a policy in place that allocates the estimated total TACC to regions using fixed (rather than dynamic) proportions. This may seem equitable on the basis of historical catches but, from a population dynamics perspective, it can be shown that the policy is risky. The advent of more complex spatial operations within the fishery as a whole imply that a need has arisen to develop spatially explicit reference points that can be used to aid in the allocation of a TACC spatially. The need for this can be seen in the following example:

Suppose the biomass in distributed across two main regions in roughly equal amounts, say 20000 and 20000 tonnes (fictional numbers), and the rule is to set an allocation of quota accordingly as 50% to each region percentages. Suppose further than an assessment leads to a TACC of 6000t and quotas of 3000 and 3000 tonnes in each region. Now suppose that the biomass in one region drops by half to 10000 tonnes. The overall TACC, based on the total biomass, may drop as much as 25% down to 4500 tonnes, reflecting the lower overall abundance. If that TACC is now distributed equally (2250 t each) across the two regions the proportion of the TACC in the region of significantly reduced biomass would increase the harvest rate (a larger proportion of the available biomass would be taken, hence lower CPUE) while the reduced allocation of the TACC in the unchanged region would experience a reduced harvest rate, and hence an expected increase in CPUE. The result is that when biomass goes down unequally across regions (leading to a lower overall TACC), the management response is to fish the region(s) of reduced abundance harder and the regions of stable or increased biomass more lightly. Exactly the same unfortunate response occurs if the biomass were to increase unevenly across regions. Intuitively, this is an inappropriate management response. Previously, while there were spatial variations in the proportion of the stock available in each region the variations did not appear sufficiently great for long enough for this issue to become a problem (or if it did it was not noticed at the time). Now however, with the stock reduction following the reduced egg and puerulus production, such variation is reported to have grown with reports of greater negative effects in the north. Ideally, one should harvest a region (set the quota in each region) at a rate in proportion to its available biomass not at some constant historically allocated rate. However, now the historical precedent has been set this may become a major issue in future years. If there is an on-going decline in the north of the fishery this fixed proportion allocation by area may be exacerbating such dynamics.

We are not suggesting that attempts be made to unscramble the egg of allocation, rather we suggest that one possible solution is to use a dynamic allocation procedure. This means that a spatially explicit TACC (sTACC) be used where the sTACC in each region should be based on the current biomass in the region. Thus, if the policy were, for example, to harvest X% of the legal-sized lobsters the quota for each region would be X% of the region-specific biomass estimate. This will no doubt lead to some areas becoming ‘winners’ in some years while others become ‘losers’ but the importance of developing a harvest strategy that distributes the catch appropriately, in proportion to available biomass, across the regions should be clear. This implies that there is an urgent need to develop spatially explicit reference points, which may entail making modifications to the various models so that spatially explicit projections can be made (but this is unlikely to be a trivial task).

Recommendations:

1. In addition to egg production (and any requirements from the MSC), consider adopting a reference point based on puerulus counts.
2. In relation to spatial allocation, consider adopting a dynamic allocation procedure where regional TACCs are based on the current biomass in each region.

TOR 2:

Review and assess the three models and determine their appropriateness.

The availability of three alternative models is an advantage that many fisheries elsewhere do not have. By using three different models that give three different views of the same stock the risk of just one model giving unexpected results in response to unusual data in any single year is reduced. Each model is appropriate for the uses they are put to and as a result the development of each could and should be continued. Simple models can be developed to a final state to be re-used every time an assessment is deemed necessary. More complex models can be adapted to changing circumstances within a fishery and are often in a state of continual development and improvement. Such changes need to be pursued in a strategic fashion so that answering a question that arises now does not compromise the uses to which a model is already being put to. Aspects that could benefit from attention are listed in the separate sections below. However, here it is possible to state that for the purposes for which they are used the current models are sufficient and appropriate. The suggested developments should make them more effective, more useful, and easier to understand. So while the models are appropriate they will always remain dependent upon the data to which they are fitted (see ToR 6).

Documentation of the models is something that needs to be progressed so that communicating their structures and being open about them is encouraged. The draft documents produced so far are an excellent start and should be treated as living documents as their development progresses.

Integrated Model (IM)

Currently the Integrated Model (IM) appears to be too complex in that its attempts to account for the dynamics of so many areas (growth and movement), with so many different conditions of catching (catchability), along with many other details (de Lestang, 2018a). One expression of this complexity is the need to attempt to estimate over 1000 parameters while fitting the model to the data. The major advantage of Integrated Models is that they can integrate a wide range of data inputs and synthesize very many different structural components. However, the development of an Integrated Model invariably has a tension between trying to include as much detail as possible while avoiding trying to include structural details for which insufficient data are available to allow for a success fit of data to the final model. While it is true that West Australian lobster are well studied, the current complex model (1000+ parameters) risks fitting the model to noise rather than focusing on the main signals in the available data about changes in the stock abundance. To ensure that the model has not become over-developed strategies need to be adopted to simplify the integrated model's description of the stock dynamics and compare simplified versions with the current version. The current model should be duplicated and then, incrementally, the descriptions of growth, then perhaps movement, should be simplified, which would entail reductions in the description of catchability across different areas. This could dramatically reduce the number of estimated parameters so that a compromise between the model's ability to capture the complexities of the fishery on this stock should be able to be found that should be less influenced by idiosyncrasies in the data streams and having a more rapid run-time. At the same time, it would be sensible to introduce a stock-recruitment relationship into the model (a Beverton-Holt model should suffice). This would add another layer of density dependence into the dynamics such that reduced stock sizes would generate, on average, a significantly lower but possibly more realistic egg-production. Such an addition would also permit the calculation of more meaningful estimates of MSY, B_{MSY}, and F_{MSY} from the IM. A more rapid run-time would also aid in using the IM to explore alternative management options.

In addition to exploring simplification it would be sensible to expand the reported outputs and diagnostics from the model, for example, include total biomass, and pre-recruit biomass, along with regional biomass estimates, in addition to legal biomass. This would permit a more comprehensive statement of the conditions within the fishery and stock, which should better inform stakeholders as to the current stock status.

The reviewers noted that the DPIRD staff are actively attempting to manage the complexity of the IM and improve on its reporting. The annual updates describing model developments (WRL Stock Assessment, 2018) are an excellent initiative for the maintenance of such a complex model providing details of on-going developments and modifications. It is assumed that the code for all models is being maintained on a source code management system and repository such as GitHub or BitBucket.

Biomass-Dynamic Model (BDM)

The Biomass-Dynamic model (BDM), also known as a surplus production model, eschews all details of size-structure and spatial structure and treats the stocks as a large collection of biomass with relatively simplified dynamics (de Lestang, 2018b). The dynamics involve new recruitment through reproduction, increases in biomass through the growth of individuals, natural mortality, and the removal of catches. Even though this is a highly simplified model it includes five periods with different catchability (fishing efficiency changes). Unusually, it also includes a means of including a puerulus driven estimates of recruitment variability (recruitment deviates). This takes especial advantage of the availability of the puerulus counts to facilitate much more flexibility in the dynamics than is usually possible with such models, which usually assume deterministic recruitment dynamics. This addition means that this model is more powerful than other models of this type, and should be more capable of detecting and describing the ups and downs of the stock through time.

Even with the modifications included to improve the performance of the WRL BDM it remains very much simpler and easier to understand than the IM, and yet is still appropriate for more rapidly detecting the implications for the stock dynamics of changes in the time series of commercial CPUE and the IBSS.

The development of this BDM is relatively new and would benefit from an explicit and documented comparison of the stock dynamics implied by the BD model with those implied by the IM over the same periods. Differences would reflect the influence of density dependence (explicit in the BDM currently missing from the IM) and the effects of spatial structuring (no spatial details currently possible with the BDM but implicit in the IM (and should be made explicit in the reporting). Of course there are other differences, including their respective uncertainties that differ because of the very different structural assumptions. But exploration of the differences between the two models will undoubtedly be enlightening with respect to the information content of the various data streams available (all used in the IM only some in the BDM).

Assuming the IM is modified to include a stock-recruitment relationship then the respective estimates of MSY, B_{MSY}, and F_{MSY} between the two models could also be explicitly compared. Without a stock recruitment curve the IM could still be used to estimate these quantities but this would be equivalent to assuming a steepness of 1.0, meaning there would be no density dependence in the recruitment dynamics. Without including such a relationship being included in the IM it would invariably be perceived as being more productive than the BDM, which is a somewhat riskier approach to management.

Tag-Recovery Model (TRM)

The implementation of the tag-recapture study and the resulting model were very well done. The basis of the model is a standard Brownie model which was adapted to fit the specific requirements for studying western rock lobster. The investigators made concerted efforts to study tag loss and tag reporting rate which are critical details of implementation and their approach was thorough and in some cases novel. We urge the investigator to publish the results. We have included some minor technical criticisms in the Appendix TRM.

A serious limitation of the TRM is that the tag-reporting rate was very low, on the order of 12%. (This means that there is a 12% chance that a fisher who catches a tagged lobster will, in fact, report the tag). This low reporting rate does not appear to be due to a lack of will on the part of fishers to cooperate nor to any difficulty in reporting tags. Rather, it seems to reflect the fact that the tags are easily overlooked. We suggest the investigators examine the possibility of tagging lobsters on the dorsal side to increase tag visibility, or at least find some other way to make the tags more obvious.

It is a property of tagging models that low tag-reporting rate makes it difficult to achieve precision in estimates of population size. (To know how many tagged lobsters were caught, one divides the reported number of tags by the tag reporting rate. Suppose 1000 tags are recovered. If the tag reporting rate is 90%, then 1000/0.9) = 1111 = estimate of number of tagging lobsters that were actually caught. But, if the tag reporting rate is 10%, then 1000/0.1 = 10,000 which reflects a big change between reported and actual number of tagged lobsters caught. Thus, when tag reporting rate is very low, it must be known very precisely in order to get reliable estimates of the number of tagged lobsters actually caught).

The low tag reporting rate limits what can be accomplished with the tagging studies, and efforts should be made to increase the tag reporting rate, perhaps through increased visibility of the tag. Despite this low reporting rate, we consider the tagging program remains useful for corroborating other models and especially for estimating changes in regional growth and natural mortality.

Recommendations:

1. Continue to use a living document to report on progress with on-going model changes and updates.
2. For the Integrated Model, consider reducing its complexity but expand the reported outputs and diagnostics.
3. For the Biomass Dynamics Model, provide explicit and documented comparison of the implied stock dynamics with those from the Integrated Model over the same periods and explore the inclusion of some spatial dynamics.
4. For the Tag Recovery Model, attempt to improve tag recovery rates.

TOR 3:

Are all three models necessary?

The three models (IM, BDM, and the TRM) do somewhat different things and emphasize different data streams. In brief all three provide a service to the western rock lobster fishery and its safe management and they should be maintained. This does not mean that they stay unchanged into the future. Each could be improved in its own way, and there will be a need to prioritize that work. The tagging model needs to improve its reporting rate (although remains valuable as it stands). The BDM provides a rapid analysis of current trends in the main indices of abundance but requires explicit documented comparisons with the IM. Finally, simpler versions of the IM need to be explored to determine whether they can become easier and faster to use while including the more important influences on the stock dynamics and providing a more complete spatial understanding of those dynamics.

The Tagging model stands somewhat apart as it can independently produce estimates of regional differences in growth and natural mortality, both of which are vital to understanding the dynamics. In addition, it can provide estimates of movement rates although the reporting rates may weaken the precision of those estimates. If the reporting rate can be improved, it may also be capable of providing independent estimates of population size. This program should be maintained if only for the estimates of growth and mortality, which, given the directional changes in the marine environment that seem to be expressed on the west coast more often in recent years, may become an important influence on the dynamics into the future.

The Biomass-Dynamics Model is innovative in its design but this very innovation means its outputs should be compared and documented against the IM outputs to characterize its behaviour and communicate its value to the western rock lobster fishery stakeholders and document any caveats required when attempting to interpret its outputs. The BDM structure explicitly includes density dependence in its dynamics, which may be sufficient explanation for its predicted productivity (~9,000+ t) to be less than that of the IM (~11,000+ t). It would be valuable to continue its development to include some limited spatial details and to simplify or automate reporting its outputs for ease of communication. It has real value in permitting the rapid demonstration of the implications of some potential management changes.

Finally, the Integrated Model is currently needed for the provision of management advice so its continued use remains important. However, it would become more valued if a revised version was developed that retained the ability to describe most of the dynamics of the current version while being simpler and more rapid in its execution. Currently its use in the exploration of alternative management scenarios is limited by its prolonged running time. Simplification would alleviate this problem and open up further options for the maintenance and management of the western rock lobster.

Using three models, each of which emphasizes different data sources, reduces the potential risks in terms of generating management advice. While all three models need not be considered necessary they are a valuable initiative and provide the western rock lobster stock with the facilities to be confident in the outcomes. As with all models their outputs can only be as useful and valid as their inputs, so the later questions concerning the appropriateness of the data collected are very pertinent here. In the meantime, use of all three models for their separate purposes is to be encouraged. The further development and simplification of the IM should generate benefits for the fishery and while that is proceeding the BDM should provide a backstop for double checking the outcomes from the current IM.

Recommendations:

1. Retain all three models but consider recommendations provided in TOR 2.

TOR 4:

What is seen while fishing is not reflective of the growth of biomass in the model(s).

The IM predicts that the stock biomass should be increasing but Industry representatives have stated that this is not the case in certain areas, particularly in the inshore areas up in the north of the fishery. Increases in biomass are predicted as a result of significant reductions in the catch levels in recent years. In addition, the increase in catch-rates and the increases observed in the IBSS suggest that the stock biomass has increased (**Figure 4**).

The industry have raised the issue that at least some of the increase in CPUE is a result of the major reduction in both the number of active operators and the number of pots in the water. This view requires consideration given recent changes in the dynamics of the fishery as there were large reductions in effort resulting from the structural changes in the fishery. When fishers and/or fishing gear are so dense on the water that they interfere with each other's operation such interactions are referred to as technical interactions (Bhat and Bhatta, 2006). Prior to the restructure, effort levels in the fishery were significantly higher. This can be a prime cause of technical interactions that reduce the catch per pot per operator and hence the profitability. The immediate increase in catch-per-pot following the reduction in fisher and pot numbers was so immediate it would appear to have been biologically implausible for such an immediate increase in the stock of the same scale (which should have been signalled by very high puerulus counts around about 2005 - 2008; see **Figure 2**). On the other hand, since the restructure the greatly reduced fishing mortality brought about by the marked reduction in catches would also have allowed the stock to grow and rebuild in density. Such a rebuild is more easily seen in the IBSS that provides an independent estimate of abundance at a time of year that used to have no commercial fishing (**Figure 4**). The results from the IBSS, however, exhibit relatively high inter-annual variation and so, to gain a better appreciation of the potential scale of change, this figure should be re-drafted using the latest estimates and including the 95% confidence intervals around the mean estimates. The rises over the first six years closely mimic the commercial CPUE but most recently there are two years of much lower catch rates.

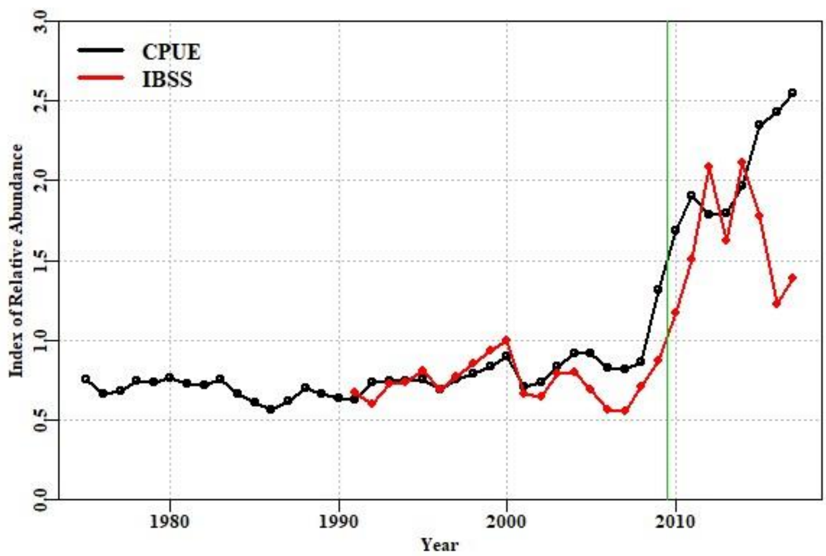

Figure 4. A plot of the draft data on the commercial CPUE and the outcome of the IBSS when they are both placed on the same scale such that they both have a mean of 1.0. Draft data from Dr de Lestang.

It seems likely that the real increase in stock biomass is indicated by the IBSS but its mean value through the years observed recently is uncertain, although it seems unlikely to be as high as the CPUE index. Unfortunately, the IBSS does not sample in waters of the depths where Industry members have noticed a strong decline in the abundance of lobsters to be caught. So while the survey suggests there has been an increase in biomass, the spatial generality of this conclusion is not clear. This is an example where currently the data that might allow this issue to be clarified and quantified are not currently being collected.

The simplest theoretical solution to this would be to extend the IBSS into the inshore regions, although in practice this may not be simple to implement if the waters are highly turbulent. An alternative would be to continue and expand the meshed-pots sampling program so that it incorporates inshore areas. An added benefit of this expansion would be the sampling of areas currently deemed by Industry to be showing reduced levels of productivity (termed the "dead-zone"). Ideally, to reduce costs, this should be undertaken by commercial fishers, but if this is not practical, then there is a case to be made for the DPIRD to set up a closed pot sampling program within the so-called "dead-zone" so as to identify the geographical extent of the problem and determine whether this "dead-zone" is getting larger or smaller through time.

The commercial CPUE data has numerous complications that cast some doubts as to how informative it can be expected to be. Importantly, in 2010 (**Figure 4**) the reporting of catch rates transitioned from monthly reports to daily reports. Such a change has the potential to greatly change the character of the resulting catch rate data. Unfortunately, such changes can introduce real breaks in what may previously have been considered to be continuous time series of CPUE. Analysing or standardizing such time-series is an out-standing problem with respect to CPUE standardization. If large changes are not associated with the management or the stock dynamics at the same time, then it is sometimes possible to connect up the two ends of the broken series. However, in this case, the break coincided approximately with the large effort reduction (reduction in pots and fishers) and the large decrease in catches. Nevertheless, it is recommended that the implications of alternative CPUE scenarios (no break in the time-series, a changed catchability after shifting to daily records, and others) be investigated. It is certainly likely that the uncertainty and variability will have increased since the shift to daily reporting as summary reports generally have the effect of masking variation.

Because of the increased importance of the IBSS this time-series needs to be maintained and possibly expanded if possible. An expansion of the offshore portion of the stock appears to have occurred although the full extent of that expansion may have been obscured due to variation in the IBSS and to changes in the reporting of the commercial CPUE. To help alleviate recent Industry concerns some way of obtaining data from the inshore region reported as the "dead-zone" should be pursued.

Recommendations:

1. Attempt to obtain data from inshore areas through either expansion of the IBSS or the meshed pot sampling program.
2. Investigate alternative CPUE scenarios in relation to time-series of data and changes in catchability.
3. Given observed changes in fishery dynamics, maintain IBSS and possibly expand as per (1).

TOR 5:

Is spatial variation in recruitment accurately captured in the model and has it changed temporally?

Recruitment is one of the fundamental drivers of productivity in any natural population. This has been well illustrated in the western rock lobster stock by the many major changes brought about by significant reductions in egg production and consequent puerulus settlement along the coast. In addition, the perception of the existence of an expanding 'dead zone' where the abundance of puerulus, juvenile and adult lobsters have all been reported to have declined, raises the question of whether or not the data being used in the modelling adequately represents spatial variation in recruitment.

The best estimator of recruitment currently used in the IM and BDM is the puerulus counts. Unfortunately, none of the puerulus collection sites are located in the current 'dead zone', although there are two that currently are close to its borders. An attempt was made to take samples of puerulus settlement within the 'dead zone' (**Figure 5**) but this is operationally difficult as the shelf in that area is wide and shallow so that the collectors deployed while in the correct depths were much further off shore than the other collectors with which they were compared.

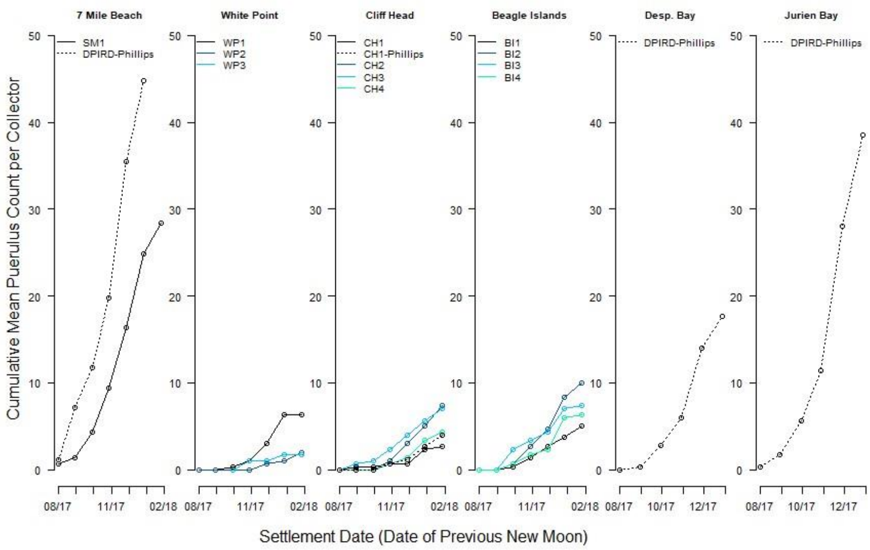

Figure 5. The mean puerulus count per collector (copied directly from the DPIRD presentation to the reviewers). The 7 Mile Beach and Jurien Bay collection sites are part of the usual

puerulus sampling regime, the others were new and were placed to explore this reported ‘dead zone’.

The difference in collector placement is unfortunate because it means it is not possible to determine whether the differences between those inside the ‘dead zone’ and those on its borders are due to the off-shore distance or due to a reduced settlement along that part of the coast. For such comparisons to be valid, it is important to ensure that puerulus collection sites are comparable across regions. If the collectors within the ‘dead zone’ cannot be placed closer inshore then collectors further off-shore at 7 Mile Beach and Jurien Bay might be installed. That would undoubtedly compromise their depth so it may not be possible to arrange for directly comparable collectors.

It needs to be emphasized just how important the puerulus sampling is for both the IM and the BDM, and for predicting the potential production. This means the sampling needs to be maintained, at least at current levels. If it can be extended into this ‘dead zone’ that might be informative. Up until the marine heatwave event, which followed the unexpected drop in egg and puerulus production, the puerulus counts made along the coast had enabled the generation of management decisions that had succeeded in maintaining this valuable fishery.

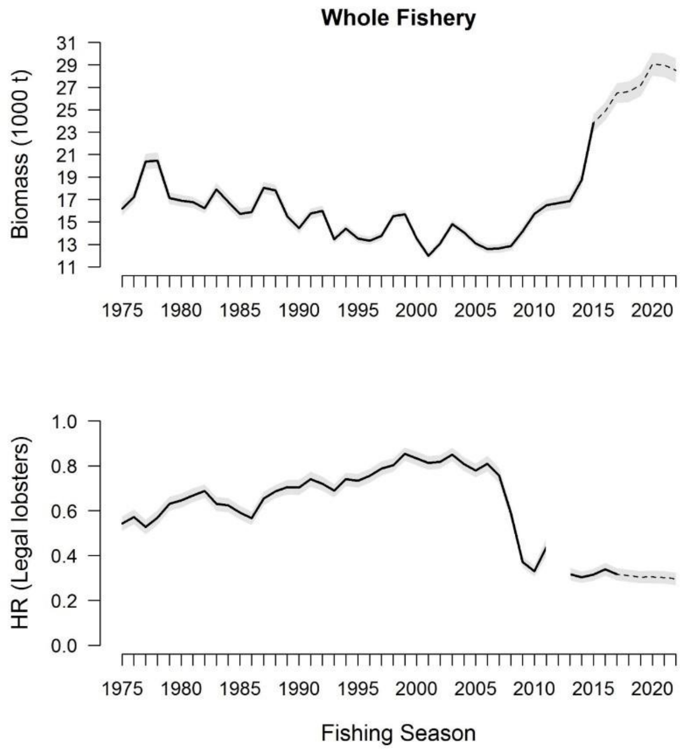

Figure 6. The estimated stock biomass and annual harvest rate from the IM since 1975 (copied directly from the DPIRD presentation to the reviewers). There are complications with this diagram such as the notion of legal lobsters and whether the biomass is of legal lobsters, so some care is needed in its interpretation.

With the advent of the IM the implied history of the fishery is one of a long and slow depletion with a gradually increasing harvest rate (Figure 6). Even without the reduced egg production and puerulus settlement this model would have recommended a significant reduction in catches. The importance of the puerulus counts to drive such insights is clear and the value of maintaining that sampling is great.

The possibility remains that the ‘dead zone’ is the remnant of the impact of the recent marine heatwave that hit the west coast in 2011 (Pearce *et al*., 2011). Given the array of different habitat types along the coast it should not be surprising that some areas are more prone to the effects of relatively hot water than others. In terms of biological sensitivity, an extensive relatively flat and shallow part of the shelf seems likely to have been more vulnerable to warm water impacts than areas of coastline that are relatively close to deeper waters. This means this area may require continued sampling into the future to determine whether it is continuing to expand or starts to exhibit signs of recovery.

In the review there was a discussion concerning the possibility that the significant reduction in fishing pressure led to an increase in the numbers and proportion of larger lobsters. The potential for cannibalism of smaller lobsters by bigger lobsters is a real risk with Crustacea, in which cannibalism is common on soft-shelled, newly moulted animals, but there is currently little or no evidence that such cannibalism is occurring.

Currently, the origin of the ‘dead zone’ and of reduced numbers and low recruitment in this area is unknown. Given the predicted increased abundance of lobsters in the south where there does not yet appear to be issues with reduced recruitment, it might be thought that cannibalism may not be a contender, but the warmer waters in the northern areas may alter such interactions. Until more is discovered then sampling needs to continue. The implications of the reported reduction in recruitment between Jurien Bay and 7 Mile Beach will only become apparent in the next few years. Any decrease in this area may be compensated at the stock level by the increase in stock size down in Zone C. Certainly more explorations of the implications for recruitment of recent changes need to be conducted using the models.

The period of reduced puerulus settlement from 2006 – 2008 (**Figure 3**) implies a reduction in stock size over the next few years (**Figure 7**). The predicted increase following that reduction assumed average settlement levels from the most recent ten years (08/09 – 17/18).

It would be worth including some sensitivity projections where the settlement rate (the R_t in the BDM) uses the recent settlement rates back to 06/07, the start of the major reduction, as the current projections leave out the worst of the lower rates.

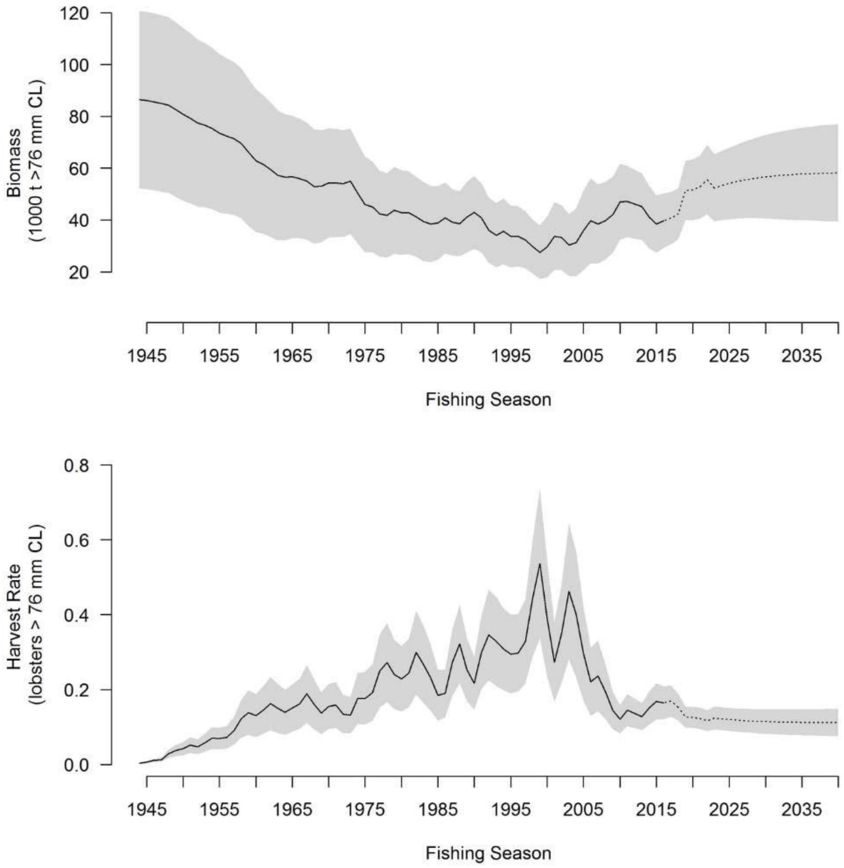

Figure 7. The predicted biomass and annual harvest rate from the BDM illustrating an expected dip in stock size out to 2020 and a related increase in harvest which is presumably due to the lower success in settlement from 2006 onwards (copied from DPIRD presentation.

Recommendation:

1. Maintain puerulus sampling at current levels and possibly expand to include areas considered to have lower levels of productivity.
2. Examine alternative projections using the BDM with different settlement rates based specifically on more recent puerulus settlement rates.

TOR 6:

Is current data collection sufficient for management of the fishery?

The stock assessment models for the western rock lobster stock are appropriate but, like all models, they will always be dependent upon the data to which they are fitted. The data available is diverse and abundant and generally appears to be analysed appropriately, although the analysis of CPUE standardization could be expanded. The documentation of these analyses is still in a state of development but this is expected to continue to improve into the future. Some concerns within the stakeholders may be alleviated with improved documentation.

Given the very many changes in the dynamics of the fishery and the stock (changes include: increased soak times, escape gap changes, minimum sizes, setose females, puerulus settlement times, 12 months of fishing) the data collections take on a new importance and wherever possible should not be reduced.

The CPUE standardization, for example, requires improved documentation and would benefit from dedicated time for exploration of alternative approaches and standard ways of reporting. During the presentations to the reviewers a number of different analyses were displayed, but each needed to be explained and caveats applied. These related to the notion of 'legal biomass', which has changed through time due to changes in minimum size, the inclusion or exclusion of setose females, and related aspects of the fishery. Standardization is essential to account for changes in CPUE which are due to changes in fishing behaviour rather than changes to the underlying fished stock size. For example, where CPUE is naturally lower as a reflection of water temperature, a shift to increased fishing in the winter would lead to an apparent reduction in CPUE, which a standardization should be able to account for if it includes either month or season as a factor potentially influencing CPUE.

When large changes are made to the management of the fishery, such as moving from monthly reporting to daily reporting, or the introduction of quotas, or both together, the risk that such a move has broken any time-series of commercial CPUE needs to be considered. Such breaks continue to be a problem when standardizing CPUE. A break occurs if there is a factor imposed that changes the catchability but cannot be accounted for in a standardization. Any influential factor that occurs across the whole fleet at a single moment of time (e.g. introduction of Quotas, changing of log-book reporting rate, introduction of a very large closed area) is difficult or impossible to include into a standardization. So more time is required to document and explain the application of CPUE standardization and examine its strengths and weaknesses with respect to the major changes that have occurred in this fishery.

Some very simple changes would improve the ability to make comparisons among areas and years. For example, having comparable axes on the graphs to be compared should be standard practice. Such things can lapse when staff are rushed or there are too few staff for the work load and deadlines. These details are not overly important but can make a difference when attempting to communicate such information to stakeholders less familiar with graphical displays of information.

Fortunately, the IBSS sampling program provides an independent view of the relative abundance and, as such, is an essential data input to the IM. Such an important index of relative abundance needs to be maintained as a primary source of information about changes in the stock size. Current reductions in the IBSS sampling hence increase the risk of missing important changes in the stock.

In line with the previous discussion of the reported 'dead zone', consideration should be given to extending IBSS sampling to inshore regions where possible. Currently the IBSS constitutes the best index of relative abundance available in this fishery.

To complement the IBSS more fishery dependent sampling in the meshed-pot program and the tag return program would obviously be helpful. In regions where the meshed-pot program becomes too great an impost on Industry members then fishery independent meshed-pot sampling might be considered to gain better insights into the relative abundance of smaller lobsters (although the potential for within-pot interactions can influence this).

Recommendations:

1. Continue to improve documentation of CPUE standardisation and consider alternative CPUE scenarios as per TOR 4.
2. Maintain and possibly extend IBSS as per TOR 4.
3. Expand either fishery-dependent or independent meshed pot sampling into areas considered to be exhibiting lower productivity levels.

Bibliography

A list of documents made available or downloaded from the www for use in the review.

Bhat, M.G. and Bhatta, R. 2006. Mechanization and technical interactions in multi-species Indian fisheries: implications for economic and biological sustainability *Marine Policy* **30**: 237-248.

Fisheries Management Paper 263. 2014. *West Coast Rock Lobster Harvest Strategy and Control Rules 2015 – 2019*. 8p. Department of Fisheries, Perth, WA. ISSN 0819-4327

Fisheries Management Paper 271. 2015. *Harvest Strategy Policy and Operational Guidelines for the Aquatic Resources of Western Australia*. 44p. Department of Fisheries, Perth, WA. ISSN 0819-4327

Fisheries Occasional Publication No. 50 2008. *Western Rock Lobster Stock Assessment and Harvest Strategy Workshop* 16 – 20 July 2007. Western Australian Fisheries and Marine Research Laboratories. Department of Fisheries, WA. 52p. ISBN: 1 92125829 2

Fisheries Occasional Publication No. 81 2010. *Western Rock Lobster International Stock Assessment and Modelling Workshop Report* 20 – 24 May 2010. Western Australian Department of Fisheries. Perth WA. 109p. ISBN: 1 921258 95 0

Fitzhardinge, J. 2018. *Paper for Peer Review Meeting June 1 2018*. 3p. (Discussion of possible recruitment failure on part of WA coast).

de Lestang, S. 2018. Could warming oceans and increased lobster biomass rates be affecting growth rates in Australia's largest lobster fishery? *Bulletin of Marine Science*. https://doi.org/10.5343/bms.2017.1100

de Lestang, S. 2018a. *Integrated model description –Western Rock Stock Assessment Model.* 23p.

de Lestang, S. 2018b. *Model description - Draft Western Rock Lobster Biomass Dynamics Model*. 8p.

de Lestang, S., Caputi, N., How, J., Melville-Smith, R., Thomson, A. and Stephenson, P. 2012. *Stock Assessment for the West Coast Rock Lobster Fishery*. Fisheries Research Report No. 217. Department of Fisheries, Western Australia. 200pp.

de Lestang, S., Caputi, N., and How, J. 2016. *Resource Assessment Report Western Rock Lobster Resource of Western Australia* Western Australian Marine Stewardship Council Report Series No. 9. Department of Fisheries, Western Australia 139p. ISBN: 978-1-87709859-8

de Lestang, S., Penn, J.W., and Caputi, N. 2017. Changes in fishing effort efficiency under effort and quota management systems applied to the Western Australian rock lobster fishery. *Bulletin of Marine Science* **94** https://doi.org/10.5343/bms.2017.1154

de Lestang, S., Caputi, N., and How, J. 2018. *Stock Assessment and MSC Audit Reporting for Western Rock Lobster Resource.* Department of Primary Industries and Regional Development. WA. 16p.

de Lestang, S., How, J., Tuffley, E-J., Taylor, M., and Robinson, C. 2018b. *Draft Science Review Report – Workshop 1.* Department of Primary Industries and Regional Development. WA. 19p.

Pearce, A., Lenanton, R., Jackson, G., Moore, J., Feng, M. and Gaughan, D. 2011. *The "marine heat wave" off Western Australia during the summer of 2010/11*. Fisheries Research Report No. 222. Department of Fisheries, Western Australia. 40pp.