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Western Rock Lobster Puerulus Workshop

prepared by
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Department of Fisheries, Western Australia

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Department of **Fisheries**

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Fish for the future

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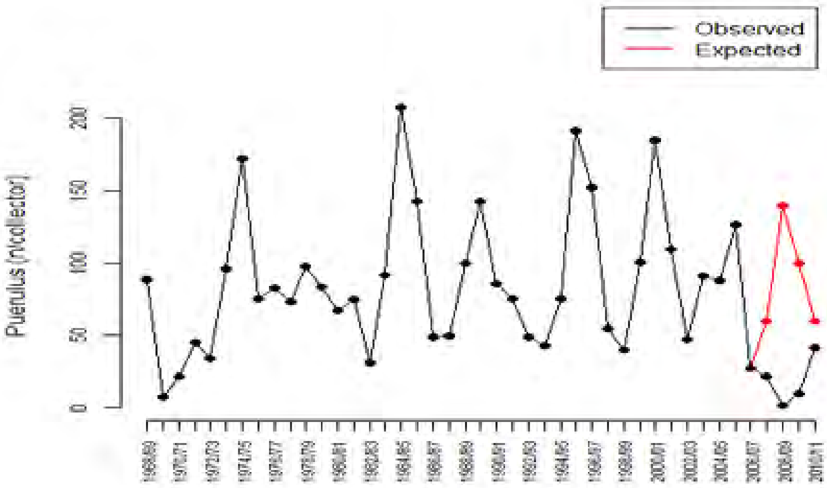
Contents

Background and Introduction

Below average puerulus settlement occurred in the western rock lobster fishery in 2006/07, very low settlement occurred in 2007/08, 2008/09 and 2009/10. A moderate recovery was observed in 2010/11.

Puerulus Settlement



The low settlements will have a major impact on the catch of rock lobsters three and four years after settlement. The first recruitment to be affected was the March-June 'reds' fishery in 2009/10. The low settlements also had the potential to result in much lower breeding stock levels four to six years after settlement if management action had not been taken to significantly reduce the exploitation on the rock lobster stocks.

Due to the uncertainty of the cause(s) of the low puerulus settlements (e.g. as yet unknown environmental factor(s), or low breeding stock effect, or a combination), a risk assessment workshop was undertaken on 1 and 2 of April 2009. The risk assessment panel and the workshop participants supported research projects being undertaken in six areas:

- Identifying factors affecting the low western rock lobster puerulus settlement in recent years.*
- Breeding stock to puerulus source – sink relationship using an oceanographic larval advection model.*
- Biological oceanography of western rock lobster larvae.*
- Investigating changes in fishing efficiency in the western rock lobster fishery.*
- Investigating rock lobster population genetic structure.*
- Assessing possible environmental causes behind the reduced colonisation of western rock lobster puerulus collectors by a wide suite of species.*

(* See Appendix 7 and/or the presentations in Appendix 1-6 for objectives and details of the research.)

These projects were of different duration (one to three years) and have been underway for between 12 and 24 months. It was decided to hold a workshop to enable researchers to present their findings to their peers and stakeholders and review the direction of ongoing research and management.

Program for the 24 May 2011 Western Rock Lobster Puerulus Workshop

Objectives

1. Review research undertaken and planned on the factors that may affect puerulus settlement, viz. breeding stock and environmental factors.
2. Identify factors that may be affecting settlement that need further research and/or management responses.

Agenda

Presentations

1. Puerulus, breeding stock and management	S de Lestang
2. Oceanographic larval modelling	M Feng/N Caputi
3. Phyllosoma larval studies	A Waite
4. Factors affecting settlement	N Caputi
5. Other species on collectors	S de Lestang
6. Genetic studies	J Kennington
7. General Discussion	Facilitator R Brown

See Appendix 8 for the list of attendees and organisations represented.

Project Summaries

Presentation 1 – Population-dynamic assessment model

Use of a spatial population-dynamic assessment model in the assessment and management of the West Australian Rock Lobster Fishery during a period of low recruitment.

Simon de Lestang, Peter Stephenson, Nick Caputi and Rick Fletcher.

Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Western Australia, PO Box 20 North Beach WA 6920, Australia

Puerulus recruitment is monitored throughout the Western Australia's Rock Lobster Fishery as it accurately represents legal recruitment 3-4 years later. The 2007/08 puerulus settlement was below the range expected given the environmental conditions. The following year water temperatures indicated that 2008/09 settlement should improve where in reality it was the lowest recorded, with the subsequent settlement being the second lowest. The impact of these low settlements on commercial catch rates and breeding stock levels (BS) were examined using a spatial population-dynamic assessment model that integrates a full range of data sources including puerulus settlement, survey and commercial catch rates, size compositions, tag recaptures and environmental measures. The projected impact identified that significant management measures were required to achieve the fishery's decision rules: Maintain BS above threshold levels over the subsequent five years with 75% certainty. The model assessed a range of management measures with the chosen suite, which were implemented in 2008/09-2009/10 seasons prior to the low settlement recruiting to the fishery, resulting in a 44% and 72% nominal effort reduction from 2007/08 levels, respectively. This has enabled a significant carryover of an additional 4500 t. into the expected low catch years. The stock assessment model projected a short-term increase in catch rates and BS, followed by a subsequent decline in catch rates and a levelling off of BS in the years when the low recruitments were entering the fishery. To date the fishery has followed these predicted trends.

Discussion Points

- The four consecutive years of very low puerulus settlement that have occurred recently in the fishery (see slide 5 Appendix 1) and the low recruitments that will flow from them over the next four to five years are outside what has been previously experienced (see slide 6 Appendix 1). Therefore management needs to take a very cautious and conservative approach to ensure the breeding stock is not adversely affected.
- Sensitivity analysis needs to be undertaken on the large confidence limits around the recruitments that are predicted to result from the very low puerulus settlements, e.g. ~400 to 2250 tonnes for 2012/13 (see slide 6 Appendix 1), and particularly the impact on future breeding stocks.
- The percentage of high grading (and the mortality incurred); changes in the time and distribution of fishing and the changes in pot efficiency due to the implementation of quota and the reduction in pot numbers needs to be 'ground truthed' to improve the estimates currently used in the model. This will be done using information from the new catch declaration returns (CDR) that all fishers have to complete and the modified voluntary research logbooks. The CDRs provide catch and effort information on a much finer scale of time, space and depth than the previous monthly returns and also provide estimates on high grading.

Presentation 2 – Modelling puerulus settlement

Individual Based Modelling of Western Rock Lobster Puerulus Settlement

Ming Feng[1], Nick Caputi[2], James Penn[2], Dirk Slawinski[1], Simon de Lestang[2], Evan Weller[1], Alan Pearce[2], Ainslie Denham[2], Liejun Zhong[1]

[1]CSIRO Marine and Atmospheric Research, Floreat, WA 6014 Australia

[2]Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Western Australia, PO Box 20 North Beach WA 6920, Australia

An individual-based model, incorporating outputs of a data-assimilating hydrodynamic model, was developed to investigate the role of ocean circulation in the recruitment processes of western rock lobster during its 9-11 month larval phase off the west coast of Australia. During austral summer, strong northward alongshore winds aid the offshore movement of early-stage model larvae from mid-shelf hatching sites into the open ocean; during the austral winter, eastward flows that feed the enhanced Leeuwin Current facilitate onshore movement of late-stage larvae towards near-shore habitats. Stokes drift induced by swells from the Southern Ocean is critical to retain larvae off the west coast. Diurnal migration and temperature-dependent growth are also important. Model larvae hatched in late-spring/early-summer grow faster due to longer exposure to warm summer temperature, which allows them to be transported towards the coast by the strong onshore flows in winter and reduces their natural mortality. Preliminary source-sink relationship indicates that the population was well mixed off the coast, with higher likelihood of settlement success from hatching sites in the north, mostly due to higher surface water temperature. Weighted with the breeding stock distribution the area between 27.5-29.5°S, including the Abrolhos Islands, is the most significant hatching area to the success of settlement.

Year-to-year variations of puerulus settlements during 1994-2009 are being assessed using an updated version of the individual-based model, which has relaxed the larval mortality to give more flexibility in the post-model analysis. It appears that the model has captured some of the year-to-year variations of the total number of puerulus settling, as well as the average settlement latitudes. Statistical analysis will aid the optimization of the scaling factors in the post-model analysis.

Discussion Points

- Sensitivity analysis on model results is being undertaken by relaxing the parameter boundaries.
- Mortality of larvae at high temperature needs to be assessed as part of the sensitivity analysis.
- The change in daylight length between summer and winter needs to be incorporated into to model. In winter when day length is up to 20% shorter, larvae would spend more time in surface waters and therefore be exposed to surface transportation mechanisms for longer than in summer.
- Vertical migration of phyllosoma in the Leeuwin Current and Leeuwin Undercurrent still need to be fully understood.

Presentation 3 – Biological oceanography

The Biological Oceanography of Western Rock Lobster Larvae

Waite, Anya M.[1], Lynnath Beckley[2], Peter A.Thompson[3], Megan Saunders[1,4], Christin Sawstrom[1],Nik Sachlikidis[5], Nick Caputi[6], Simon DeLestang[6], Andrew Jeffs [7], Roger Barnard[8]

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3. CSIRO Marine Research, Hobart 7001, Tasmania, Australia
4. Current Address: Univ. of Queensland
5. Queensland Department of Primary Industries
6. Department of Fisheries, Western Australian Fisheries and Marine Research Laboratories, PO Box 20 North Beach WA 6920 Australia
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8. Lobster Harvest Ltd., WA Australia

Anya.Waite@uwa.edu.au

We examine in detail, for the first time, the biological oceanographic mechanisms affecting nutrition, growth and survival of larvae of the Western Rock Lobster while they undergo their planktonic *phyllosoma* phase in the Eastern Indian Ocean. The Western Rock Lobster is the most valuable single-species fishery in Australia, representing about 20% of the total value of Australia's fisheries. Variability in settlement of *puerulus* stage and catch of adults has been shown to be highly correlated with the strength of the Leeuwin Current (in turn impacted by El Niño events) and westerly wind conditions. The below-average puerulus settlement for five years, including the two lowest on record, triggered a profound re-examination of mechanisms driving year class strength of larval settlement, since such fluctuations can pose a serious risk to a sustainable rock lobster industry.

Here we present outcomes from the first research voyage (July 2010) of a 3-year study of the biological oceanography of the Western Rock Lobster larvae. We present a new understanding of the feeding of late-stage *phyllosoma* in the wild, and describe its oceanographic context. We show evidence that the *phyllosoma* have a preference for key prey with specific nutritional attributes, and suggest that this is directly related to the need to accumulate substantial nutritional reserves before they can metamorphose into the *puerulus* stage, cross the continental shelf, and settle to form the next generation of fishable adult lobsters. We propose that the autumn phytoplankton bloom within the Leeuwin Current, as identified by satellite ocean colour, is a key food resource driving production of healthy *phyllosoma*, and thus a strong year class. We speculate that the "Abrolhos Front" is a seasonally important feature supporting shoreward fluxes of *phyllosoma*. Our study directly addresses the hypothesis that productivity of the oceanic planktonic ecosystem offshore is a critical variable driving *phyllosoma* health and therefore recruitment success.

Discussion

- Food availability plays a pivotal role in larvae growth and survival. Discussion of whether a broad scale easily monitored species or group of species could be used as an indicator of the level (e.g. high-medium-low) of food available for the phyllosoma. Suggested that phytoplankton / chlorophyll A measurements that are available from satellite imagery could be a cost effective and reasonably robust indicator for long term monitoring of the phyllosoma's food availability.

- About three years of plankton data collection would be required to develop a robust understanding of the phyllosoma's food web and its link to phytoplankton / chlorophyll A concentrations that could then be tracked by satellite.
- The eddy vortexes and boundary zones of the Leeuwin Current appear to be biologically productive areas.
- Zooplankton predators can very quickly reduce their prey in discrete areas.
- The Abrolhos front of the Leeuwin Current system may play a role in larval transport and biological productivity.

Presentation 4 - The cause of the record low puerulus settlement

Preliminary assessment of the cause of the record low puerulus settlement in the West Australian Rock Lobster Fishery.

Nick Caputi[1], Simon de Lestang[1], Ming Feng[2], James Penn[1], Evan Weller[2], Dirk Slawinski[2], Alan Pearce[1], Ainslie Denham[1]

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[2]CSIRO Marine and Atmospheric Research, Floreat, WA 6014 Australia

Puerulus settlement has been monitored for 40 years in the western rock lobster fishery and has accurately predicted catches 3-4 years later. Historically high settlement has been correlated with warm water La Niña conditions, resulting in strong Leeuwin Current flows, and westerly winds in late winter/spring. In the last five years (2006/07 to 2010/11) settlement has been below average with a record low in 2008/09 when water temperature was conducive to good settlement. Some additional factors that may have negatively affected settlement include: three consecutive positive Indian Ocean Dipole events (2006-2008) associated with unusual winter/spring offshore winds during the shoreward phyllosoma movement phase and a reduced breeding stock in the far northern section of the fishery. This section of the breeding stock had declined partly through lower sub-adult lobster migration northward into the area, linked to above average strength southward currents in six of the last eight years. Oceanographic larval modelling suggests that larvae released in the northern part of fishery and from deeper hatching sites have higher chances of survival and settlement. Management actions taken to influence future settlement, include increasing egg production, particularly in northern areas, by a 50-70% reduction in fishing effort, a lower maximum size limits for females, and an area closure to increase protection for animals in the far northern area. The effect of strong La Niña conditions resulting in above-average water temperatures in early 2011 and improving breeding stock levels in the far northern sector of the fishery will be assessed in puerulus settlement in 2011/12.

Discussion

- The major risk for the fishery is managing it through the next four to six years as the unprecedented low recruitments flow through the catch and what is left over flows into the breeding stock.

- The small mesh pot project will help monitor the recruitment flow from the low settlements as they come into the fishery.
- There is a risk that the ‘effective’ residual breeding stock is not as large as estimated. Good breeding stock estimates, particularly in the important deepwater, northern Abrolhos and Big Bank areas are limited due to lack of knowledge of the extent of suitable habitat and biological data collection (e.g. catch rates, size-sex ratios, breeding state, etc are only available for a few years).
- As a precautionary measure, consideration should be given to further protect what appear to be the most effective breeding stocks, by closing the northern Abrolhos Is area, which, habitat-wise, is similar to Big Bank (now protected by a closure).

Presentation 5 - Reduced colonisation of puerulus collectors

Assessing possible environmental causes behind the reduced colonisation of Western Rock Lobster puerulus collectors by a wide suite of species

Simon de Lestang[1] and Jason How[1] and Shelley Foster[2]

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[2]School of Plant Biology, University of Western Australia, 35 Stirling Highway Crawley WA 6009

In response to the lower than expected puerulus settlement for the western rock lobster (*Panulirus cygnus*) on the Western Australian coast during 2008, monitoring of macro invertebrate communities associated with puerulus collectors was initiated. Anecdotal information suggested that there was a reduction in the colonization of the collectors by other invertebrate species, namely shrimps and crabs. Five sites spanning over 1000 km of coastline from Coral Bay to Warnbro were examined for each of two seasons (winter and spring), with two of these sites examined for all four seasons. This allowed for an examination of the spatial and seasonal variation of the macro invertebrate communities. Overall 157 740 individuals, encompassing 67 taxa, were counted from 55 samples that were processed. The compositions of the communities were found to vary significantly both spatially and seasonally, with the main difference occurring between sites located in the tropics/sub-tropics, from those in temperate locations. There was greater abundance of taxa in the temperate locations compared with the tropics. Spatial and monthly variation in environmental parameters measured during this study did not correlate well with variation in the structure of the communities despite clear spatial and temporal differences. The dominant separation of tropical/subtropical from temperate locations probably indicates the importance of the surrounding habitat with the settlement on the collectors. Benthic habitat variation has yet to be quantified, but will be the focus of further work. Climate change in the West Australian coastal zone is predicted to result in increased water temperatures and salinity and less frequent and severe storm events. These environmental factors were found to significantly influence the abundance of a number of taxa found commonly on the collectors. These relationships, along with the discovery of some individuals outside of their normal distributional range, such as the tropical species *Strombus mutabilis* being found at Dongara, indicates that the monitoring of a range of species on the puerulus collectors can provide an indication of the localised environment and the impact of climate change.

Discussion

- There was a significant difference in mobile macro-invertebrate communities between tropical and temperate locations,
- Primarily driven by greater abundances in the temperate locations,
- Baseline study to continue, with collections over the period of improved puerulus settlement (2009/10) and dramatically increased water temperatures (2010/11).

Presentation 6 - Population genetic structure

Investigating rock lobster population genetic structure.

Jason Kennington[1], Oliver Berry[2], David Groth[3], Michael Johnson[1] and Roy Melville-Smith[4]

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[2]CSIRO Marine and Atmospheric Research, Private Bag 5, Wembley, Western Australia, 6913

[3]Curtin Health Innovation Research Institute, WA Biomedical Research Institute, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

[4]Department of Environment and Agriculture, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

In this presentation I gave a progress report on our FRDC funded project to evaluate population genetic structure in the western rock lobster. Our research project had four aims. These include (i) developing new genetic markers for studying population genetic structure in the western rock lobster, (ii) testing for population genetic structure in the adult population, (iii) testing for population genetic structure in the recruits (pueruli) and (iv) estimating the effective population size. We successfully developed 18 new microsatellite loci. These loci together with six previously published microsatellite loci were used to examine population genetic structure in the adults and recruits. Six hundred and thirty one individuals from eight locations were analysed in the survey of adults and 367 individuals from eight sites were analysed in the survey of recruits. Our preliminary analyses found no evidence of population structure in the adults or in the recruits (Overall Fst's were 0.002 and 0 respectively). However, when loci were analysed individually, we found that one locus did show significant population structure in the adults after correction for multiple comparisons. This suggests there may be local adaptation despite high levels of gene flow, though further studies are required to test if this is indeed the case. We tested for a small effective population size by comparing levels of gene diversity in samples of recruits collected between 1995 and 1999 to those in samples collected in 2009. There was no evidence of a decline in gene diversity over this period, suggesting that the effective population size was large. Finally, I talked about a new genetic marker we developed that identifies western rock lobster from other lobster species, which should be useful for species identification of phyllosoma and pueruli.

Discussion

- Population genomic approaches could be used to test for signatures of local adaptation.
- Tracking allele frequencies across life-history stages could be used to test for post recruitment selection.
- A data base of gene sequences from local species would be valuable resource for species identification of plankton.

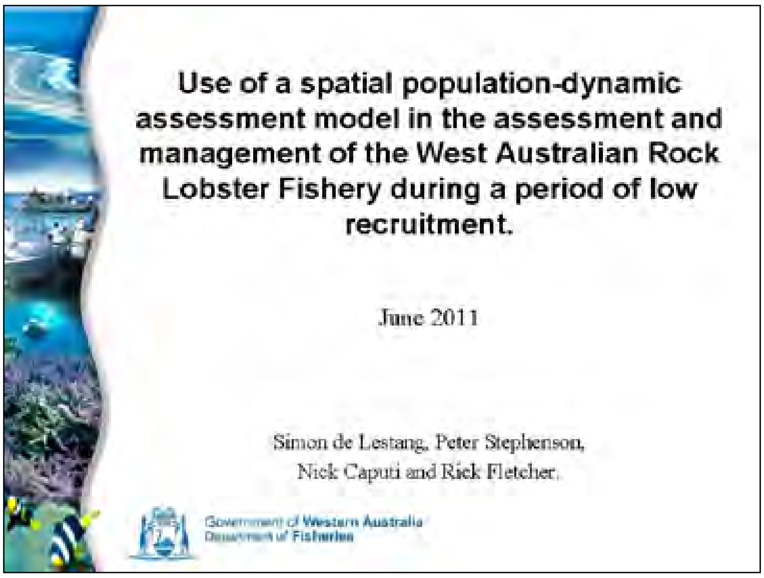
General Discussion and Recommendations

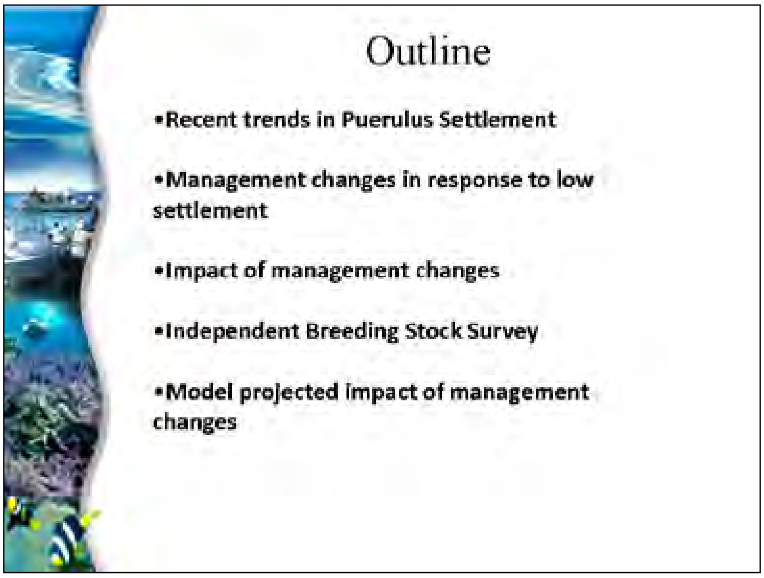
Discussion centred on the management implications of the low puerulus settlements as they flow through into the breeding stock (BS).

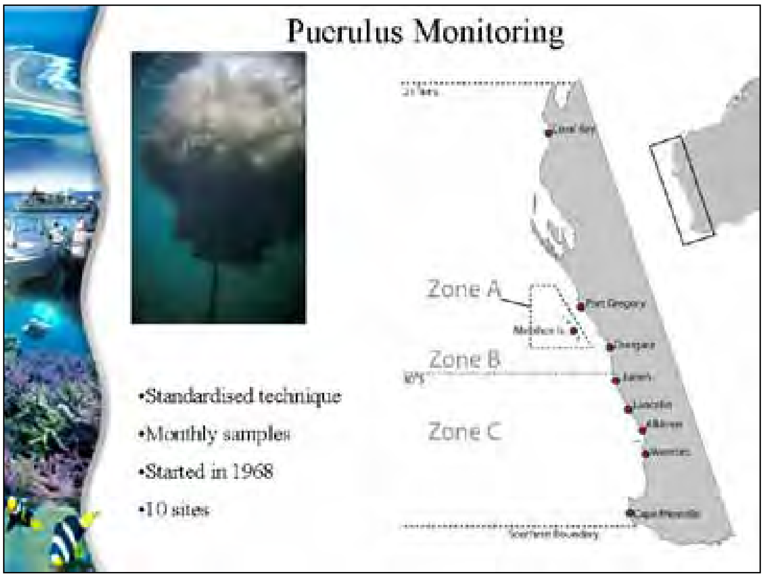
- The rock lobster research team should review the adequacy of the current fishery-independent approaches for measuring the year to year variation in abundance of the residual breeding stock, i.e. the BS that remains in the fishery at the end of the fishing season. If estimates of the residual breeding stock are not robust, it raises two significant risks.
  - If the residual BS is overestimated the quota levels would be set too high and the breeding stock (or potential breeding stock, e.g. the migrating whites) would be overfished. This could lead to a recruitment failure (very low puerulus settlements) and the need to impose significant cuts to the quota (or in the worst case scenario to have to close the fishery) in order to recover the BS.
  - If the residual BS is underestimated the quotas would be set lower than need be for sustainability purposes and would therefore be imposing ongoing economic hardship on the fishing industry without justification.
- The main causes of uncertainty regarding the estimates of the level of residual breeding stock include the:
  - potential to under estimate increases in both pot and fleet efficiencies, because competition between pots has declined very significantly due to pot reductions (~50%); something that has not previously occurred on such a scale in the fishery,
  - the very wide confidence limits around the predictions of recruitment to the fishery (and hence BS) at these historically low levels of puerulus settlement,
  - the strongly held view of many in the fishing industry, of the importance of the unmeasured puerulus settlement they believe may have occurred in deep water, and
  - the potential for increased patchiness of puerulus settlement in years of low settlement.
- The greatest risk for the fishery over the next four to six years is in getting the management setting right to deal with the unprecedented low recruitments that will flow through into the breeding stock.
- There is a risk that the ‘effective’ residual breeding stock may not be as large as estimated, as good breeding stock estimates, particularly in what appears to be the most important areas – central west coast deepwater, northern Abrolhos and Big Bank, are limited due to lack of knowledge of the extent of suitable habitat and biological data collection (e.g. catch rates, size-sex ratios, breeding state, etc are only available for a few years).
- As a precautionary measure to further protect what appears to be the most effective / important breeding stock, consideration should be given to closing the northern Abrolhos Is area. This area has similar habitat characteristics to Big Bank, which is now protected by a closure. The closure of this area is unlikely to impact significantly on the ability of Zone A fishers to take their quota allocation.

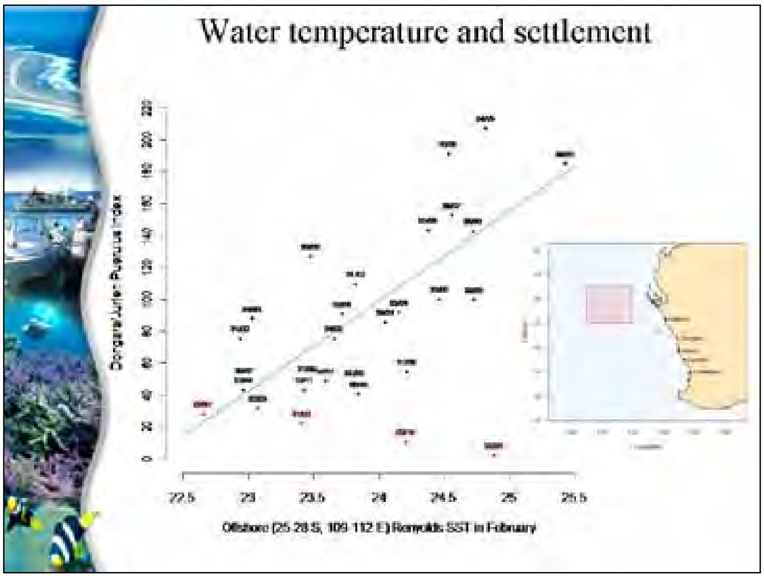
Appendix 1 Presentation 1 – Population-dynamic assessment model

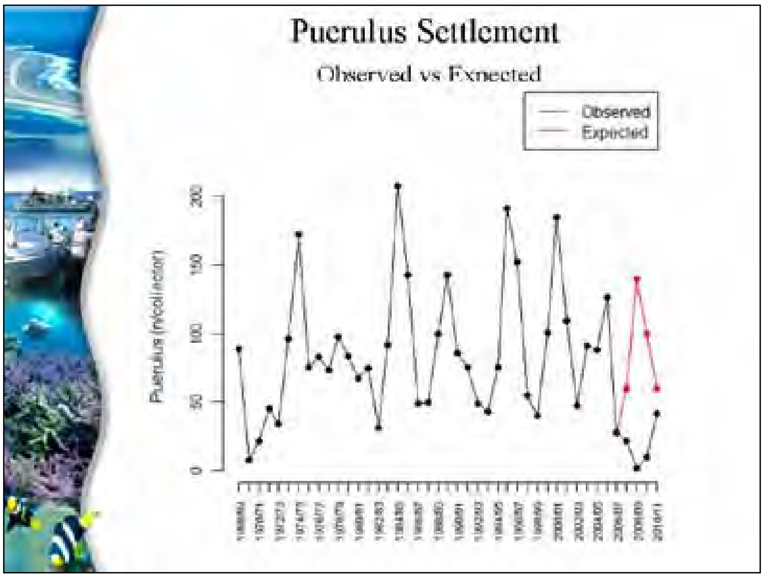
Use of a spatial population-dynamic assessment model in the assessment and management of the West Australian Rock Lobster Fishery during a period of low recruitment.



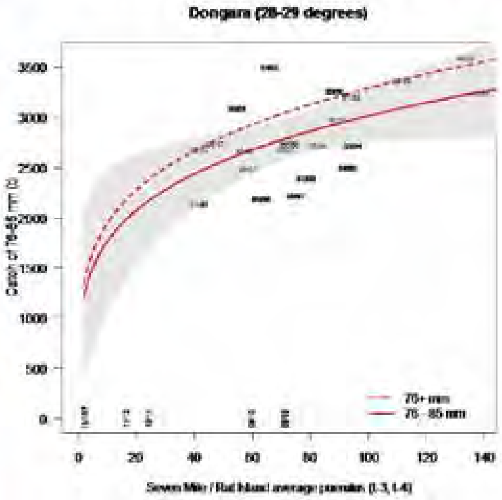



Puerulus Monitoring
•Standardised technique
•Monthly samples
•Started in 1968
•10 sites
Zone A
Zone B
Zone C
Coral Bay
Port Gregory


Water temperature and settlement
Dongara/Jurien Puerulus Index
0
20
40
60
80
100
120
140
160
180
200
220
22.5
23
23.5
24
24.5
25
25.5
Offshore (25-28 S, 109-112 E) Reynolds SST in February


Puerulus Settlement
Observed vs Expected
Observed
Expected
Puerulus (n/collector)
0
50
100
150
200

What does the low settlement mean?



Action required

3-4 years until the recruits enter the fishery

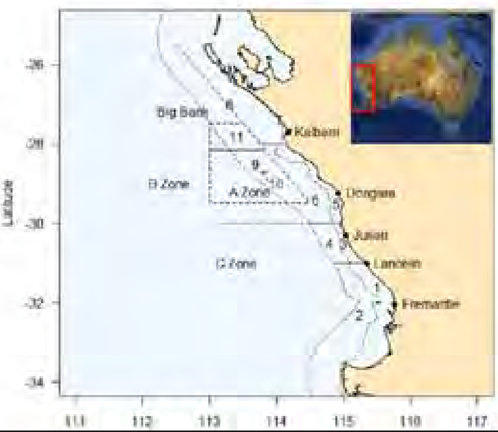
1. **How will this impact the Egg production?**
   - **Examine with Stock Assessment Model**

2. **How will this impact catch rates?**
   - **Examine with Stock Assessment Model**

3. **What was the cause?**
   - **Use a range of targeted projects**

Stock Assessment model (SAM) developed to assess the impact.

- **11 regions**
- **11 time-steps**
- **Starts 1975**
- **Projects 5 yrs**
- **Fits to:**
  - Catches
  - Size Comp.
  - Puerulus
  - Tag data



Management Changes

2007/08 – Puerulus was concerning

- Small pot reduction

•2008/09 – Recruitment failure

- Large pot reduction
- Reduced number fishing days
- Reduced female max size
- Catch Limit of 7800 t

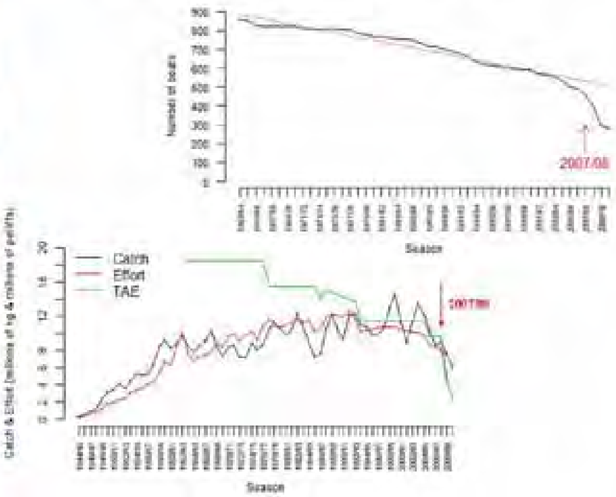
•2009/10 – Slight improvement still v bad

- Additional pot reduction
- Increased minimum size
- Competitive TACC 5500 t

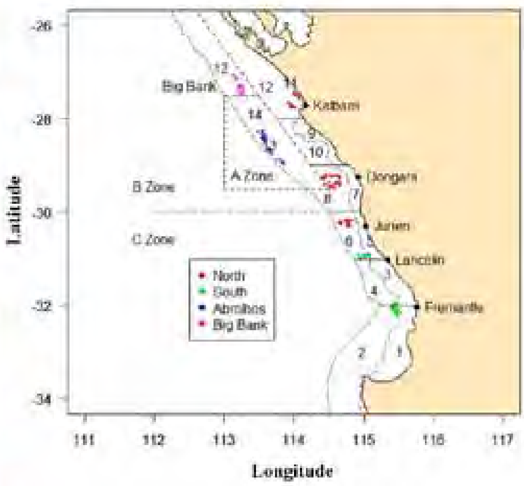
•2010/10 – Improved to 20th pecentile

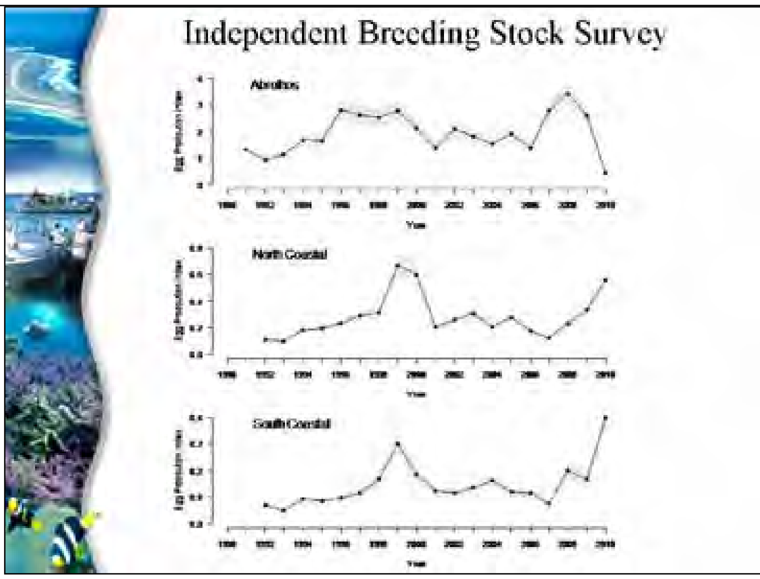
- Individual catch limits – total 5500 t

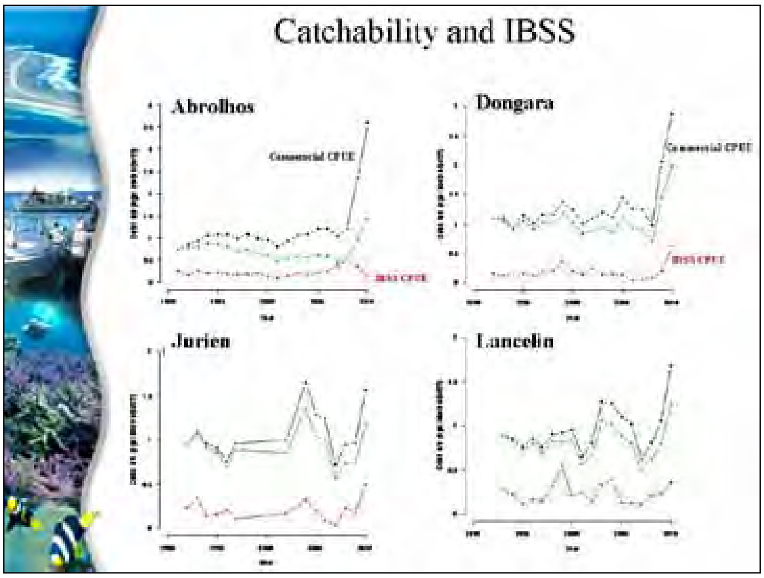
Impact on boats and effort

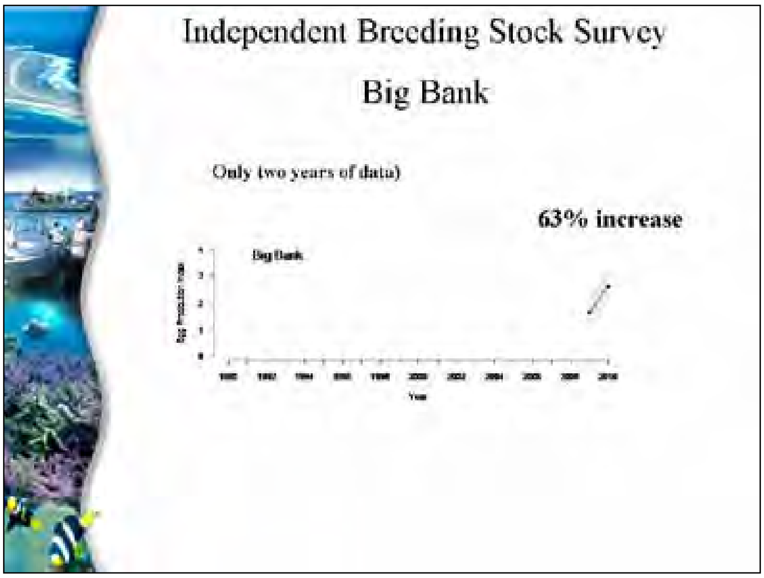


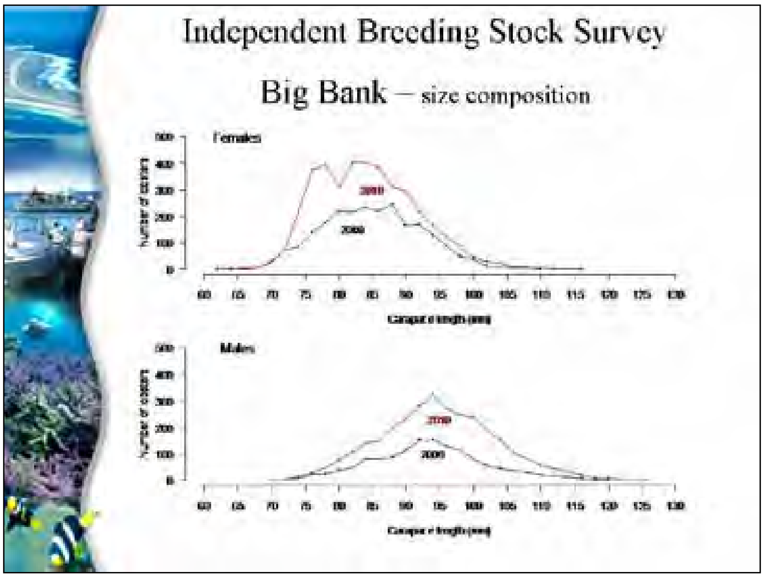
Independent Breeding Stock Survey

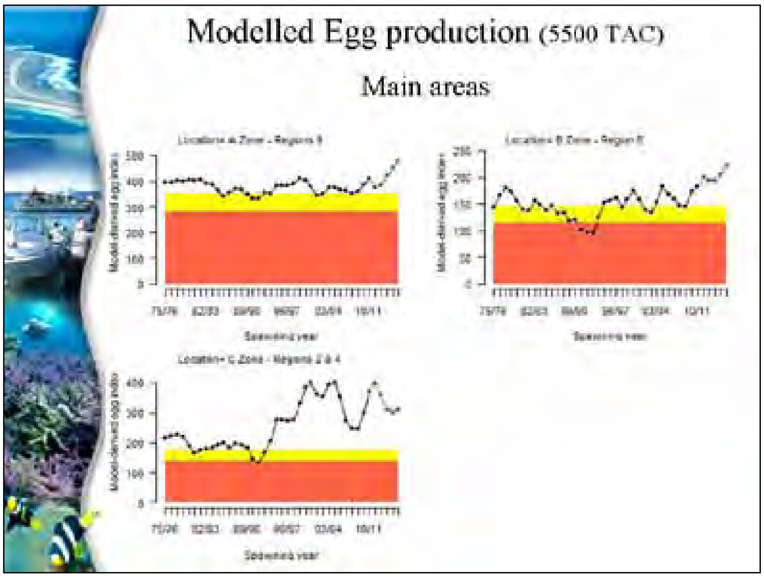


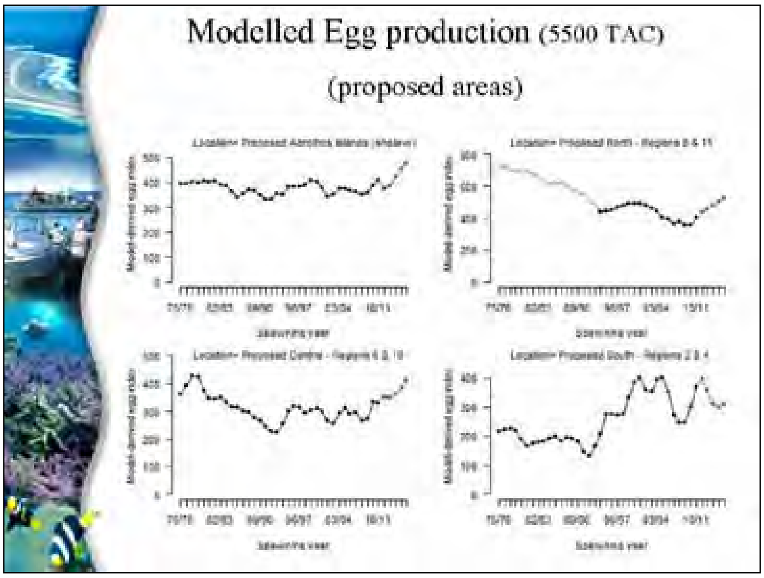

Independent Breeding Stock Survey
Abrolhos
North Coastal
South Coastal

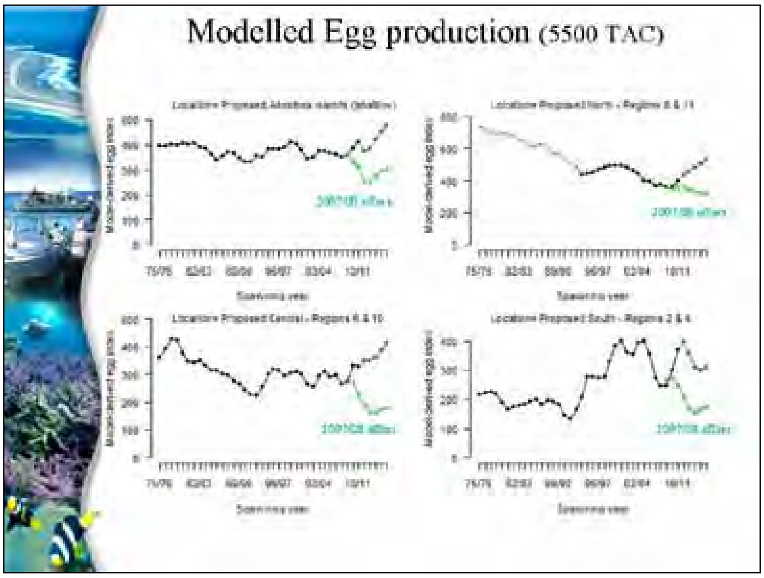

Catchability and IBSS
Abrolhos
Commercial CPUE
IBSS CPUE
Dongara
Commercial CPUE
IBSS CPUE
Jurien
Lancelin

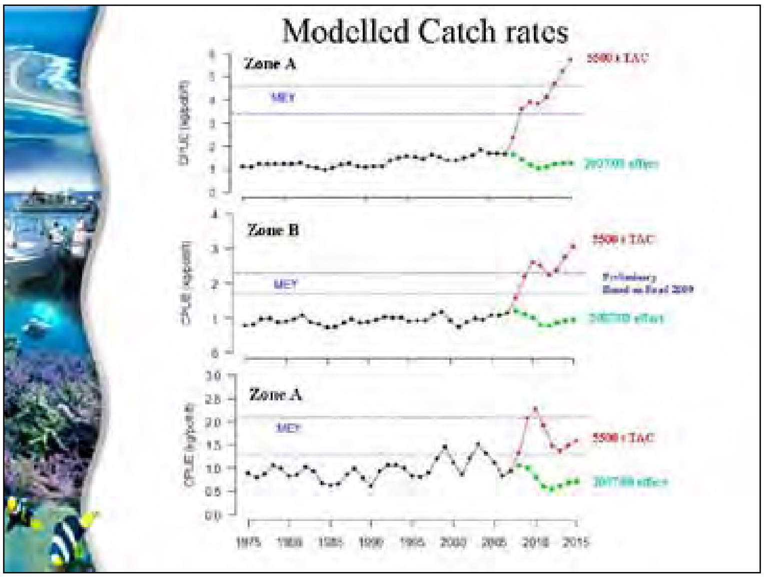

Independent Breeding Stock Survey
Big Bank
Only (two years of data)
63% increase
Big Bank


Independent Breeding Stock Survey
Big Bank – size composition
Females
Males
2010
2009


Modelled Egg production (5500 TAC)
Main areas
75/76
82/83
89/90
96/97
03/04
10/11
Spawning year


Modelled Egg production (5500 TAC)
(proposed areas)
Spawning year


Modelled Egg production (5500 TAC)
Spawning year
Spawning year
Spawning year
Spawning year


Modelled Catch rates
Zone A
MEY
5500 t TAC
2007/08 effort
Zone B
MEY
5500 t TAC
2007/08 effort
Zone A
MEY
5500 t TAC
2007/08 effort
1975
1980
1985
1990
1995
2000
2005
2010
2015

Appendix 2 Presentation 2 – Modelling puerulus settlement

Individual Based Modelling of Western Rock Lobster Puerulus Settlement

Outline of presentation

- Individual based model
  - Oceanography module
  - Larval behaviour module
- Model results
  - **2009 model** (Mean seasonal cycle)

    Feng, M., Caputi, N., Penn, J., Slawinski, D., de Lestang, S., Weller, E., Pearce, A. (2011). Ocean circulation, Stokes drift and connectivity of western rock lobster population, *Canadian Journal of Fisheries and Aquatic Sciences* (in press).
  - **2011 model** (Variations between different seasons)

Oceanography model components

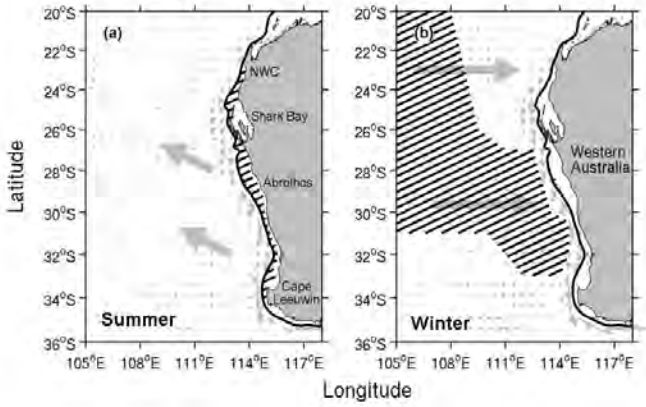
2009 model

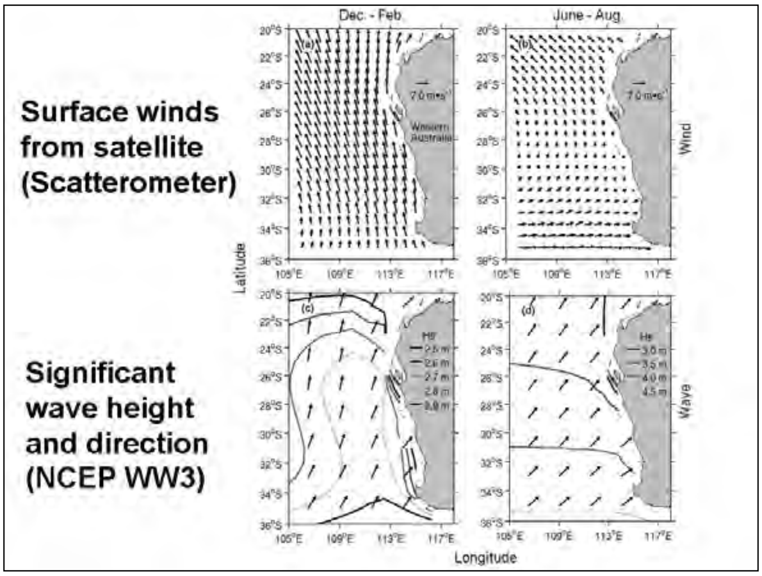
- Bluelink ReANalysis (BRAN) output (daily, 10km)
  - Geostrophic and wind-driven currents
- Satellite (QuikScat) winds (daily, ¼ degree)
  - Enhanced surface wind drift
- Wave Watch 3 model output (daily, 1 degree/1.25 degree)
  - Wave (swells) derived Stokes Drift at sea surface

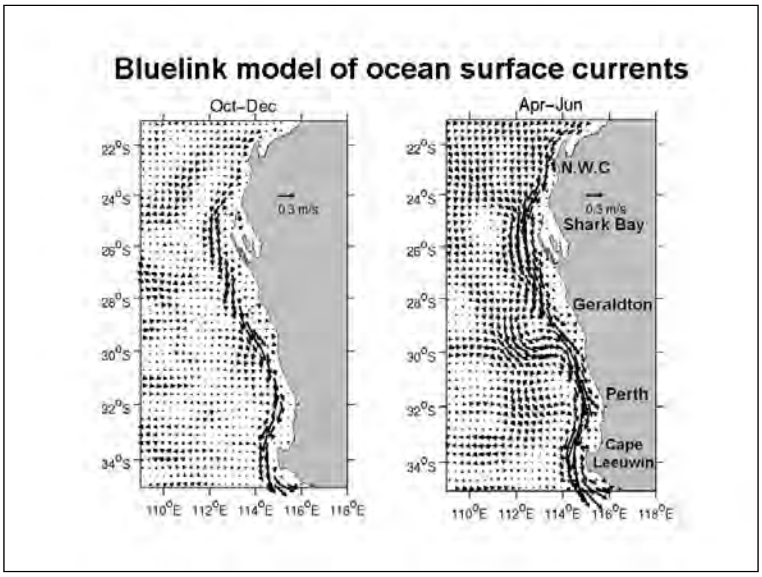
2011 Model

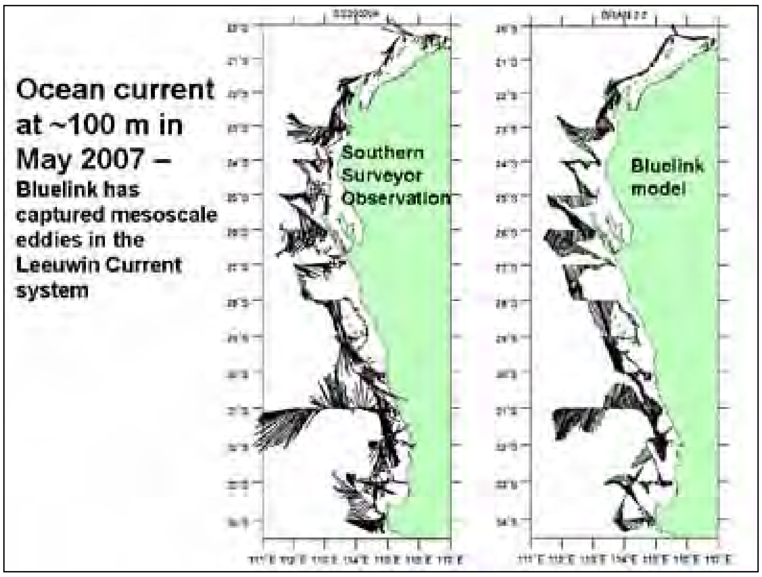
- BRAN + OCEANMAPS (1994 – 2009 seasons)
- ECMWF winds (6-hourly, 1 degree)
- ECMWF waves (6-hourly, 1 degree)

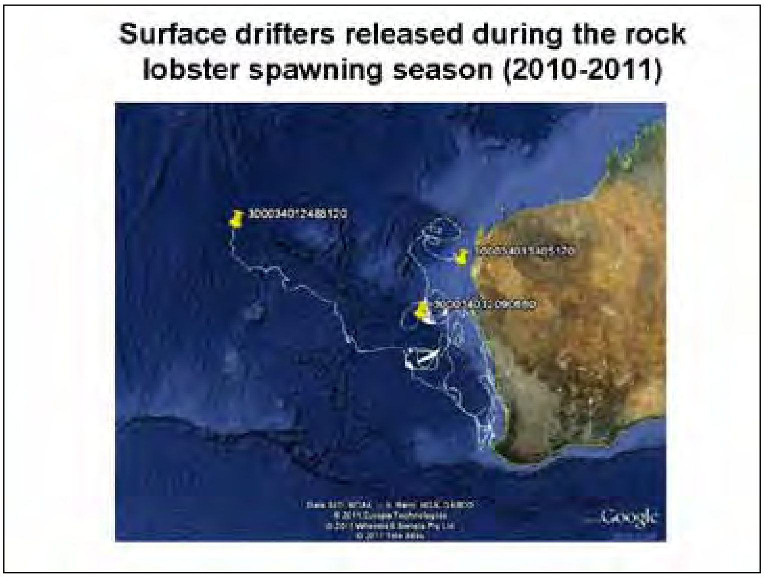
Working hypothesis:
Ocean currents carry early-stage larvae offshore in summer and bring late-stage back inshore in winter

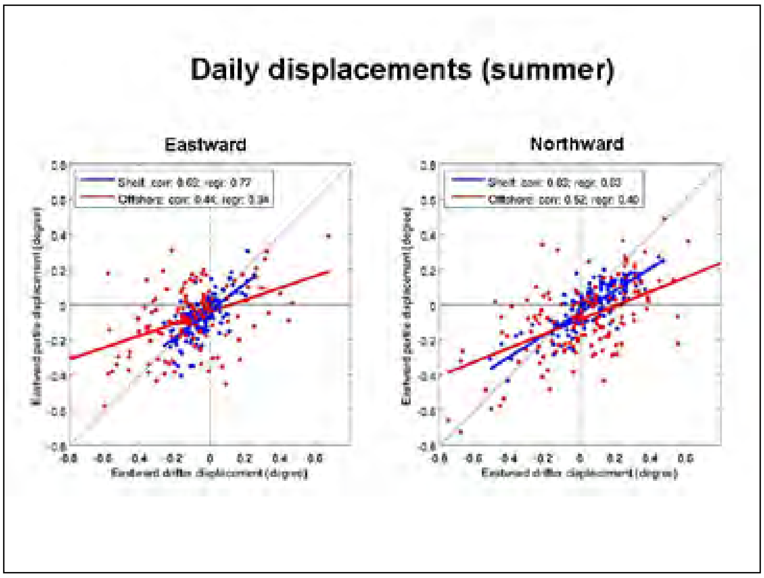


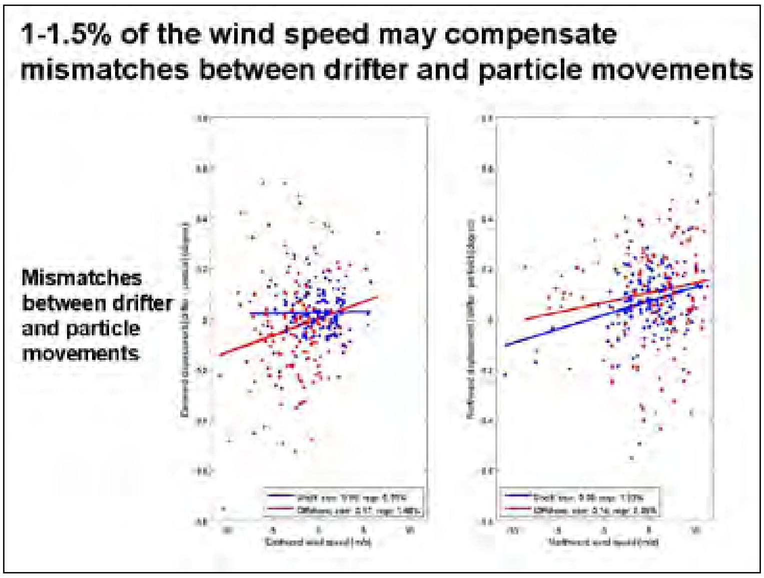

Surface winds from satellite (Scatterometer)
Significant wave height and direction (NCEP WW3)
Dec. - Feb.
June - Aug.
Western Australia
Wind
Wave
Latitude
Longitude


Bluelink model of ocean surface currents
Oct–Dec
Apr–Jun
0.3 m/s
N.W.C
Shark Bay
Geraldton
Perth
Cape Leeuwin

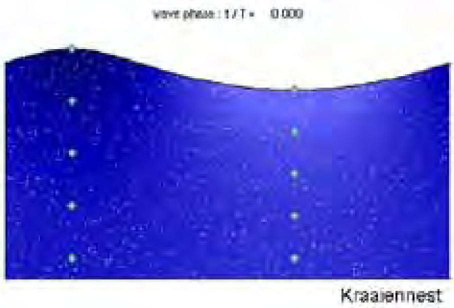

Ocean current at ~100 m in May 2007 –
Bluelink has captured mesoscale eddies in the Leeuwin Current system
Southern Surveyor Observation
Bluelink model


Surface drifters released during the rock lobster spawning season (2010-2011)
Google


Daily displacements (summer)
Eastward
Northward


1-1.5% of the wind speed may compensate mismatches between drifter and particle movements
Mismatches between drifter and particle movements

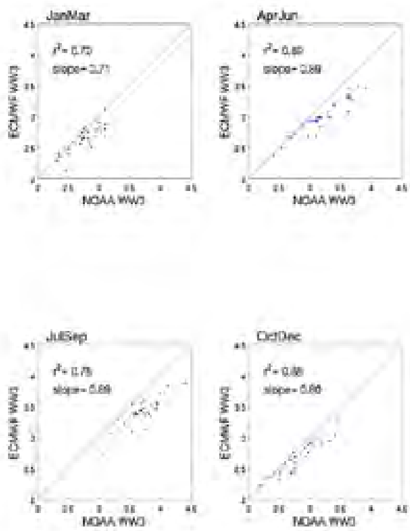
Stokes drift due to swells – not captured in Bluelink



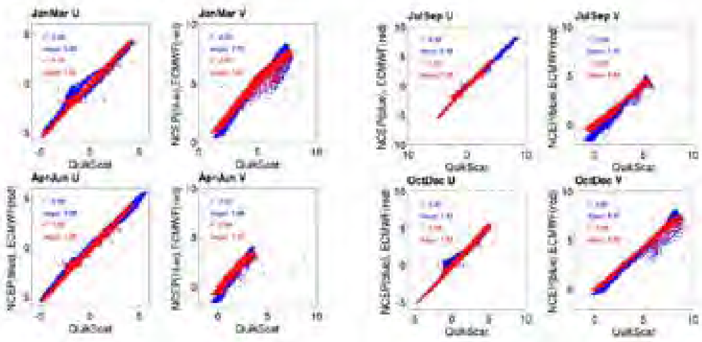
Summary: oceanography model components

- Bluelink model (10 km horizontal resolution, 10 m vertical resolution, daily output)
- Wind driven current (0-20 m uniform)
  - 2009 model – Scatterometer winds
    - 1% of wind speed offshore of 200m isobath
    - 3% of wind speed inshore of 200m isobath (Capes Current)
  - 2011 model – ECMWF winds
    - 1.5% of wind speed
- Swell driven Stokes drift (0-20m exponential profile)
  - 2009 model – NCEP
  - 2011 model – ECMWF

ECMWF wave model has weaker wave amplitudes compared to NCEP model



ECMWF winds compare well with satellite observations (QuikScat), except having lower peak northward winds in summer



Larval behaviour module

- Hatching
  - 40-100 m depth range
  - "Super-larvae" – post-model analysis
- Larval stages – Categories
  - Group different stages into categories
- Growth
  - Temperature dependency
- Mortality
  - Shelf mortality
  - Age mortality
  - Temperature dependent
  - Natural mortality (post-model analysis)
- Metamorphosis and settlement

Hatching locations

2009 model: 40, 60, 80 m, 10 per site

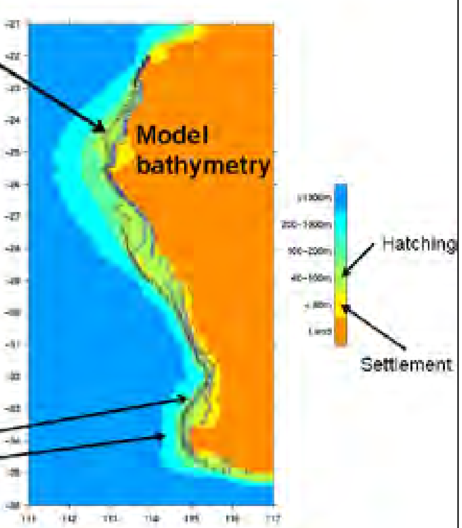
2011 model: 50, 70, 90 m, inshore Abrolhos, 1 per site (boundary reflection)

Shelf mortality

2009 model: 15 days
2011 model: 60 days

Metamorphosis

2009 model: 200 m
2011 model: 1000 m

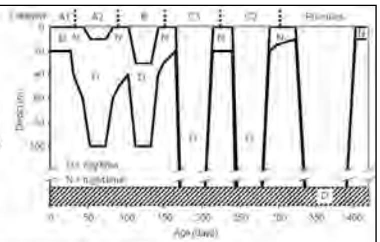


New category used in both 2009 and 2011 models:

Category A1 – Stage I phyllosoma
Category A2 - Stage II+III phyllosoma
Category B – Stages IV, V+ VI phyllosoma
Category C – Stages VII, VIII + IX phyllosoma (max: 420d for 2009 model)
Category D1 – Swimming Puerulus (21d for 2009 model; 60d for 2011)
Category D2 – Settling puerulus (< 40 m waters)

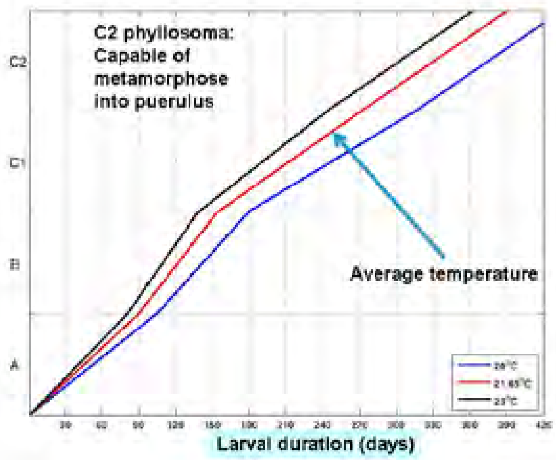
	Category A		Category B	Category C	
	A1	A2		C1	C2
Larval duration (days)	30	60	60	120	<150
Average temperature (°C)	21.5		22.4	21.4	

Diurnal migration of phyllosoma and puerulus



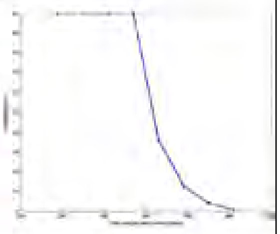
	Category A		Category B	Category C	
	A1	A2		C1	C2
Day time (9:00-17:00)	0-20m	10-100m	30-100m	Below Leeuwin Current	
Transition time (17:00-21:00 and 05:00-9:00)	0-20m	0-100m	0-100m	Surface to below Leeuwin Current	
Night time (21:00-05:00)	0-20m	0-60m	0-40m	0-20m	

Temperature dependent growth rates



Mortality rates

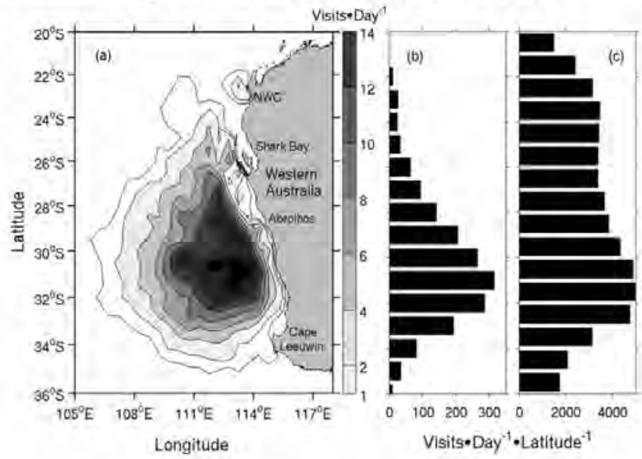
- Shelf mortality
  - 2009 model: A (15 days); B, C (2 days)
  - 2011 model: A (60 days); B, C (10 days)
- Age mortality
  - 2009 model: 420 days
  - 2011 model: 570 days
- Natural mortality (post-model analysis)
  - apply to full larval duration
  - apply to Category A duration
- Weak temperature dependent mortality
  - 7 days (< 15C)
  - 14 days (< 16C)

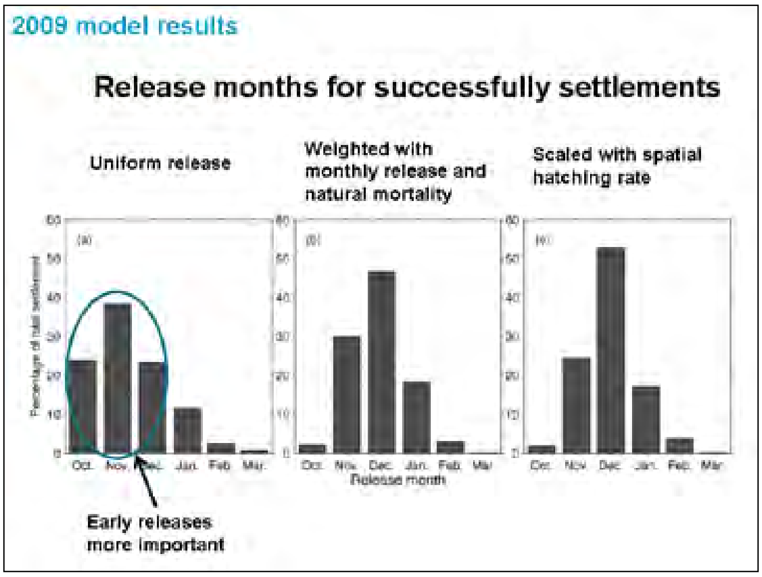


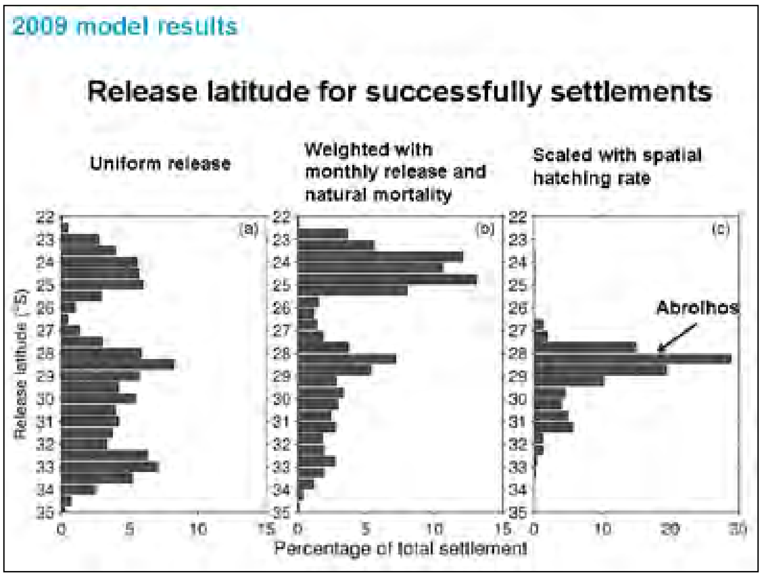
Metamorphosis and settlement of Puerulus

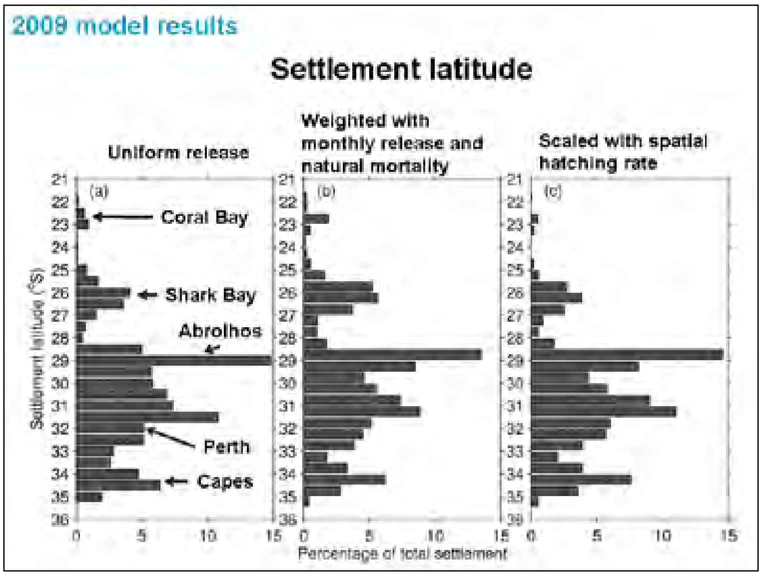
- Puerulus survive for 21 days (60 days in 2011 model) after metamorphosis
- Puerulus swims at 15 cm/s toward the coast at night time
- Metamorphosis trigger: C2 phyllosoma crossing 200m depth contour (1000 m contour in 2011 model)
- Successful settlement occurs when puerulus cross 40m contour

Spatial distribution of June-July phyllosoma contributing to the successful settlements



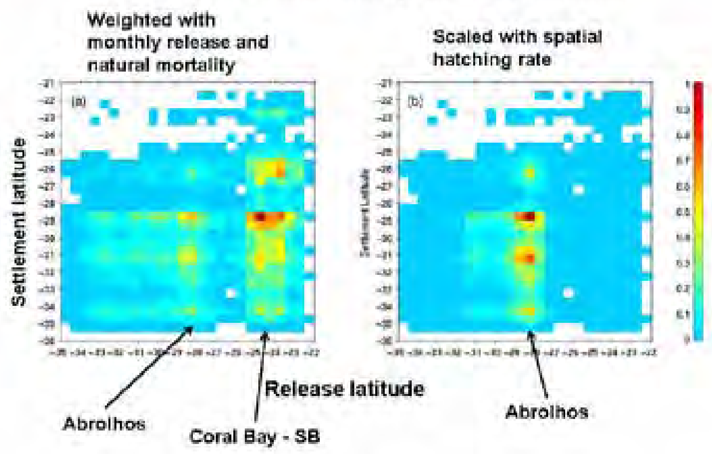

2009 model results
Release months for successfully settlements
Uniform release
Weighted with monthly release and natural mortality
Scaled with spatial hatching rate
Release month
Early releases more important


2009 model results
Release latitude for successfully settlements
Uniform release
Weighted with monthly release and natural mortality
Scaled with spatial hatching rate
Release latitude (°S)
Abrolhos
Percentage of total settlement


2009 model results
Settlement latitude
Uniform release
Weighted with monthly release and natural mortality
Scaled with spatial hatching rate
Settlement latitude (°S)
Coral Bay
Shark Bay
Abrolhos
Perth
Capes
Percentage of total settlement

2009 model results

Source-sink relationship of settlements

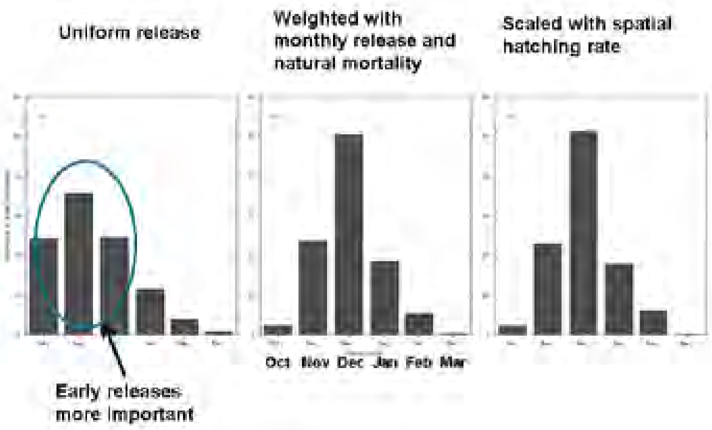


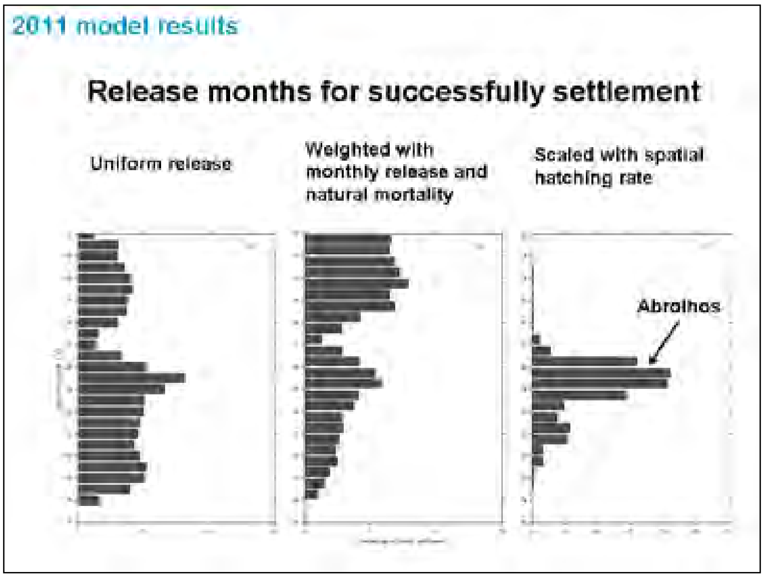
2009 model summary

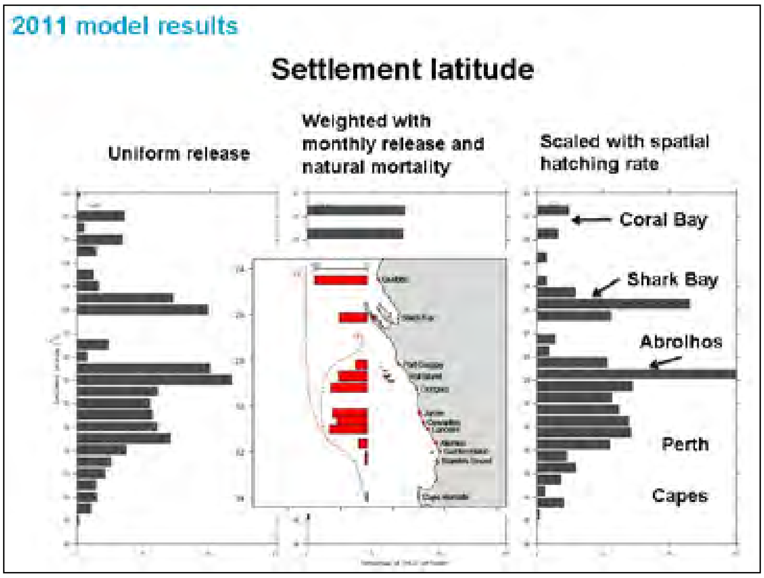
- Confirmed the roles of ocean circulation in the rock lobster recruitment process – Leeuwin Current, wave, wind
- Phyllosoma hatched early in the breeding season are more likely to contribute to puerulus settlement due to longer exposure to warm summer temperature
  - Grow faster, which allows them to be transported towards the coast by the strong onshore flows in winter
  - Reduce natural mortality
- Source-sink relationship indicates that the population was well mixed off the coast
  - Higher likelihood of settlement success from hatching sites in the north, mostly due to higher surface temperature
  - Areas near the Abrolhos Islands are the most significant hatching grounds to the success of settlement

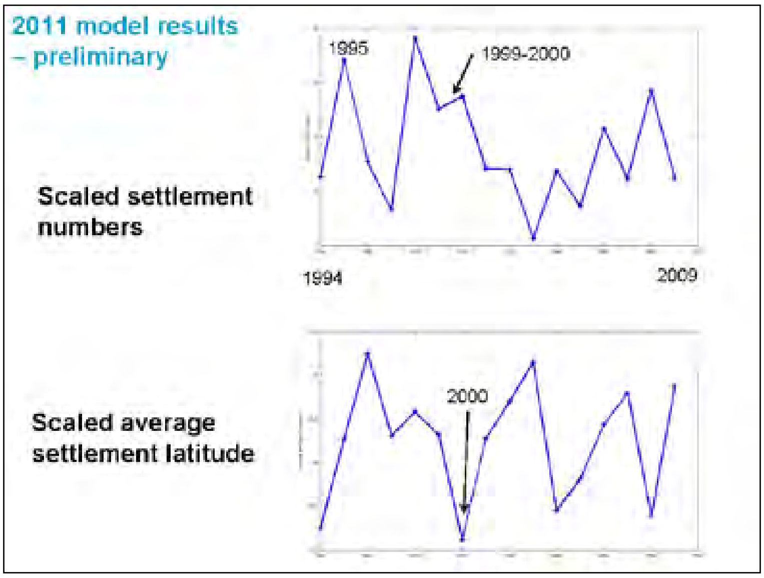
2011 model results

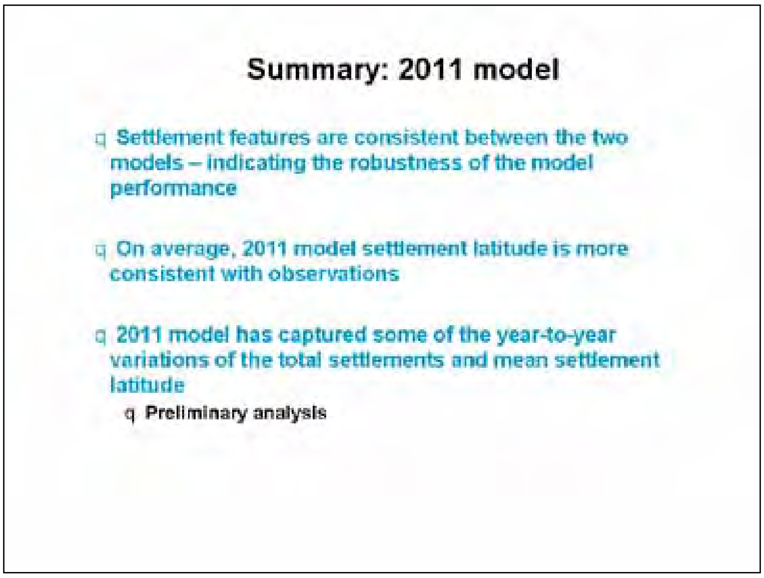
Release months for successfully settlement




2011 model results
Release months for successfully settlement
Uniform release
Weighted with monthly release and natural mortality
Scaled with spatial hatching rate
Abrolhos


2011 model results
Settlement latitude
Uniform release
Weighted with monthly release and natural mortality
Scaled with spatial hatching rate
Coral Bay
Shark Bay
Abrolhos
Perth
Capes


2011 model results – preliminary
Scaled settlement numbers
1995
1999-2000
1994
2009
Scaled average settlement latitude
2000


Summary: 2011 model
q Settlement features are consistent between the two models – indicating the robustness of the model performance
q On average, 2011 model settlement latitude is more consistent with observations
q 2011 model has captured some of the year-to-year variations of the total settlements and mean settlement latitude
q Preliminary analysis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National Research
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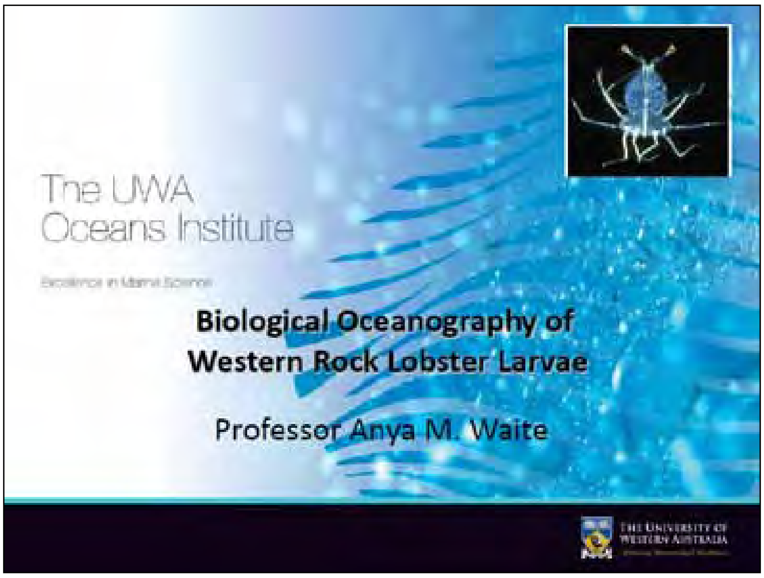
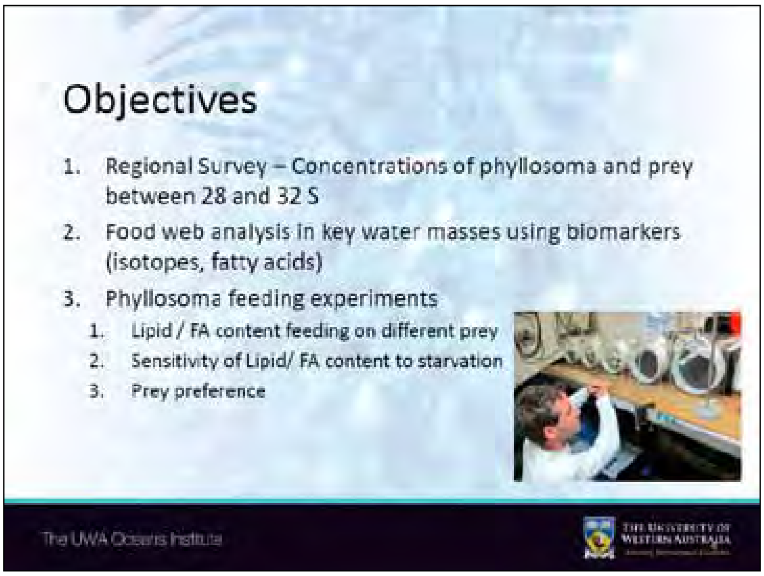
Appendix 3 Presentation 3 – Biological oceanography

Biological oceanography of western rock lobster larvae




Dr. Christin Säwström
• PhD in food web dynamics and carbon flow, Lund University, Sweden
• Post-doctoral Fellowship Umeå University and Griffiths Univ. – microbial dyamics, cyanobacteria
• Antarctic field work
The UWA Oceans Institute
The University of Western Australia


Objectives
1. Regional Survey – Concentrations of phyllosoma and prey between 28 and 32 S
2. Food web analysis in key water masses using biomarkers (isotopes, fatty acids)
3. Phyllosoma feeding experiments
1. Lipid / FA content feeding on different prey
2. Sensitivity of Lipid/ FA content to starvation
3. Prey preference
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What do Western Rock Lobster phyllosoma eat?
• Scarce data suggest phyllosoma are "opportunistic carnivores" (Suzuki et al., 2007)
• Lipid increases during larval development; mesoscale eddies important (Jeffs et al., 2004)
• Phyllosoma nutritional status important for metamorphosis – this depends on ocean food sources (when is the LC most productive?)
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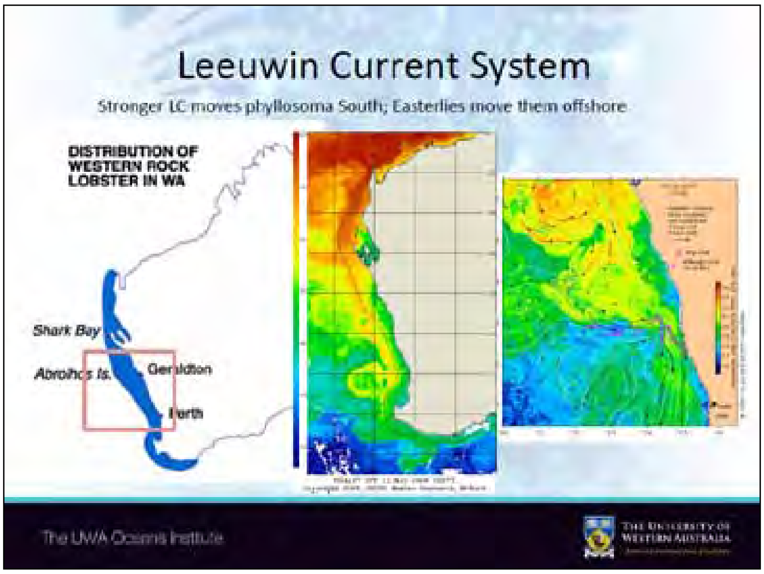
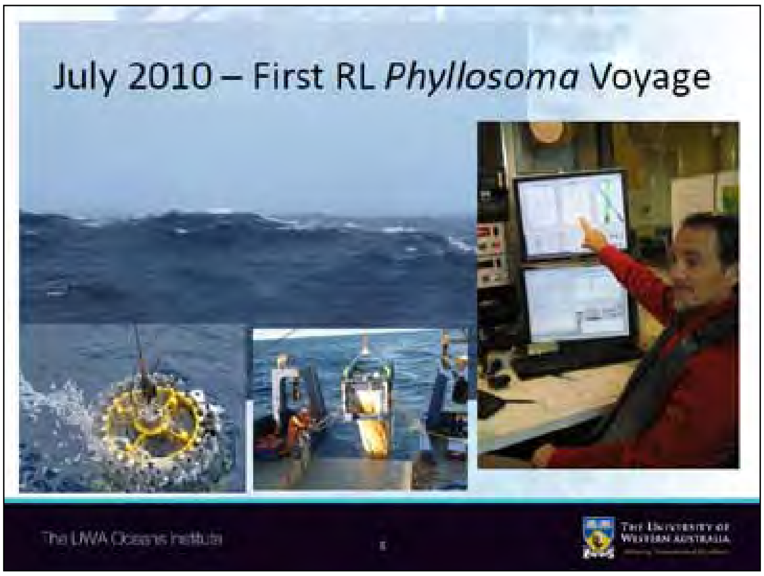
Ship-based research on the Australian National
Marine Facility, the Southern Surveyor
RV Southern Surveyor off Rottnest May 06


Leeuwin Current System
Stronger LC moves phyllosoma South; Easterlies move them offshore
DISTRIBUTION OF WESTERN ROCK LOBSTER IN WA
Shark Bay
Abrolhos Is.
Geraldton
Perth
The UWA Oceans Institute
The University of Western Australia


July 2010 – First RL *Phyllosoma* Voyage
The UWA Oceans Institute
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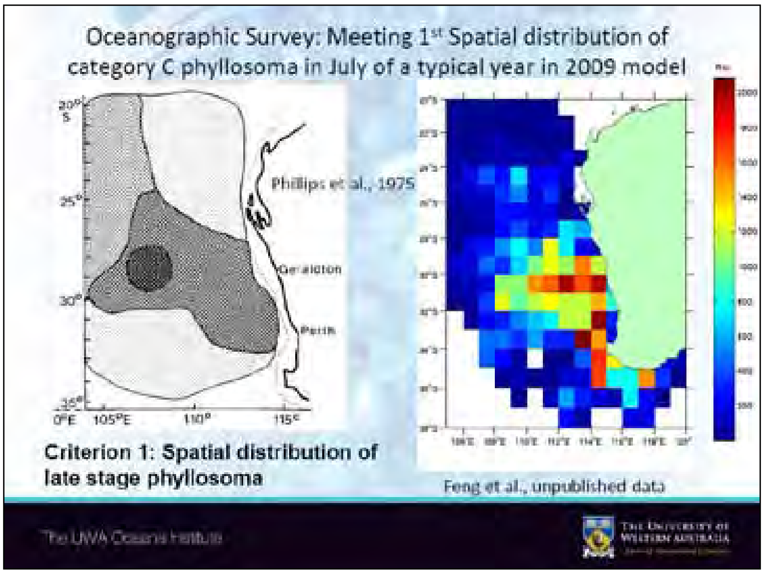
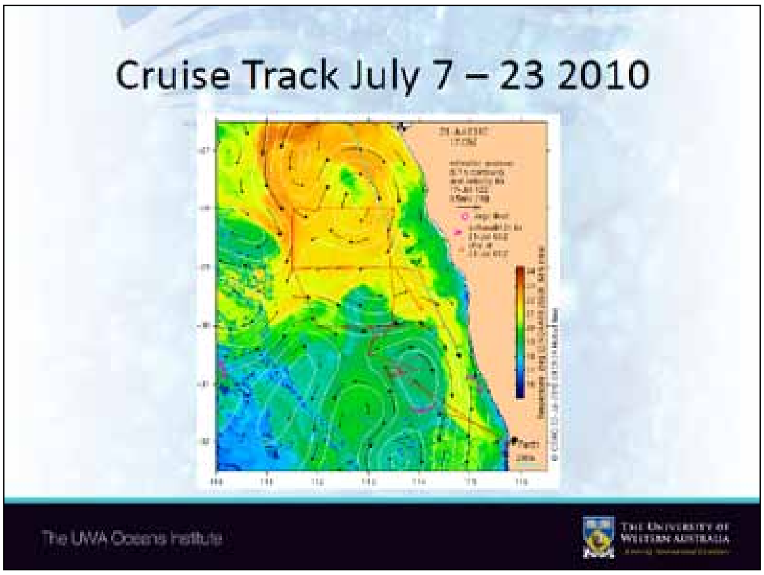
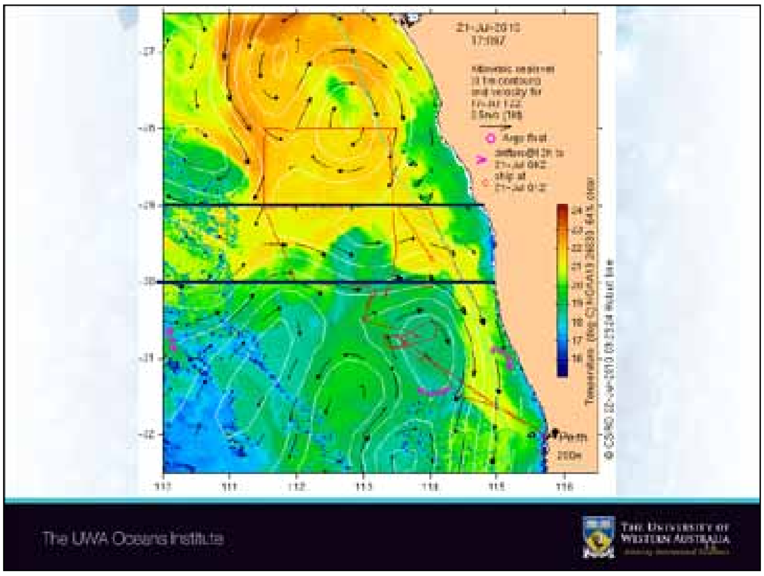


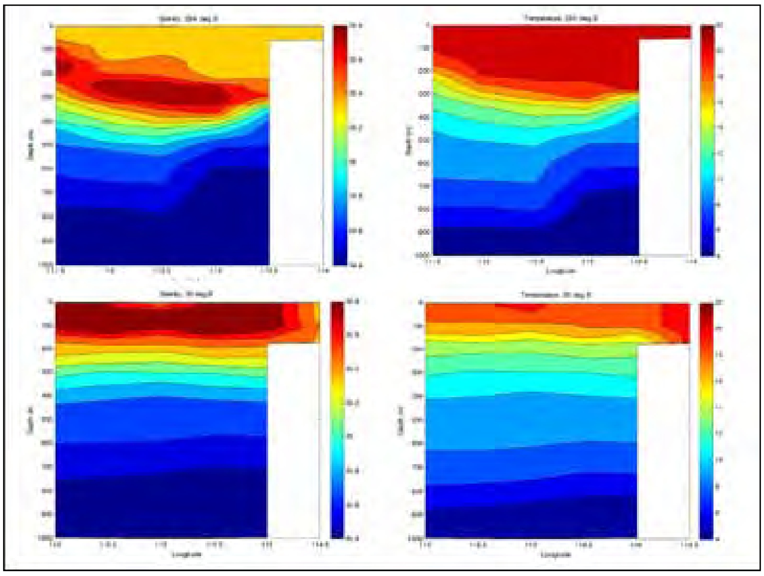
Oceanographic Survey: Meeting 1st Spatial distribution of category C phyllosoma in July of a typical year in 2009 model
Phillips et al., 1975
Geraldton
Perth
Criterion 1: Spatial distribution of late stage phyllosoma
Feng et al., unpublished data
The UWA Oceans Institute
The University of Western Australia

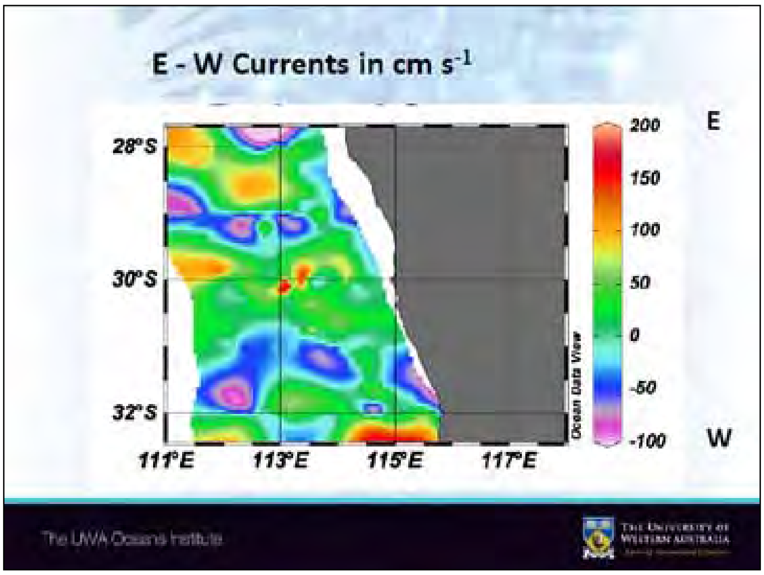


Cruise Track July 7 – 23 2010
Perth
The UWA Oceans Institute
The University of Western Australia



21-Jul-2010
Argo float
Perth
The UWA Oceans Institute
The University of Western Australia




E - W Currents in cm s^{-1}
28°S
30°S
32°S
111°E
113°E
115°E
117°E
Ocean Data View
200
150
100
50
0
-50
-100
E
W
The UWA Oceans Institute
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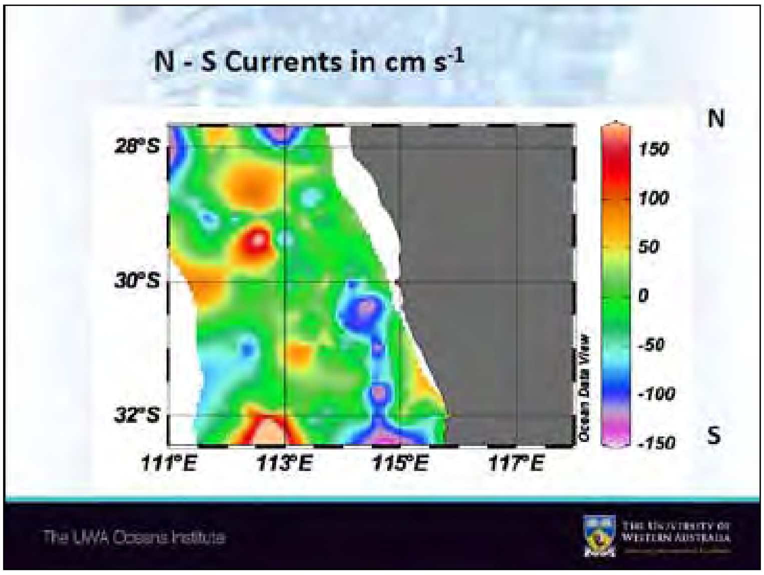
N - S Currents in cm s^{-1}
28°S
30°S
32°S
111°E
113°E
115°E
117°E
Ocean Data View
150
100
50
0
-50
-100
-150
N
S
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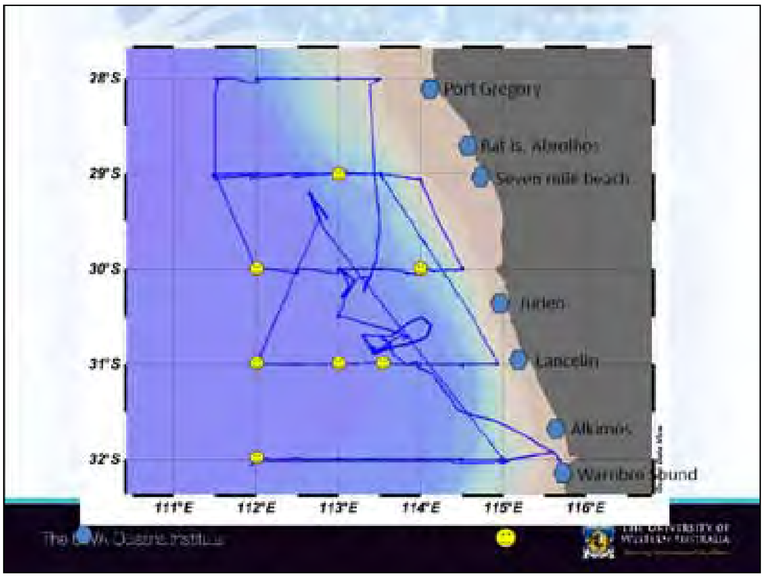
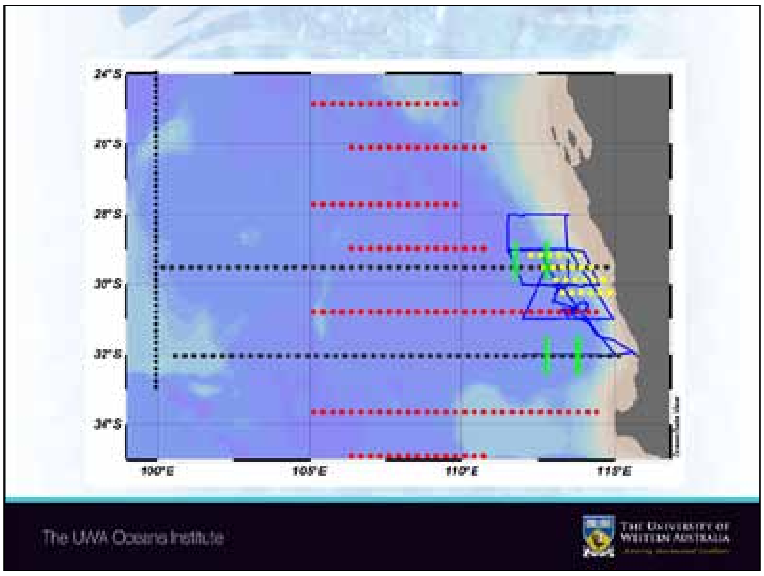

Port Gregory
Rat Is. Abrolhos
Seven mile beach
Jurien
Lancelin
Alkimos
Warnbro Sound
28°S
29°S
30°S
31°S
32°S
111°E
112°E
113°E
114°E
115°E
116°E
The University of Western Australia


24°S
26°S
28°S
30°S
32°S
34°S
100°E
105°E
110°E
115°E
The UWA Oceans Institute
The University of Western Australia

*~35 EZ Net + ~15 Neuston Nets

Date	#Hauls	Phyllosoma haul $^{-1}$	Phyllosoma 1000m^{-3}	Phyllosoma 1000m^{-2}	Source
July 2010	52*	8	0-5	0-257	Waite *et al* (unpublished)
June-July 1976	-	-	(0?) 5-80	-	Phillips *et al* (1979)
May & Sept 1976	-	-	(0?)5-100	-	Phillips *et al* (1979)
July & Nov 1975	-	-	-	(0?)12-116	Phillips *et al* (1978)
July & Nov 1974, 1975, 1976	472	8			Phillips *et al* (1978)
1962-1963	-	2-6	-	-	Chittleborough & Thomas (1969)

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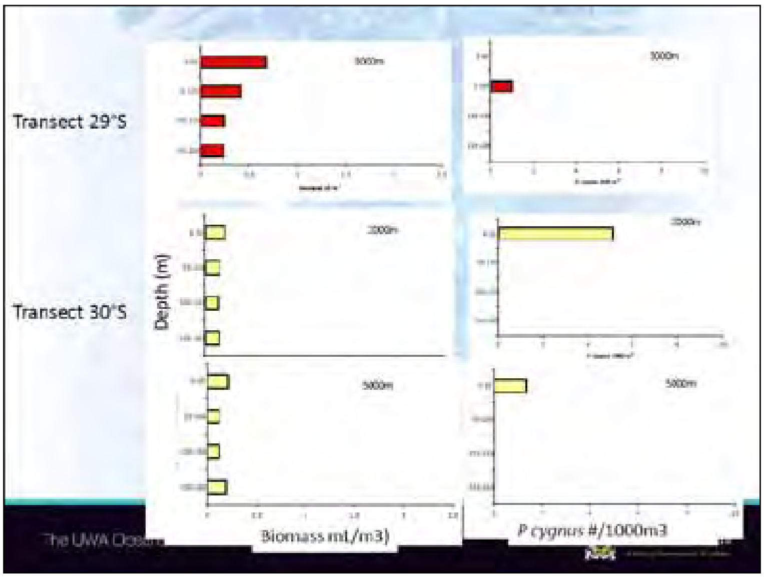

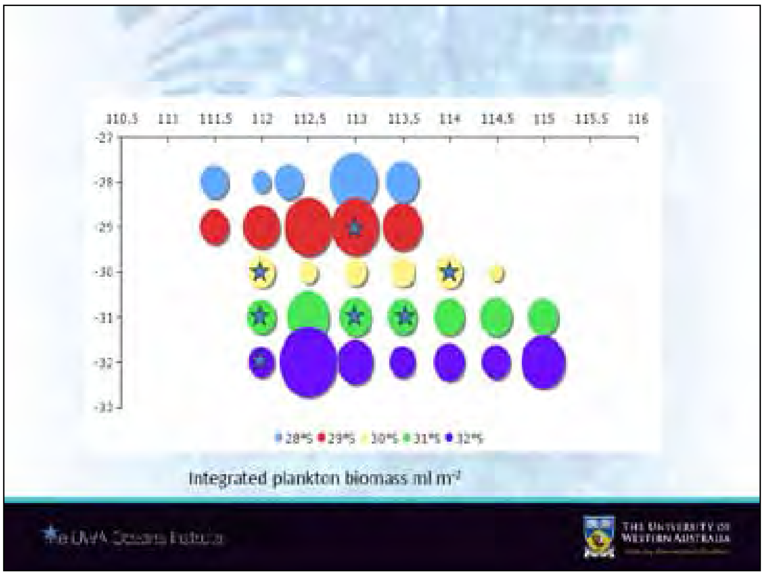

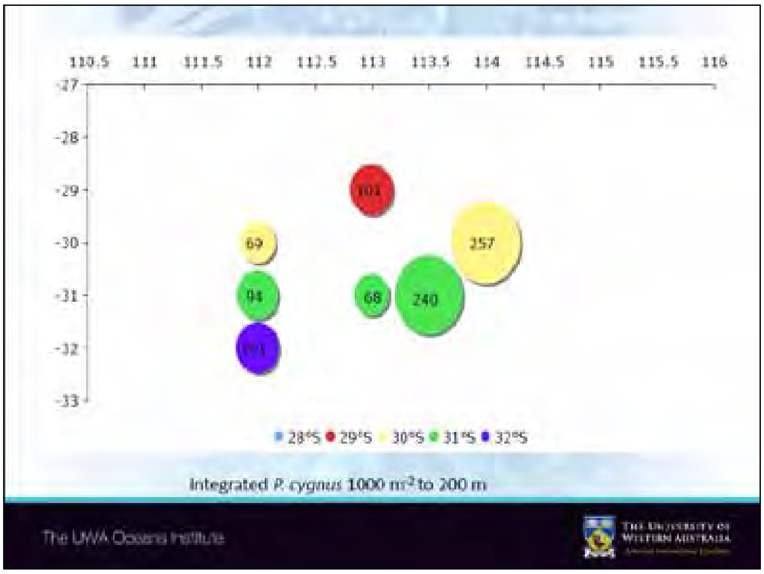

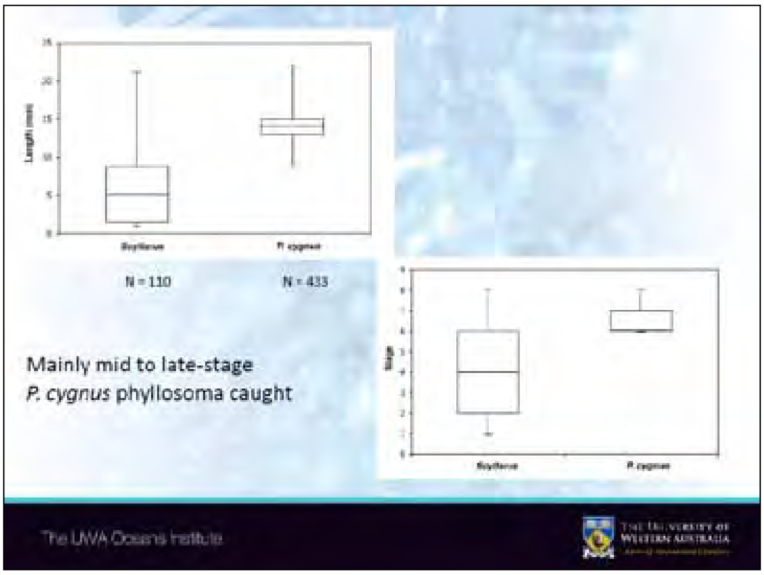

Oceanographic Survey - Status

- Oceanography – preliminary analyis underway – more modeling work with Feng in 2011
- EZNet samples – 100 % counted for phyllosoma and potential prey (salps, copepods, krill, chaetognaths)
  - Similar concentration to Phillips' work
- Neuston Net Samples – counted
- Will interact with modelling to define key oceanographic processes such as the Abrolhos front

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Feeding experiments
☐Feeding preference studies with range of prey items
☐Fatty acid/lipid analyses of dietary items and body composition
☐Isotope analyses of dietary items and body composition
☐Genetic analyses of dietary items and gut contents
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Phyllosoma for feeding experiments
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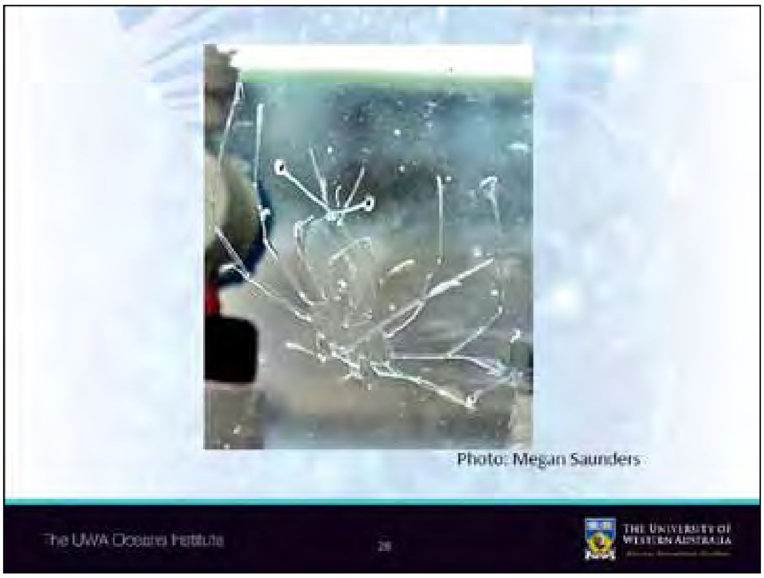
Photo: Megan Saunders
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28
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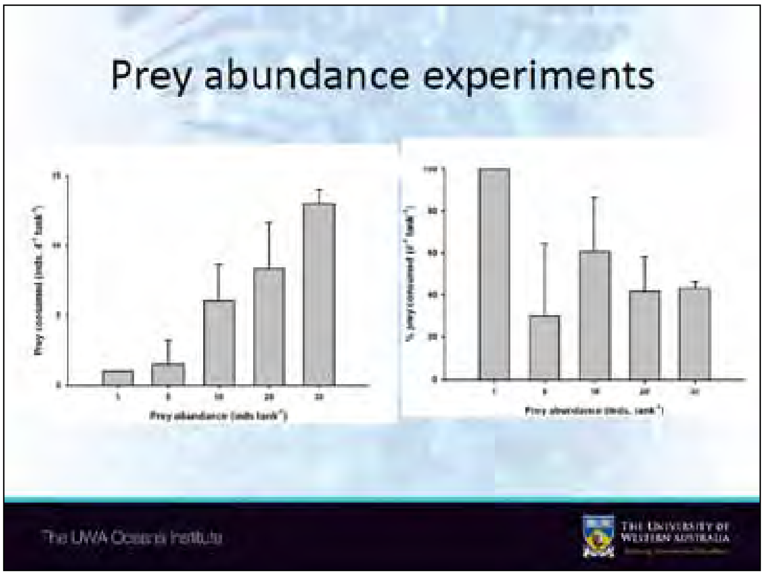
Prey abundance experiments
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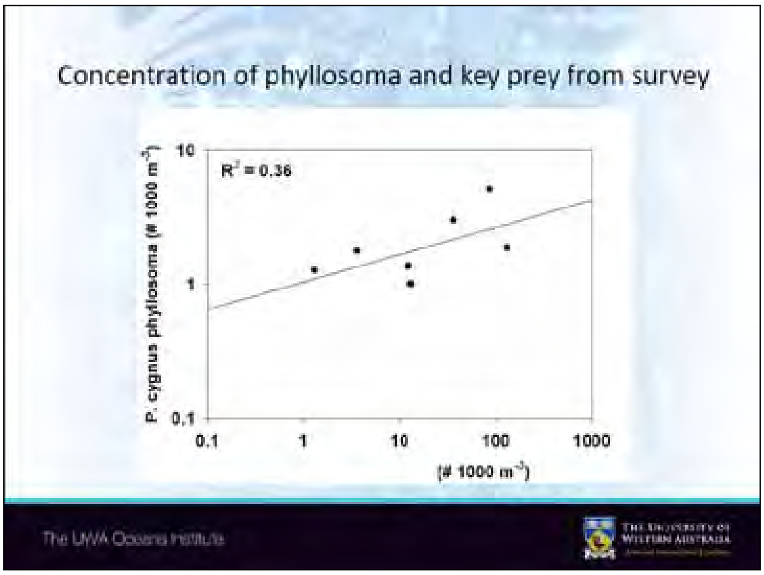
Concentration of phyllosoma and key prey from survey
$R^2 = 0.36$
P. cygnus phyllosoma (# 1000 m^{-3})
10
1
0.1
0.1
1
10
100
1000
(# 1000 m^{-3})
The UWA Oceans Institute
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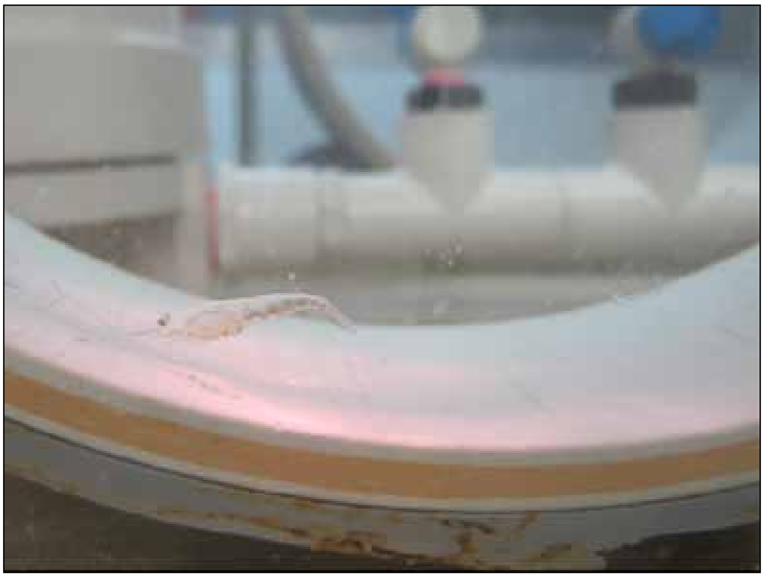


Feeding Experiment - Status
• Fatty acid and lipid analysis underway
• Preferred prey identified
• P. cygnus as "fussy feeder"
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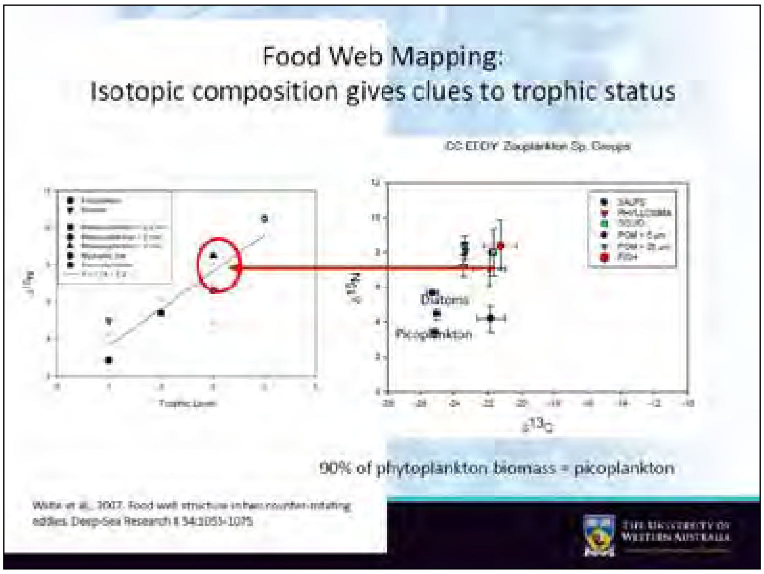
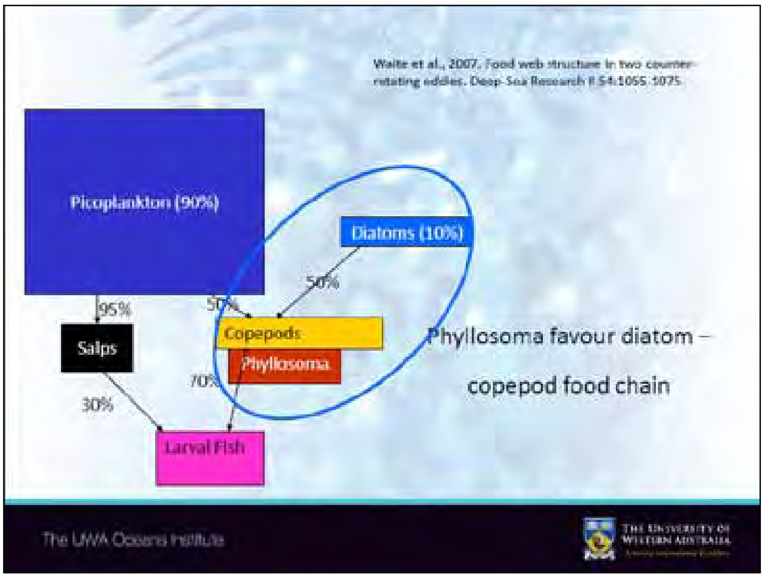


Food Web Mapping:
Isotopic composition gives clues to trophic status
Trophic Level
Diatoms
Picoplankton
90% of phytoplankton biomass = picoplankton
Waite et al., 2007. Food web structure in two counter-rotating eddies. Deep-Sea Research II 54:1055-1075

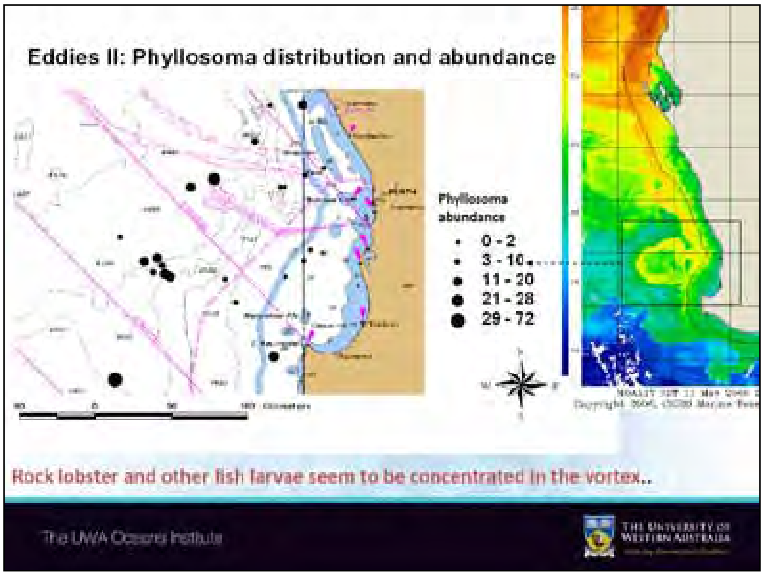


Waite et al., 2007. Food web structure in two counter-rotating eddies. Deep-Sea Research II 54:1055-1075
Picoplankton (90%)
Diatoms (10%)
50%
95%
50%
Salps
Copepods
Phyllosoma
70%
30%
Larval Fish
Phyllosoma favour diatom – copepod food chain
The UWA Oceans Institute

Food Web Analysis - Status
• Samples all taken and stored
• Chemical analysis complete for phytoplankton
• Zooplankton underway
The UWA Oceans Institute


Southern Surveyor Voyage 2011
• Successful ship time proposal Aug / Sept 2011
• FRDC proposal in to support this research voyage
• Targetting later stage (IX) phyllosoma
The UWA Oceans Institute
The University of Western Australia


Acknowledgements
• Australian Marine National Facility
• University of Western Australia, Murdoch, CSIRO
• Department of Fisheries WA
• Fisheries Research and Development Corporation
• Lobster Harvest (Pty Ltd)
The UWA Oceans Institute


Eddies II: Phyllosoma distribution and abundance
Phyllosoma abundance
0 - 2
3 - 10
11 - 20
21 - 28
29 - 72
Rock lobster and other fish larvae seem to be concentrated in the vortex..
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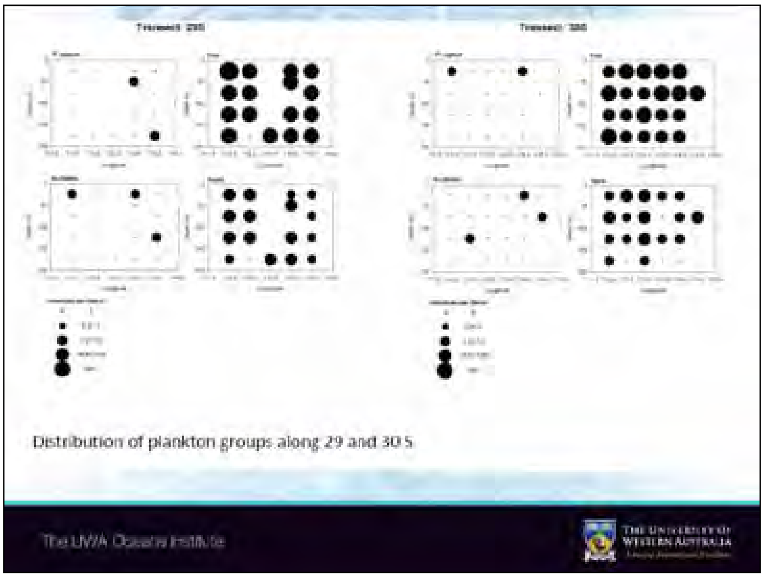
Transect 29S
Transect 30S
Distribution of plankton groups along 29 and 30 S
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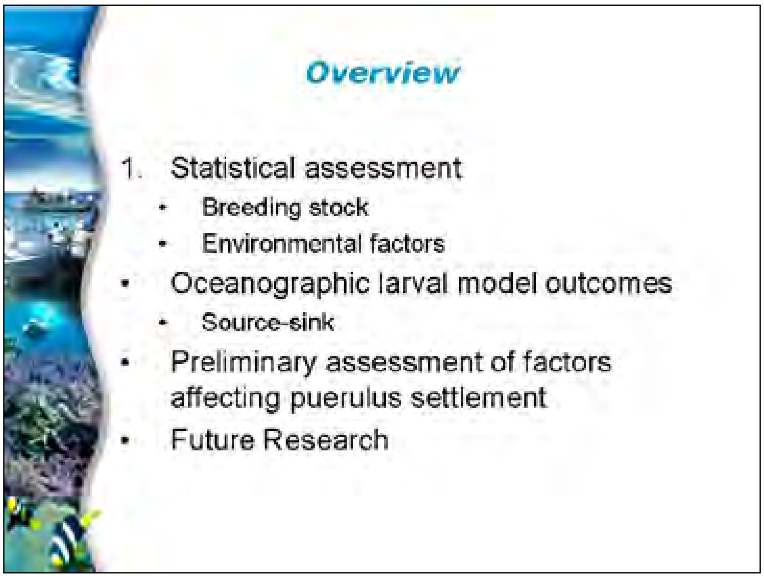
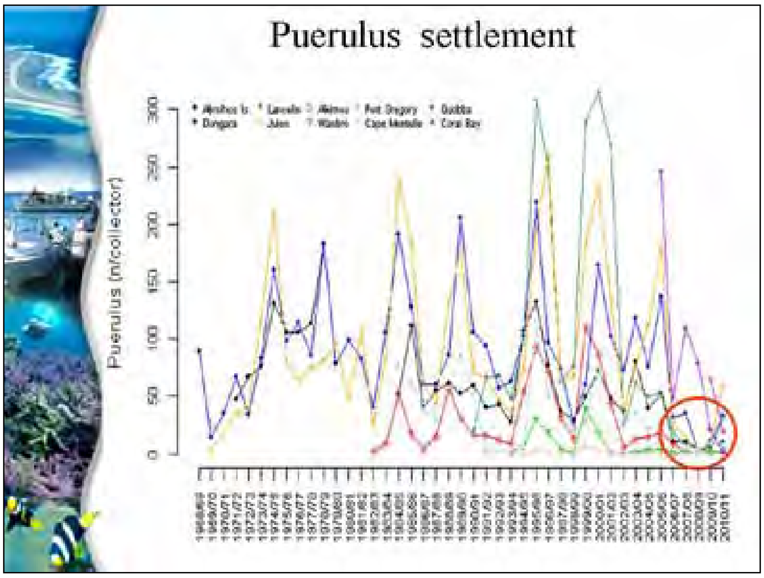
Appendix 4 Presentation 4 – The cause of the record low puerulus settlement

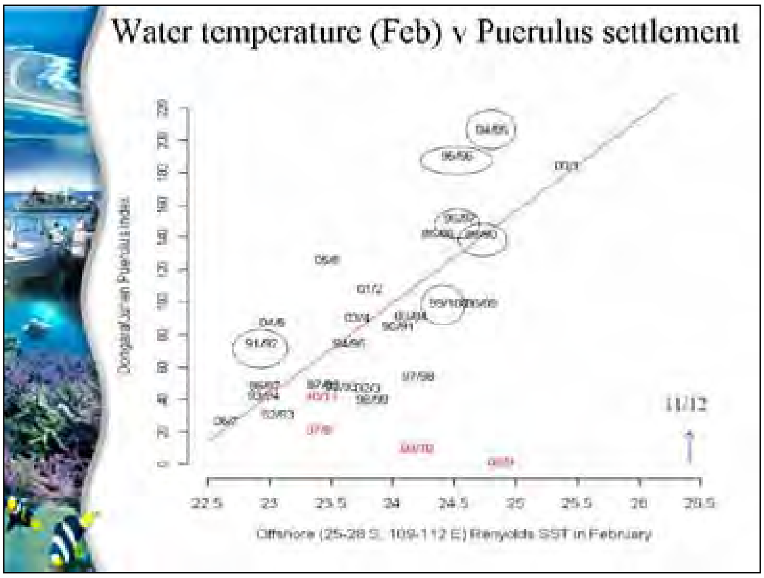
Preliminary assessment of the cause of the record low puerulus settlement in the West Australian Rock Lobster Fishery.

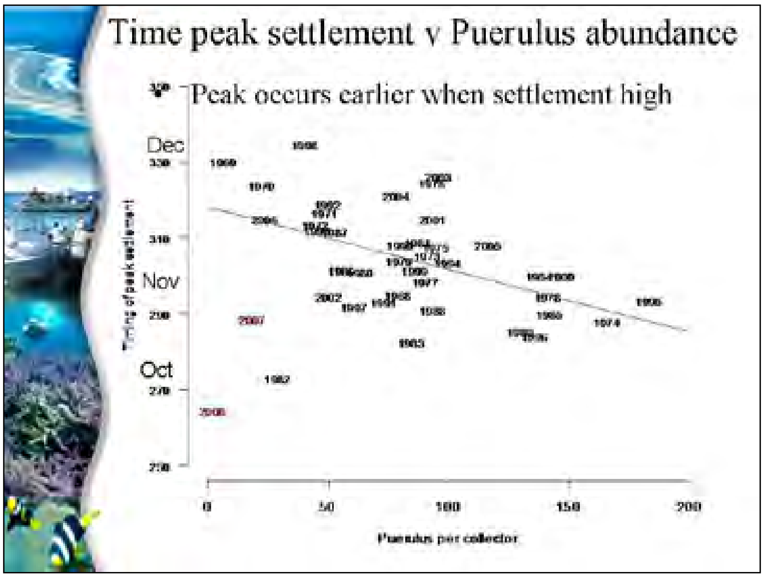


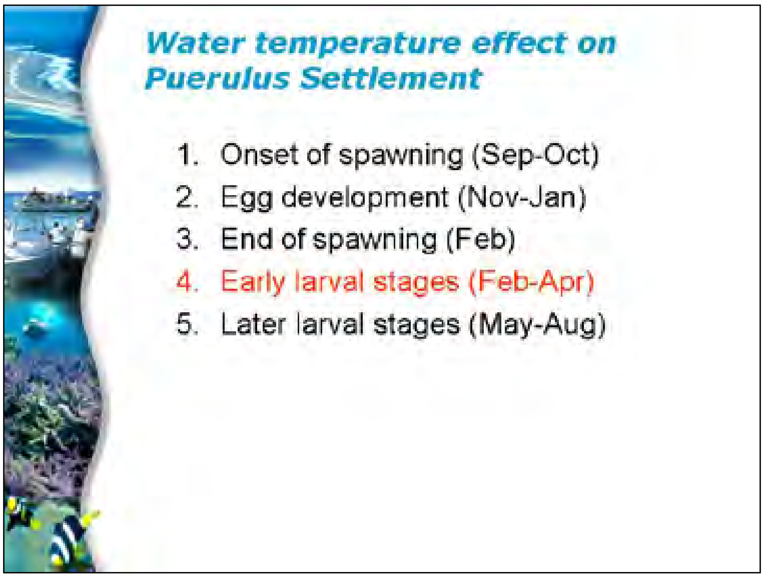


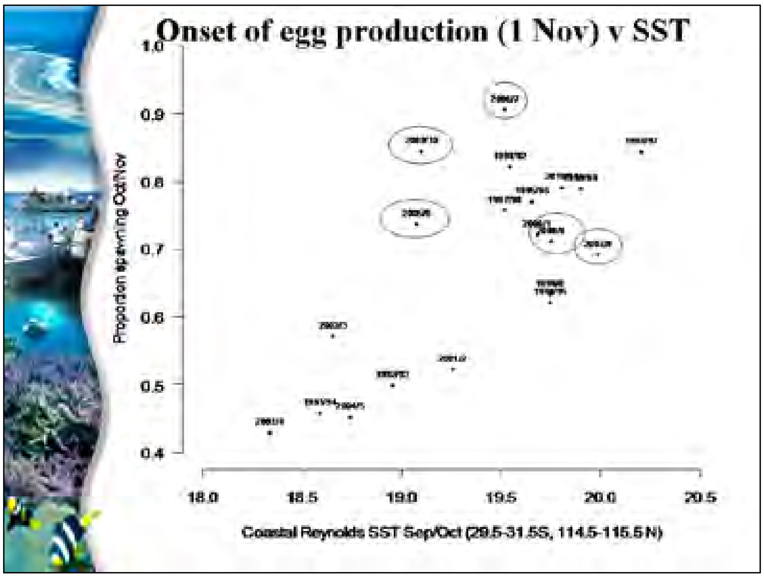
Environmental effects on puerulus

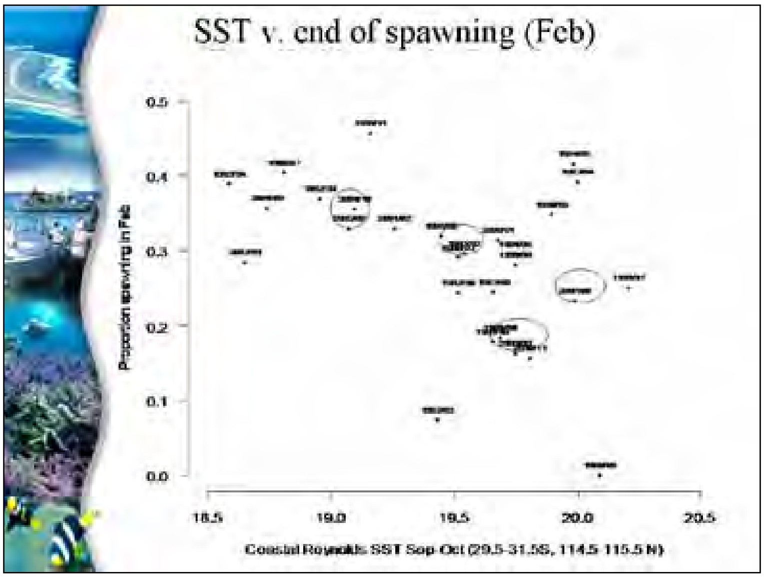
1. SOI/Leeuwin Current (Fremantle sea level- FSL)
2. FSL/SST (Feb-Apr) - early larval phase (survival)
3. Storm (rain Jul-Nov) – late larval phase (advection EW)
4. Leeuwin Current (June-Dec) – late larval phase (advection North-South)
5. SST prior to spawning
6. Easterly winds moving early stage larvae offshore
7. Westerly winds at time of settlement
8. Current strength and direction
9. **Wave strength and direction**
10. Productivity (ChlA)
11. Eddy structure (correlated to FSL)
12. Indian Ocean Dipole

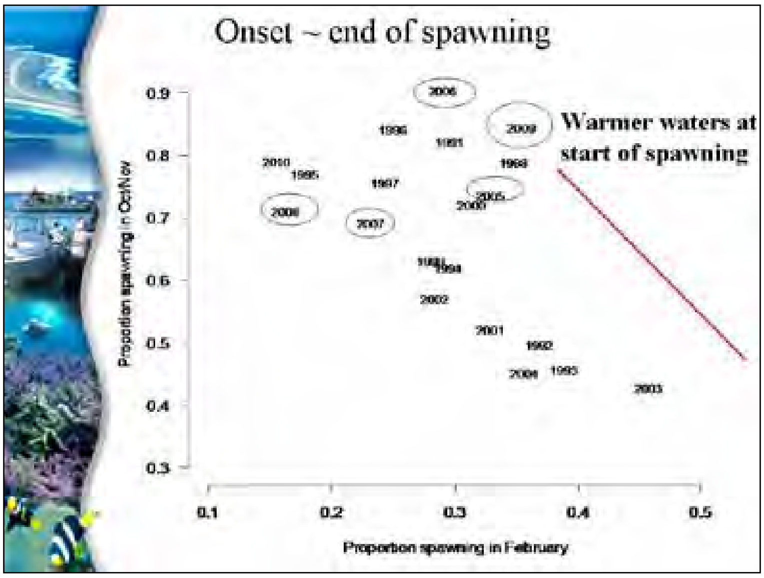


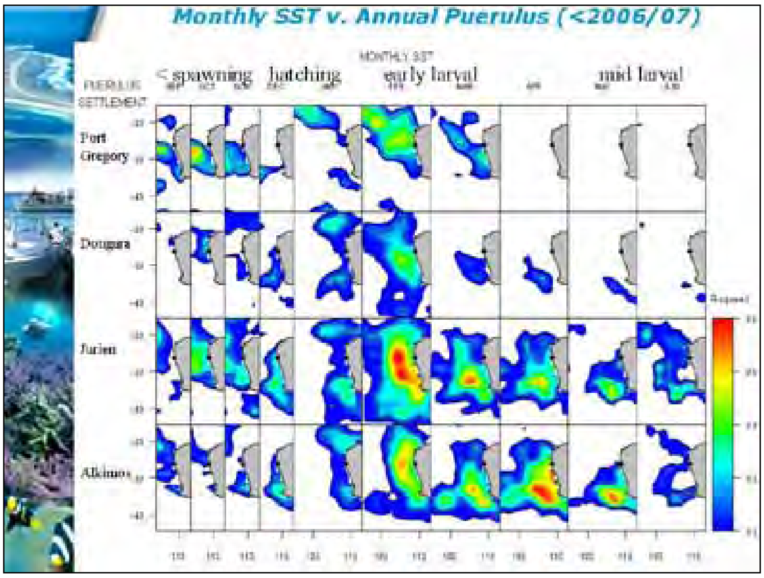

Time peak settlement v Puerulus abundance
Peak occurs earlier when settlement high
Dec
Nov
Oct
Timing of peak settlement
Puerulus per collector
0
50
100
150
200


Water temperature effect on Puerulus Settlement
1. Onset of spawning (Sep-Oct)
2. Egg development (Nov-Jan)
3. End of spawning (Feb)
4. Early larval stages (Feb-Apr)
5. Later larval stages (May-Aug)


Onset of egg production (1 Nov) v SST
Proportion spawning Oct/Nov
1.0
0.9
0.8
0.7
0.6
0.5
0.4
18.0
18.5
19.0
19.5
20.0
20.5
Coastal Reynolds SST Sep/Oct (29.5-31.5S, 114.5-115.5N)


SST v. end of spawning (Feb)
Proportion spawning in Feb
Coastal Reynolds SST Sep-Oct (29.5-31.5S, 114.5-115.5 N)

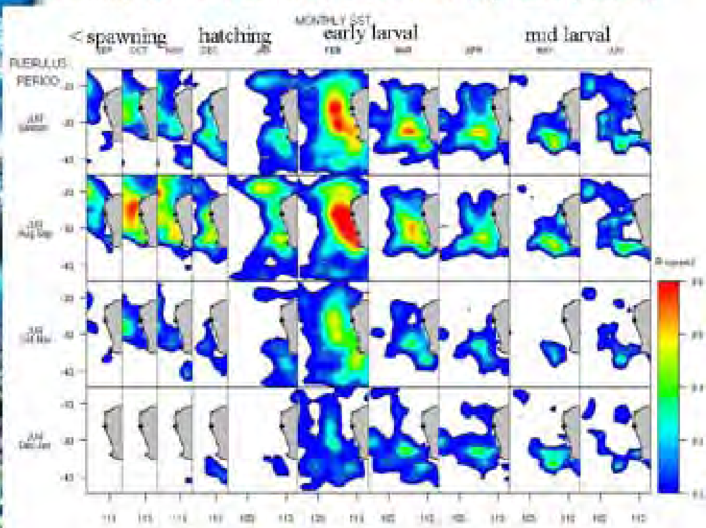

Onset ~ end of spawning
Warmer waters at start of spawning
Proportion spawning in Oct/Nov
Proportion spawning in February


Monthly SST v. Annual Puerulus (<2006/07)
PUERULUS SETTLEMENT
MONTHLY SST
< spawning
hatching
early larval
mid larval
Port Gregory
Dongara
Jurien
Alkimos

Monthly SST v Annual Puerulus(<06/07)

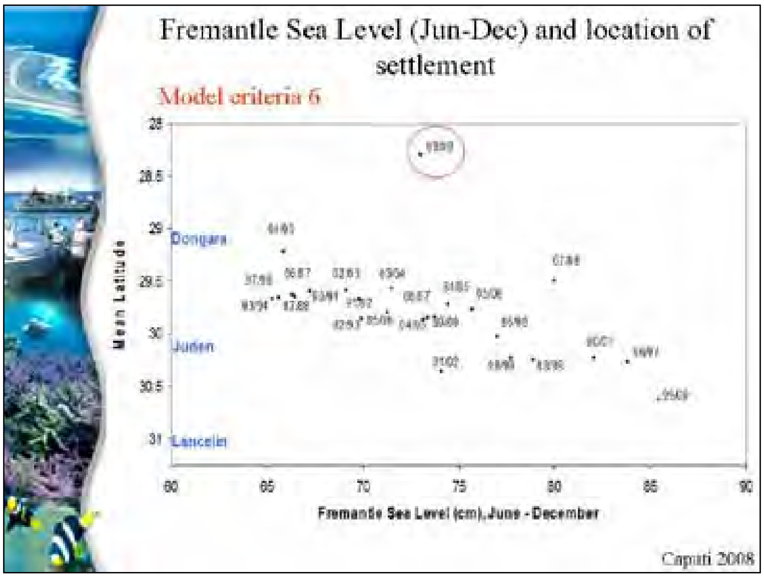
- SST (Feb-northern areas)
  - effects all puerulus locations
- SST (Mar-Apr: southern areas)
  - effects southern puerulus locations
- SST Sept-Oct(t-1)
  - Weaker corr with puerulus
- SST Dec-Jan not significant
- SST at 2 locations (Shark Bay, Mid-west)
  - highest correlations with puerulus
  - Eddies with high larval abundance?
- SST not explain low settlement 07/08-09/10

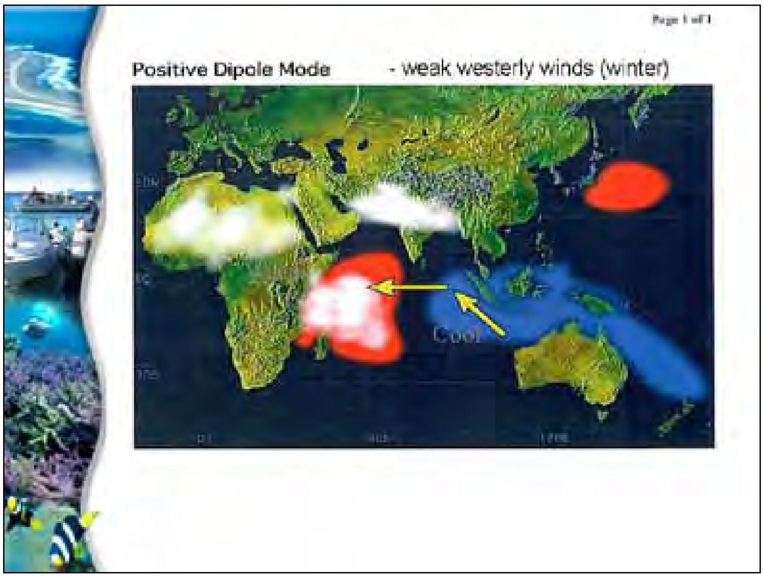
Monthly SST v. Puerulus <2006/07 (by time period)

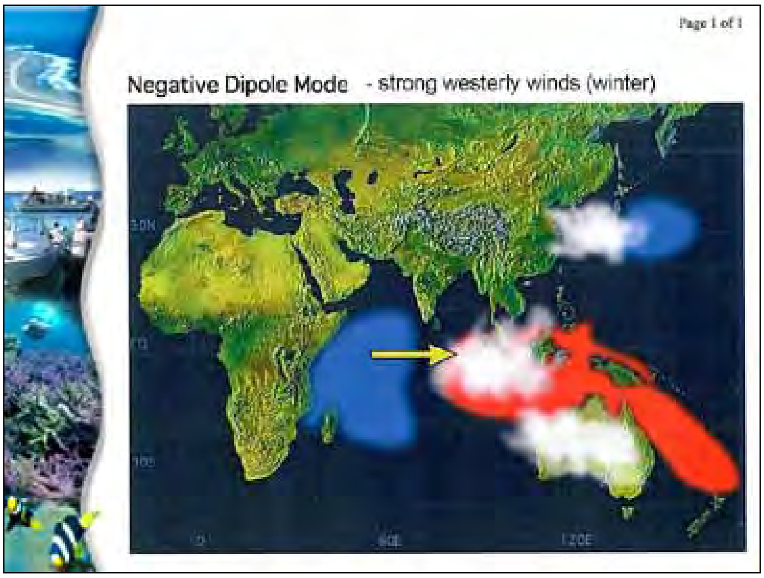


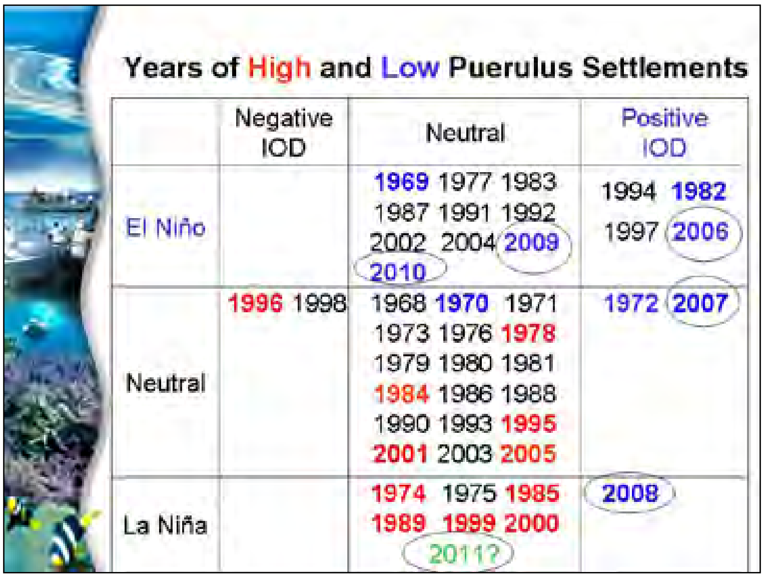
Monthly SST v Puerulus time periods (<2006/07)

- Monthly SST
  - Highest correlation puerulus Aug-Sept
  - Feb SST - significant for puerulus Oct-Nov
  - Little effect on puerulus (Dec-Jan)
- SST Oct-Nov (<spawning)
  - Effects Aug-Sept puerulus
  - No effect on Oct-Nov puerulus


Fremantle Sea Level (Jun-Dec) and location of settlement
Model criteria 6
Mean Latitude
28
28.5
29
29.5
30
30.5
31
Dongara
Jurien
Lancelin
60
65
70
75
80
85
90
Fremantle Sea Level (cm), June - December
Caputi 2008

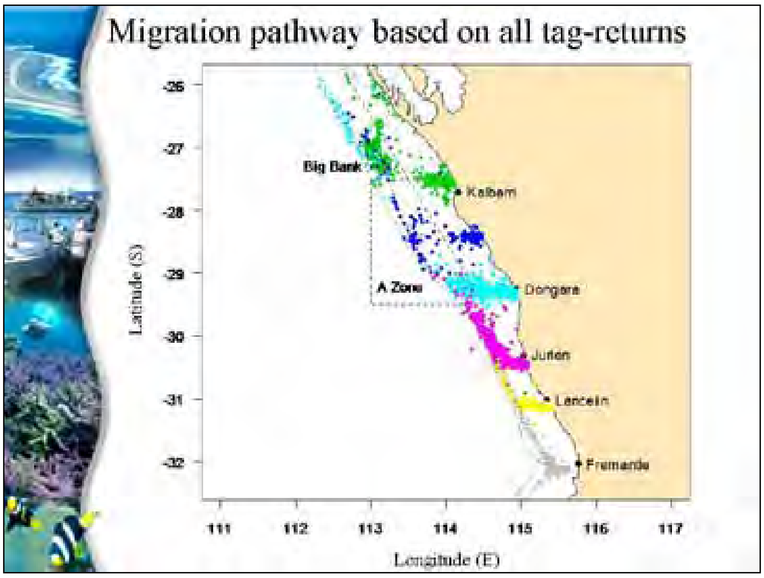

Page 1 of 1
Positive Dipole Mode - weak westerly winds (winter)
Cool

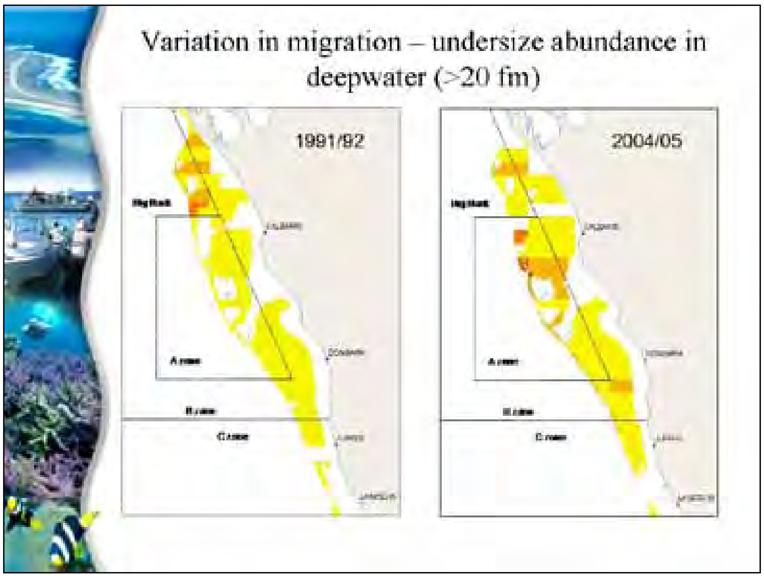

Page 1 of 1
Negative Dipole Mode - strong westerly winds (winter)



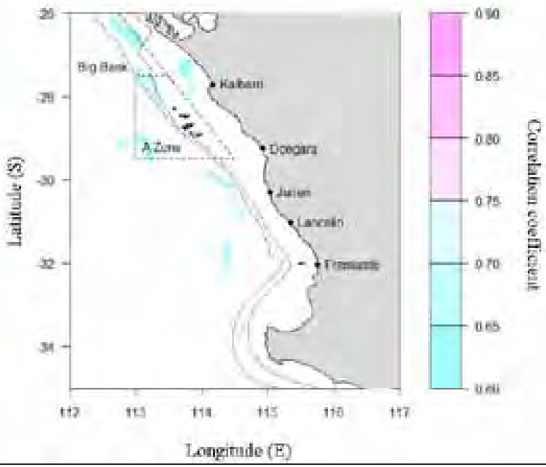
Years of High and Low Puerulus Settlements

	Negative IOD	Neutral	Positive IOD
El Niño		1969 1977 1983 1987 1991 1992 2002 2004 2009 2010	1994 1982 1997 2006
Neutral	1996 1998	1968 1970 1971 1973 1976 1978 1979 1980 1981 1984 1986 1988 1990 1993 1995 2001 2003 2005	1972 2007
La Niña		1974 1975 1985 1989 1999 2000 2011?	2008

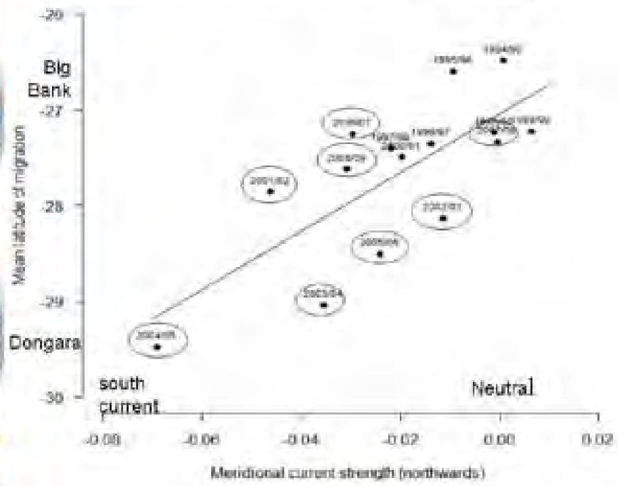




Influence of currents on migration

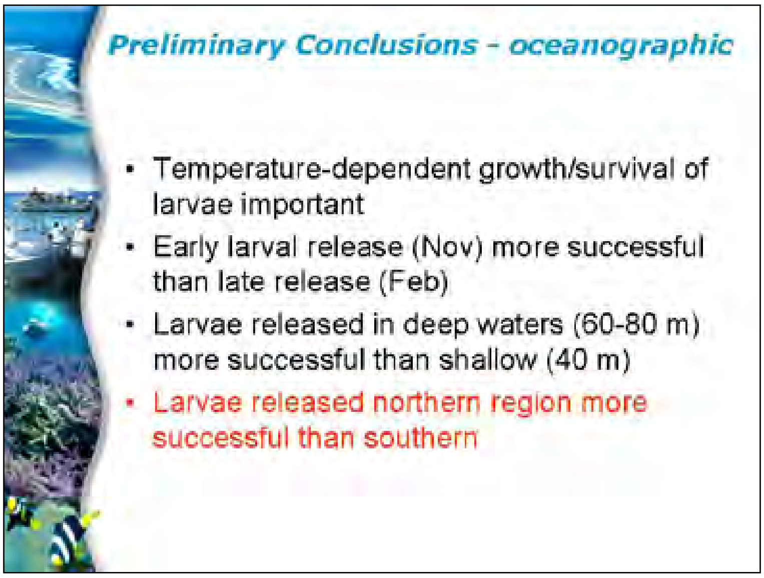


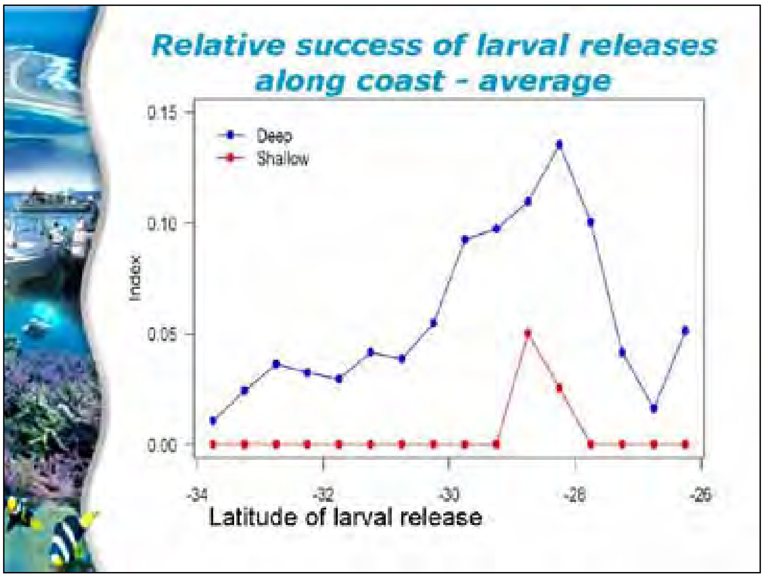
Meridional current vs latitude of migration

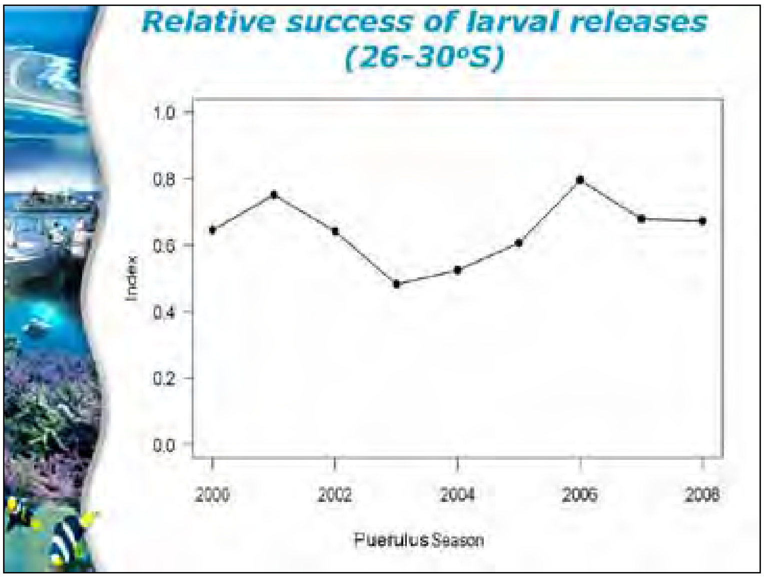


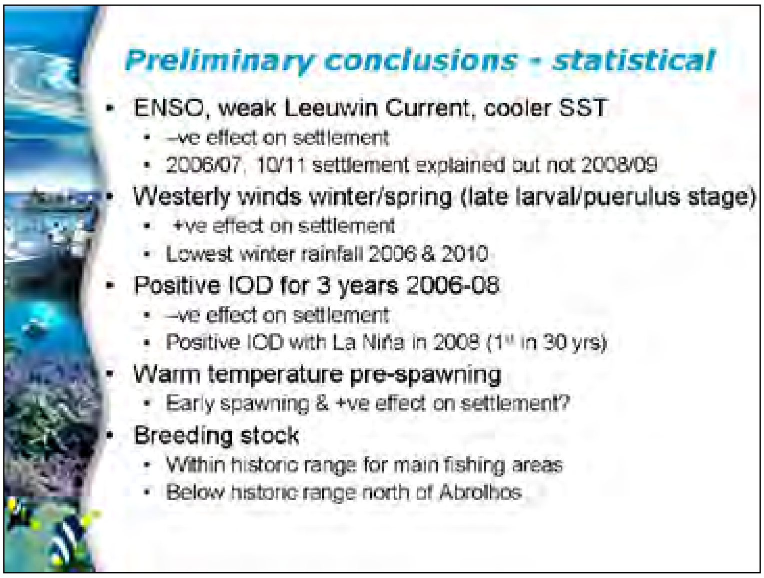
Preliminary conclusions – migration/breeding stock

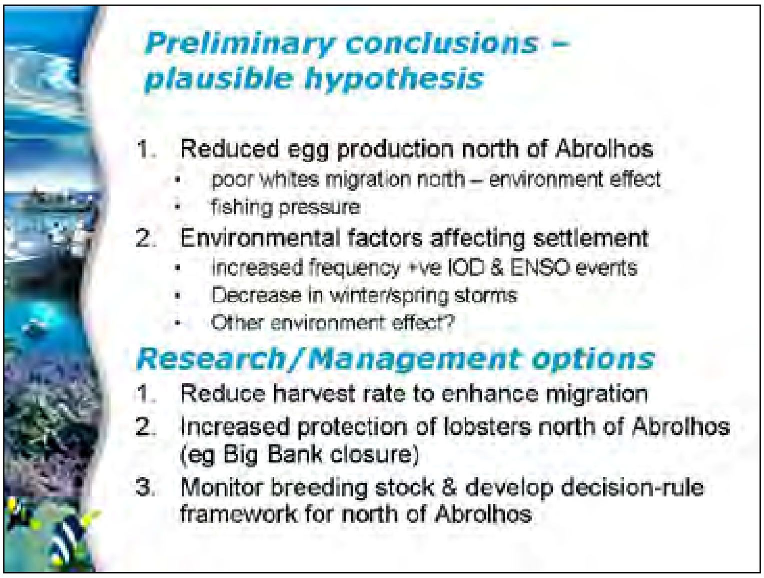
- Big Bank fishery increased since 1990s
- Northerly migration below average 6/8 yrs
- Recruitment deepwater north Abrolhos dependent on migration
- Big Bank closed in 2008/09
  - Survey 2009 - lack of small lobsters
  - Survey 2010 - Improvement in abundance

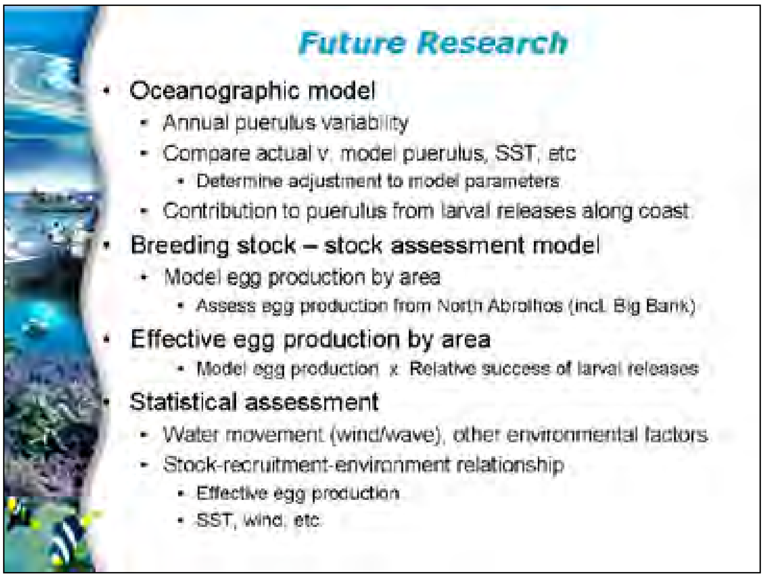

Preliminary Conclusions - oceanographic
• Temperature-dependent growth/survival of larvae important
• Early larval release (Nov) more successful than late release (Feb)
• Larvae released in deep waters (60-80 m) more successful than shallow (40 m)
• Larvae released northern region more successful than southern


Relative success of larval releases along coast - average
Deep
Shallow
Index
0.00
0.05
0.10
0.15
-34
-32
-30
-28
-26
Latitude of larval release


Relative success of larval releases (26-30°S)
Index
0.0
0.2
0.4
0.6
0.8
1.0
2000
2002
2004
2006
2008
Puerulus Season

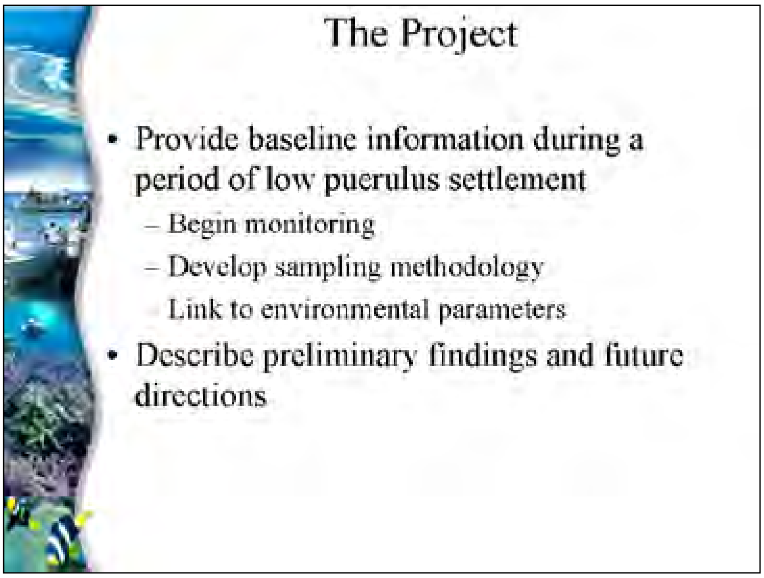

Preliminary conclusions - statistical
ENSO, weak Leeuwin Current, cooler SST
–ve effect on settlement
2006/07, 10/11 settlement explained but not 2008/09
Westerly winds winter/spring (late larval/puerulus stage)
+ve effect on settlement
Lowest winter rainfall 2006 & 2010
Positive IOD for 3 years 2006-08
–ve effect on settlement
Positive IOD with La Niña in 2008 (1st in 30 yrs)
Warm temperature pre-spawning
Early spawning & +ve effect on settlement?
Breeding stock
Within historic range for main fishing areas
Below historic range north of Abrolhos


Preliminary conclusions – plausible hypothesis
1. Reduced egg production north of Abrolhos
poor whites migration north – environment effect
fishing pressure
2. Environmental factors affecting settlement
increased frequency +ve IOD & ENSO events
Decrease in winter/spring storms
Other environment effect?
Research/Management options
1. Reduce harvest rate to enhance migration
2. Increased protection of lobsters north of Abrolhos (eg Big Bank closure)
3. Monitor breeding stock & develop decision-rule framework for north of Abrolhos


Future Research
Oceanographic model
Annual puerulus variability
Compare actual v. model puerulus, SST, etc
Determine adjustment to model parameters
Contribution to puerulus from larval releases along coast
Breeding stock – stock assessment model
Model egg production by area
Assess egg production from North Abrolhos (incl. Big Bank)
Effective egg production by area
Model egg production x Relative success of larval releases
Statistical assessment
Water movement (wind/wave), other environmental factors
Stock-recruitment-environment relationship
Effective egg production
SST, wind, etc

Appendix 5 Presentation 5 – Reduced colonisation of puerulus collectors

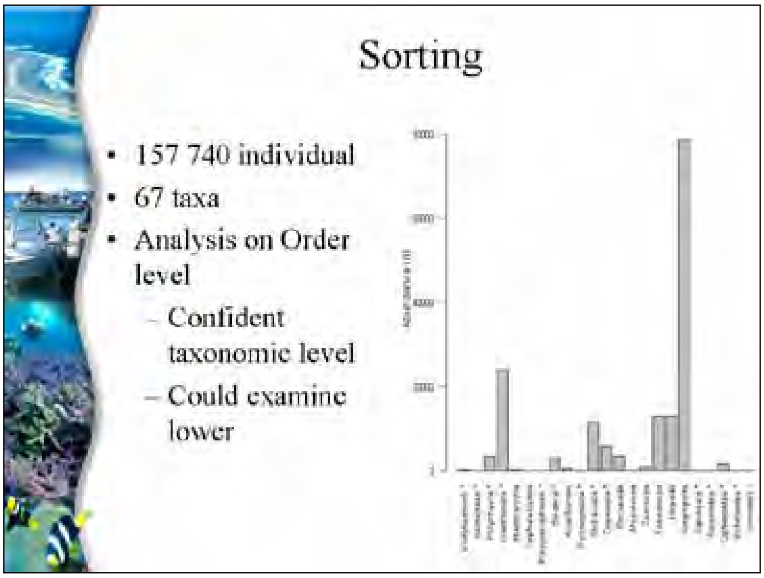
Assessing possible environmental causes behind the reduced colonisation of Western Rock Lobster puerulus collectors by a wide suite of species

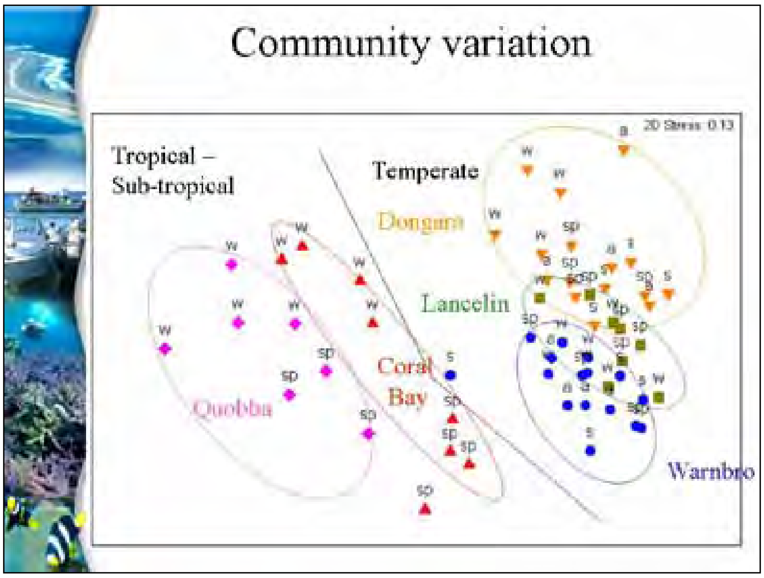


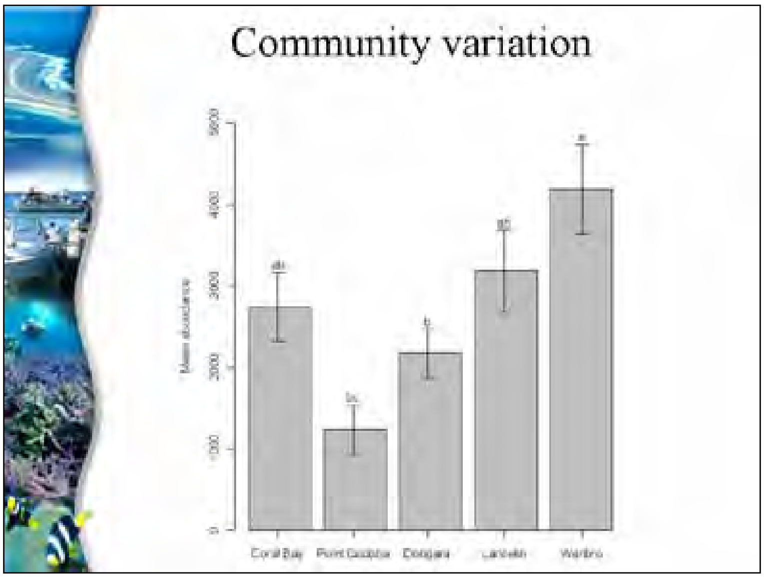

Collection
• Temporal
– 2 sites (Warnbro & Dongara)
– 4 seasons
• Spatial
– 5 sites
– 2 seasons (autumn & spring)
Zone A
Zone B
Zone C
Coral Bay
Dongara
Southern Boundary

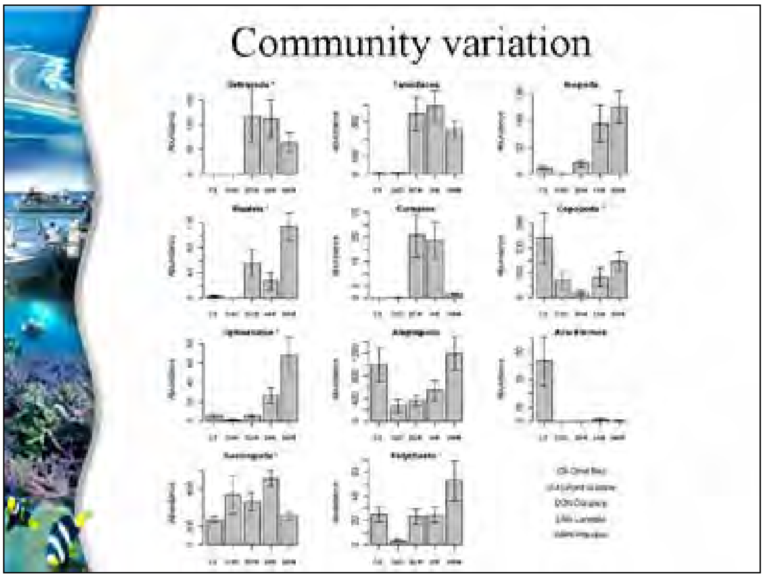

Collection

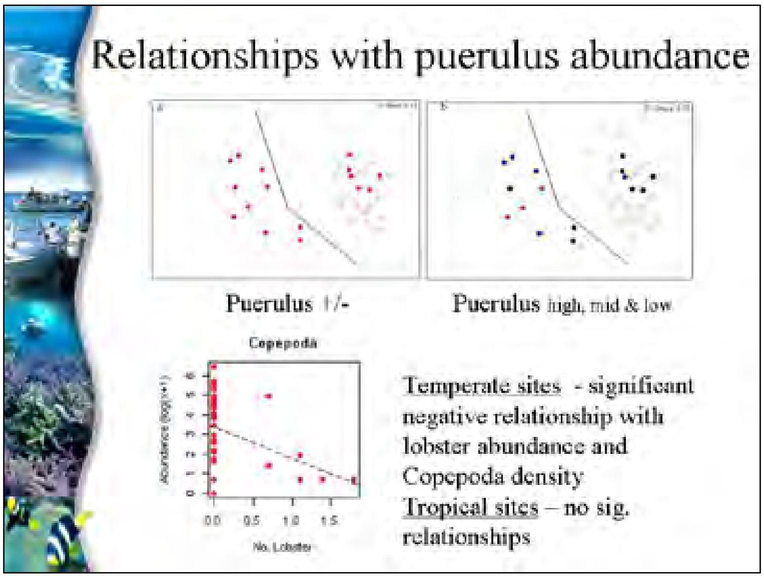

Collection

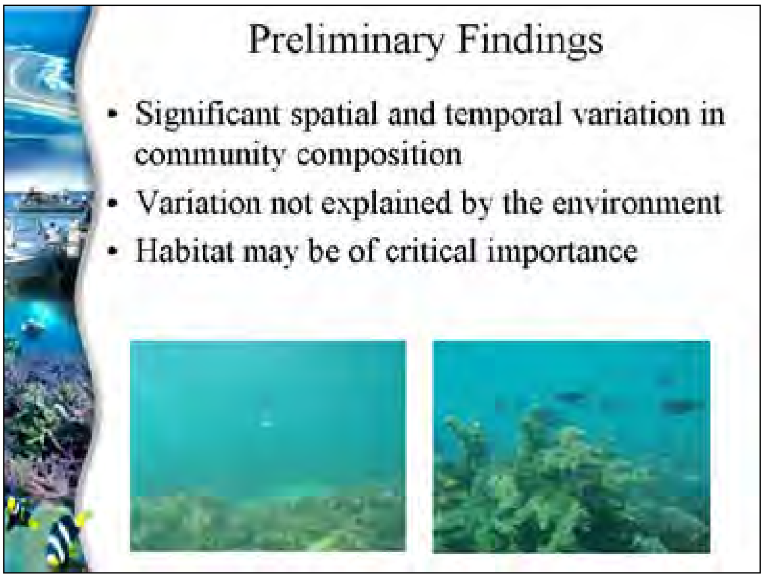

Sorting
• 157 740 individual
• 67 taxa
• Analysis on Order level
– Confident taxonomic level
– Could examine lower

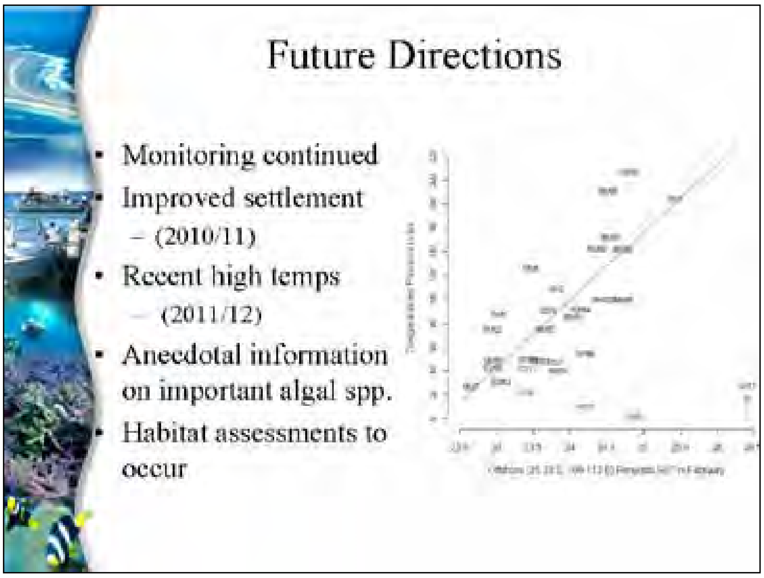

Community variation
2D Stress: 0.13
Tropical – Sub-tropical
Temperate
Dongara
Lancelin
Coral Bay
Quobba
Warnbro


Community variation
Mean abundance
Coral Bay
Point Quobba
Dongara
Lancelin
Warnbro


Community variation

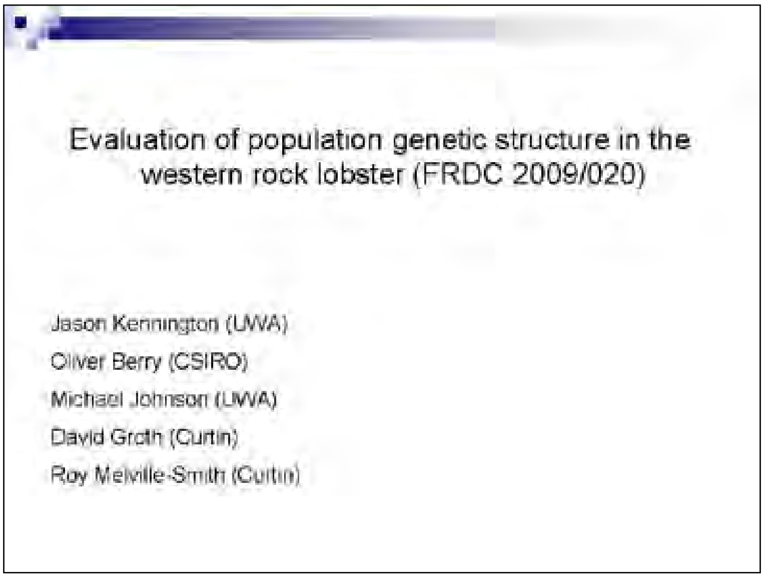

Relationships with puerulus abundance
Puerulus +/-
Puerulus high, mid & low
Copepoda
Abundance (log(x+1))
No. Lobster
0.0
0.5
1.0
1.5
Temperate sites - significant negative relationship with lobster abundance and Copepoda density
Tropical sites – no sig. relationships

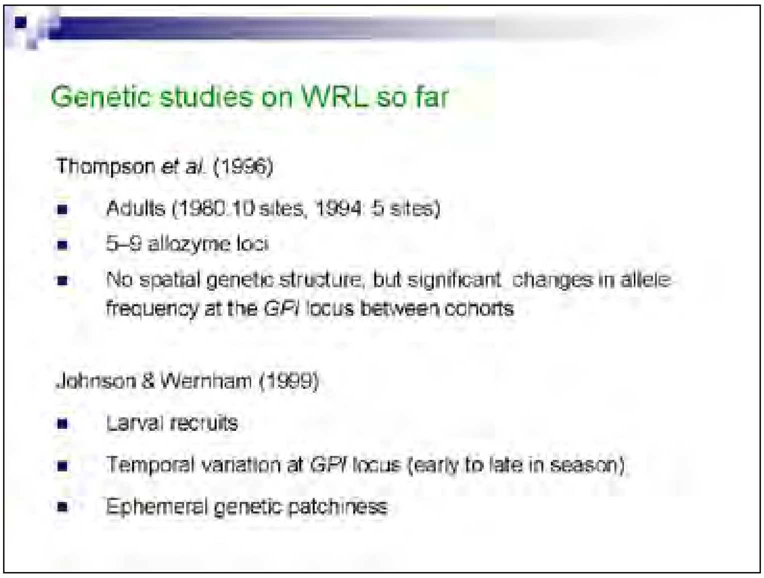

Preliminary Findings
• Significant spatial and temporal variation in community composition
• Variation not explained by the environment
• Habitat may be of critical importance


Future Directions
• Monitoring continued
• Improved settlement
– (2010/11)
• Recent high temps
– (2011/12)
• Anecdotal information on important algal spp.
• Habitat assessments to occur

Appendix 6 Presentation 6 – Population genetic structure

Investigating rock lobster population genetic structure.





Project aims

1. Develop new microsatellite markers for WRL
2. Test for population genetic structure in the adult population
3. Test for population genetic structure in the next generation of recruits (pueruli)
4. Estimate effective population size

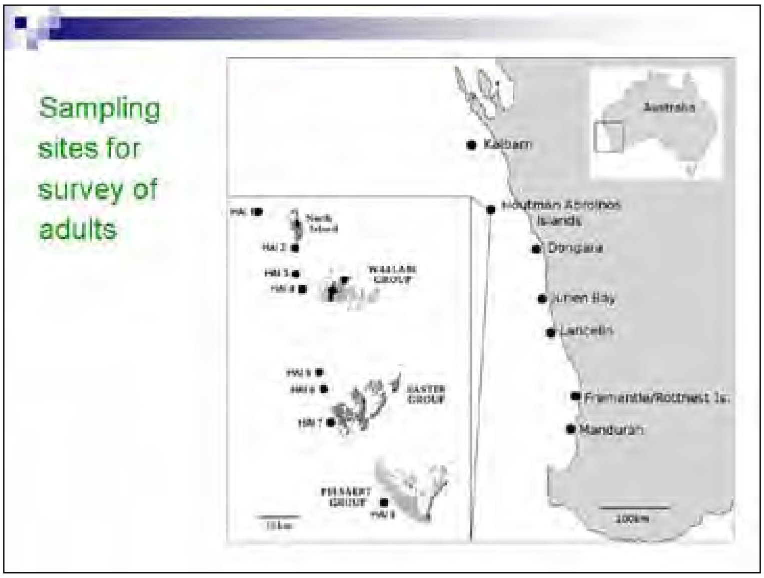
1. Develop new microsatellite markers

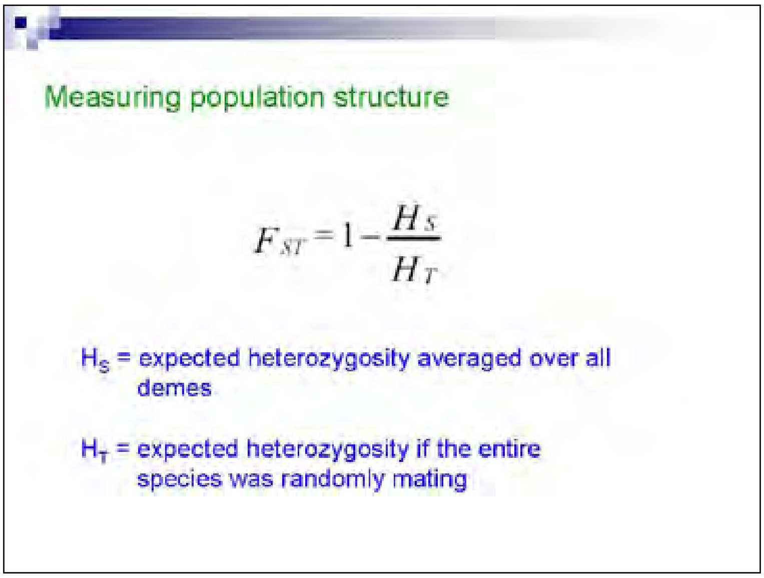
- 18 loci (Kennington *et al.* 2010)
  - 3 × di-, 6 × tri- and 9 × tetra nucleotide repeats
- 9 loci (Groth *et al.* 2009)
  - 3 × di-, 6 × tetra nucleotide repeats

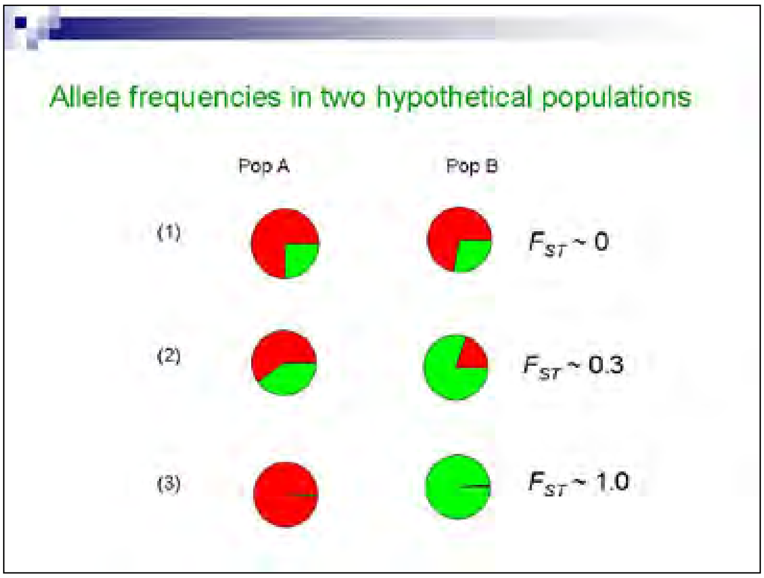
2. Test for population genetic structure in adults

Sampling

- 8 locations (Mandurah to Kalbarri)
- 21 to 348 individuals per location (631 individuals in total)
- Each individual genotyped at 24 loci (~15,000 genotypes in total)


Sampling sites for survey of adults
Kalbarri
Houtman Abrolhos Islands
Dongara
Jurien Bay
Lancelin
Fremantle/Rottnest Is.
Mandurah
Australia
100km


Measuring population structure
$$F_{ST} = 1 - \frac{H_S}{H_T}$$
H_S = expected heterozygosity averaged over all demes
H_T = expected heterozygosity if the entire species was randomly mating


Allele frequencies in two hypothetical populations
Pop A
Pop B
(1)
F_{ST} ~ 0
(2)
F_{ST} ~ 0.3
(3)
F_{ST} ~ 1.0

Population genetic structure in adults

- F_{ST} = 0.002
- Randomisation test, P = 0.168

STRUCTURE: an individual-based analysis

Inference of Population Structure Using Multilocus Genotype Data

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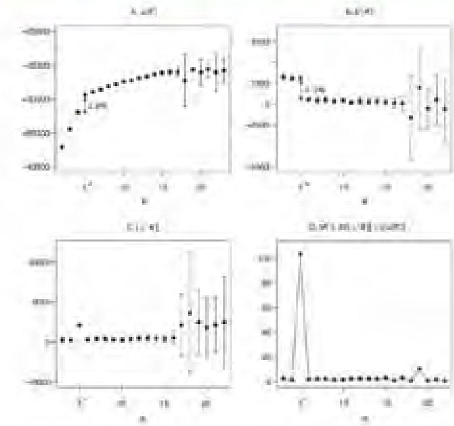
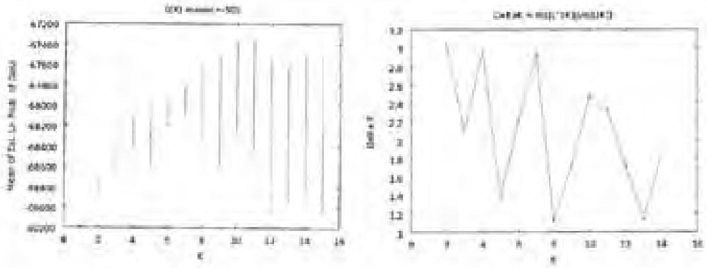
Manuscript received September 23, 1999
Accepted for publication February 18, 2000

K	log $P(X\|K)$	$P(K\|X)$
1	−3144	~0
2	−2769	~0
3	−2678	0.993
4	−2683	0.007
5	−2688	0.00005

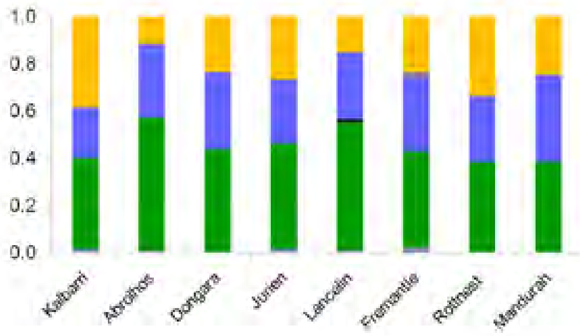
Detecting cluster number (Evanno *et al.* 2005)





Locus	F_{ST}	*P*	Locus	F_{ST}	*P*
S28	0.000	0.869	D2	-0.001	0.764
S3	0.002	0.267	D109	0.000	0.250
WRL1	0.010	0.126	D114	-0.004	0.651
S8	0.001	0.502	A7	0.001	0.608
S50	0.000	0.312	D4	0.001	0.504
W25	-0.002	0.550	B108	0.000	0.512
B111	-0.004	0.619	A5	0.001	0.058
D107	0.030	0.001	B112	0.001	0.484
B5	0.000	0.051	D113	-0.004	0.175
C103	0.006	0.009	A103	-0.003	0.806
B116	0.002	0.420	B4	-0.001	0.808
C107	0.000	0.067	C7a	0.000	0.962

Allele frequencies locus D107

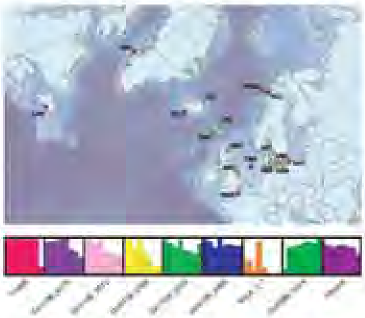


Research article

Open Access

Genomic signatures of local directional selection in a high gene flow marine organism; the Atlantic cod (Gadus morhua)

Einar E Nielsen*[†1], Jakob Hemmer-Hansen[†1], Nina A Poulsen[1,2], Volker Loeschcke[2], Thomas Moen[3], Torild Johansen[4], Christian Mittelholzer[5,6], Geir-Lasse Taranger[4], Rob Ogden[6] and Gary R Carvalho[7]



Methods:
708 individuals
17 sites
98 SNP loci (15 from candidate genes)

Results:
88 Neutral +10 outliers

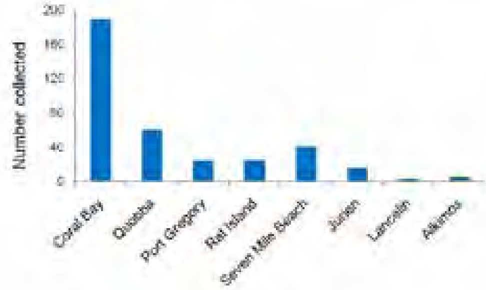
3. Test for population genetic structure in recruits

Sampling

- Pueruli from 8 collection sites (Alkimos to Coral Bay)
- 2 to 189 individuals per location (367 individuals in total)
- Each individual genotyped at 22 loci (~8,000 genotypes in total)

Sampling sites for survey of recruits

Puerulus collection 2009



Molecular marker for WRL

Samantha Cadee (2010)

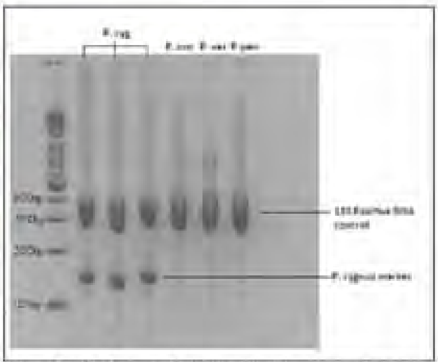


Figure 2. Gel photograph showing the *P. cygnus* marker with a positive DNA control (18S). The *P. cygnus* samples show both the 300-400bp 18S fragment as well as the 150bp *P. cygnus* band while the other three species show just the 18S fragment.

Species identification at Coral Bay

Number of pueruli tested = 189

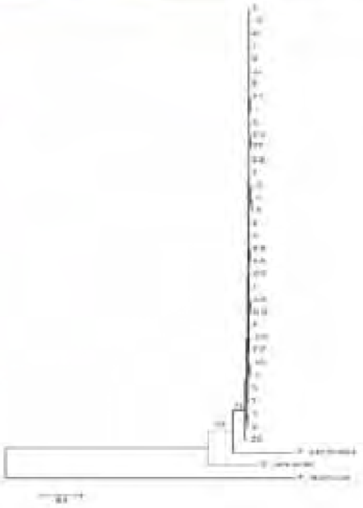
Positive for WRL = 187

Negative for WRL = 1

PCR failure (no WRL band or positive control) = 1

36 pueruli from Coral Bay sequenced and compared to pueruli sampled from southern sites (Alkimos to Abrolhos)

Relationships among haplotypes (12S)



Population genetic structure in recruits

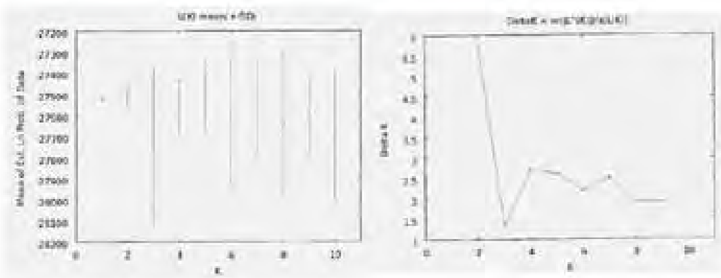
Microsatellites

- $F_{ST} = 0$
- Randomisation test, $P = 0.358$

Mitochondrial DNA (12S)

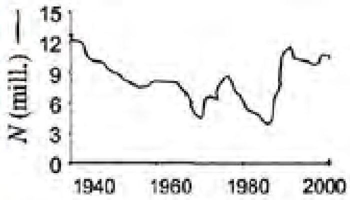
- $F_{ST} = 0.002$
- Randomisation test, $P = 0.370$

Population genetic structure in recruits

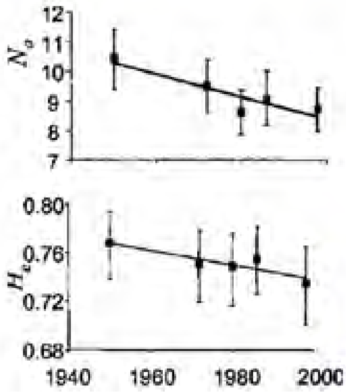


Loss of microsatellite diversity and low effective population size in an overexploited population of New Zealand snapper (*Pagrus auratus*)

Lorenz Hauser, Greg J. Adcock, Peter J. Smith, Julio H. Bernal Ramírez, and Gary R. Carvalho



PNAS 99:11742-11746 (2002)



$$\Delta h = -\frac{1}{2N}$$

N_e = 180 (80 – 720, 95% CL)

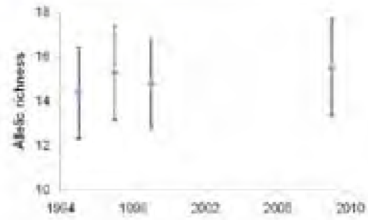
N_e/N_C ≈ 500 / 5,000,000 ≈ 0.0001

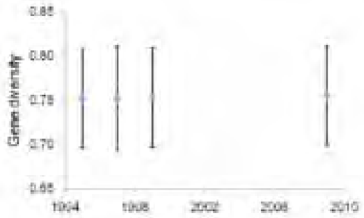
4. Effective population size

Sampling

- 4 collections (1995 to 2009)
- 40 to 277 individuals per collection (447 individuals in total)
- Each individual genotyped at 22 loci (~10,000 genotypes in total)

Temporal variation in microsatellites

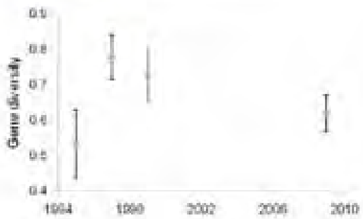


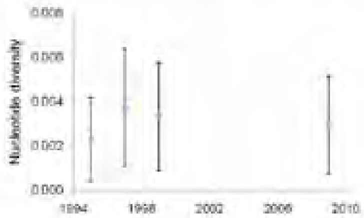


$F_{ST} = 0$

Randomisation test, $P = 0.440$

Temporal variation in mtDNA





$F_{ST} = 0.002$

Randomisation test, $P = 0.220$

Species identification of phyllosoma

- Extreme morphological similarity among Indo-Pacific *Panulirus* species (Berry 1971)
- High species diversity in tropical & temperate waters

Species identification of phyllosoma

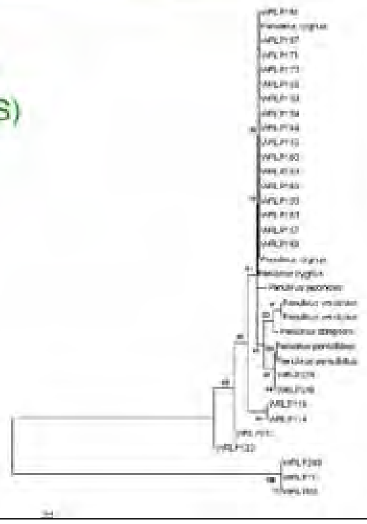
Number of phyllosoma tested = 183

Positive for WRL = 161

Negative for WRL = 21 (11.5%)

PCR failure (no WRL band or positive control) = 1

Species identification of phyllosoma (12S)



Blast match results (CO1)

Species	Distribution	Number
Scyllarides herklotsii (slipper lobster)	Atlantic coast W. Africa	3
Scyllarides latus (slipper lobster)	Mediterranean Sea and eastern Atlantic Ocean	5
Neosarmatium meinerti (crab)	Western Indian Ocean	1
Panulirus penicillatus	Indo-Pacific	2

Appendix 7 Project Objectives

FRDC PROJECTS TO INVESTIGATE

THE LOW PUERULUS SETTLEMENTS

(as at January 2009)

The five projects outlined below were submitted to the Fisheries Research and Development Corporation (FRDC) and were successful in securing funding. The objectives of the projects are to investigate various aspects of the possible causes and factors associated with the low puerulus settlements of 2007-08 and 2008-09.

Project 1 (FRDC 2009/018)

Identifying factors affecting the low western rock lobster puerulus settlement in recent years.

Objectives

1. To use a larval advection model and the rock lobster population dynamics model to assess the effect of the spatial distribution of the breeding stock on the puerulus settlement.
2. To assess environmental factors (water temperature, current, wind, productivity, eddies) and breeding stock affecting puerulus settlement.
3. To examine climate change trends of key environmental parameters and their effect on the western rock lobster fishery.
4. Provide industry (WRLC), RLIAC and Fisheries managers with an evaluation of relative impact of breeding stock and environmental effects on the puerulus settlement and its implications for management in the protection of the breeding stock.

Project 2 (FRDC 2008/087)

Evaluating source-sink relationships of the Western Rock Lobster Fishery using oceanographic modeling.

Objectives

1. To determine the relative contribution of larval production from different areas to the abundance and spatial distribution of puerulus settlement over 15 years using a larval advection model.
2. Provide industry (WRLC), RLIAC and Fisheries managers with an evaluation of source-sink relationships and its implications for management in the protection of the breeding stock

Project 3 (FRDC 2009)

Evaluating the use of novel statistical techniques for determining harvest rates and efficiency increases in the Western Rock Lobster Fishery. The project looks at using change-in-ratio and index removal to further examine fishing efficiency and harvest rates and pulls together some of the best mathematicians in this field, i.e. Professor Norm Hall, Assoc Professor Stewart Frusher and Professor John Hoenig

Objectives

1. Assess current data sources and their potential for use in estimating harvest rates and efficiency increases in the western rock lobster fishery.
2. Evaluate whether additional sources of information are needed to produce more robust estimates of harvest rate and efficiency increase.
3. Assess whether the estimates of harvest rate and fishing efficiency are reliable and could be used to assist in the management of the western rock lobster fishery.
4. Provide industry (WRLC), RLIAC and fisheries managers with an evaluation of change-in-ratio and index removal techniques for determining harvest rates and efficiency creep.

Project 4 (FRDC 2009)

Evaluation of population genetic structure in the western rock lobster

Objectives

1. Develop additional new microsatellite markers for western rock lobster.
2. Test whether the adult population of western rock lobster is genetically homogeneous throughout its range.
3. Test whether the spatial genetic structure in the next generation of recruits (pueruli) matches the spatial genetic structure found in adults. (If so, this suggests spatial structure is due to limited dispersal or local adaptation).
4. Estimate effective population size of the western rock lobster and test for severe bottlenecks in population size.

Project 5 (FRDC 2008)

Assessing possible environmental causes behind the reduced colonization of puerulus collectors by a wide suite of species.

Objectives

1 Begin monitoring the community composition of marine flora and fauna along the Western Australian coastline during this current poor settlement period.

2 Develop standard methodology for monitoring the spatial and temporal variability in the settlement of marine flora and fauna.

3 Determine what environmental parameters may be linked to the majority of variation in the floral and faunal communities colonizing puerulus collectors, focusing on those relating to puerulus settlement.

4 Identify indicator marine flora and fauna species for monitoring the influences of environmental change on Western Australian marine environment.

5 Detect any known or potential introduced marine pests within the Western Australian environment.

Appendix 8 List of Workshop Attendees

NAME	ORGANISATION
Nick Dunlop	Conservation Council of WA
Dirk Slawinski	CSIRO
David Griffin	CSIRO
Evan Weller	CSIRO
Liejun Zhong	CSIRO
Ming Feng	CSIRO
Malcolm Haddon	CSIRO
Bruce Phillips	Curtin University
Roy Melville Smith	Curtin University
David Griffiths	Department of Fisheries
Graeme Baudains	Department of Fisheries
John Looby	Department of Fisheries
Matt Pember	Department of Fisheries
Nick Caputi	Department of Fisheries
Peter Stephenson	Department of Fisheries
Rod Lenanton	Department of Fisheries
Simon de Lestang	Department of Fisheries
Glenn Hyndes	Edith Cowan University
Peter Rogers	Independent
Lynnath Beckley	Murdoch University
C Moss	Rock Lobster Fisher
J Newby	Rock Lobster Industry
G Andrich	Rock Lobster Fisher Association
Sabine Daume	Scientific Certification Systems
S Frusher	University of Tasmania (UTAS) - IMAS
Anya White	University of WA
Christin Sawstrom	University of WA
Jason Kennington	University of WA
Richard Stevens	Western Australian Fishing Industry Council
F J Camarda	Western Rock Lobster Council
Nic Sofoulis	Western Rock Lobster Council
Peter Trott	World Wildlife Fund