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Torres Strait rock lobster (TRL) fishery surveys and stock assessment. AFMA Project 2016/0822

ÉVA PLAGÁNYI, DARREN DENNIS, ROB CAMPBELL, MARK TONKS, MICK HAYWOOD, ROY DENG, NICOLE MURPHY, KINAM SALEE

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Important disclaimer

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Executive summary

The Torres Strait TRL fishery provides an important source of income for greater than 400 Torres Strait islanders and many island communities; and also supports a non-islander sector, based on ~11 licensed primary vessels. The TRL stock is shared with adjacent fisheries in PNG and on the northern Queensland coast. The Australian and PNG Torres Strait catch has averaged 693 t live weight since 1989. The Australian Torres Strait catch is important economically to all sectors, and primarily supports a lucrative export market for live lobsters to China (Hutton et al. 2016). Given its significant traditional, economic and social importance there is an obvious need to address the long-term biological sustainability of the stock through research supporting management decisions.

Annual fishery-independent monitoring of the Torres Strait ornate rock lobster (TRL) *Panulirus ornatus* population has been carried out during 1989 to 2016. These surveys, conducted mid-year (June) up until 2014 and pre-season (November) during 2005-2008 and from 2014-2016, provide the only long-term information on the relative abundance of recruiting (1+) lobsters. Prior to the introduction of mandatory logbooks in the TVH sector and subsequently the docket book system in the TiB sector these surveys also provided the only long-term information on the relative abundance of fished (2+) lobsters.

Pre-season population surveys of recruiting (1+) lobster abundance were identified by the TRL RAG as critical to support the move to a quota managed system (QMS) proposed in 2005. As a result annual pre-season surveys were conducted during 2005-2008, in addition to mid-year surveys, and have replaced midyear surveys since 2014, to provide managers with information on the abundance and biomass of fishery recruits and the likely stock biomass available to be fished each year. These data sets are integral to the outputs of the fishery model developed to assess fishery status and to forecast stock size and inform the Recommended Biological Catch (RBC). In addition, these data are essential inputs to an empirical Harvest Control Rule (eHCR) that is being developed for TRL.

The 7th annual pre-season population survey was conducted in November 2016. The sample design employed during the 2016 pre-season survey was consistent with previous surveys. A total of 77 sites (down from the original 140) were allocated to the established sampling strata. Measured belt transects (500 m by 4 m) were employed as the primary sampling unit. At the completion of each transect a diver recorded; the number of lobsters caught (and measured), the number and age-class of those observed but not caught, depth, visibility, distance swum, numbers of pearlshell (*Pinctada maxima*) and holothurian species observed, and percent covers of standard substratum and biota (including seagrass and algae species) categories.

The strong correlation obtained in previous work between the mid-year and pre-season lobster abundance indices motivated reducing the scale of the pre-season surveys to include only the 74 mid-year lobster survey sites. This reduces the overall cost of research for management. Recruiting (1+) lobster indices calculated using all sites were strongly correlated with indices calculated using only the 74 mid-year survey sites. Hence when only one annual index is used there is little difference in stock forecasts and RBC using either index. However, the standard errors of the indices using only mid-year sites were ~30% greater than for indices calculated using all sites. Hence, there is greater uncertainty in the mid-year only forecasts. Nevertheless, supplementary survey site data from industry run surveys could address this shortfall or possibly increase precision of the pre-season abundance estimates.

The 2016 pre-season distributions of recently-settled (0+) and recruiting (1+) lobsters were generally consistent with the distributions recorded previously. However, recruiting lobsters were significantly less abundant throughout all sampling stratums; particularly at several of the southern sites which had very high abundances in 2015. Recently-settled lobsters were observed mainly along the western margin of the fishery, as per previous pre-season surveys. Fished lobsters were rarely observed, as the vast majority of fished lobsters would have emigrated from Torres Strait during August/September to undertake the breeding migration

The 2016 index of recruit abundance was one of the lowest recorded in recent years, only slightly higher than the 2005 and 2008 indices and about 40% of the 2015 index. The low index was a reflection of low densities observed in all survey regions. This was in contrast to 2015 when lobsters showed high variations of abundance across the study area.

Fishers reported sand incursions in several regions in 2015, and this was corroborated during the 2015 pre-season survey. Nevertheless the mean percent covers of the habitat variables recorded were consistent with longer term trends suggesting the incursions were localised rather than broad scale. Likewise in 2016 seabed habitat at the survey sites was consistent with previous years, and did not appear to explain the anomalous low lobster abundance.

The population surveys were initially designed to provide accurate and precise indices of 1+ and 2+ lobster abundance, and 0+ lobsters were rarely observed during mid-year surveys as they only settle in June. Hence, refined sampling would likely provide better estimates of 0+ abundance. Although all 0+ lobsters observed during the pre-season surveys are recorded, it is not known how many are missed due to their small size and cryptic behaviour. Nevertheless, if the percentage of lobsters observed has remained constant throughout the study period, the density indices should be a reliable indicator of relative recruitment strength one year in advance. As for recruiting lobsters, additional future industry-run surveys could provide greater certainty about strength of the 0+ year-classes, and even earlier forecasting of stock size and TAC.

The persistent low abundance of 1+ lobsters in the northern strata is of concern for the local fishers, and particularly if the cause of the low abundance persists. The Mabuiag stratum is a key habitat for recently-settled lobsters and future recruitment and stock would be impacted by persistent poor habitat. However, the recovery of 0+ lobsters there in 2016 provided an encouraging sign that the impacts of the recent sand incursions and seagrass die backs are relatively transient.

The TRL integrated stock assessment model was again used to inform an RBC for the 2017 fishing season. This document summarises the post-Nov 2016 preseason survey update of the integrated stock assessment model presented at the December 2016 TRLRAG, as well as further work to revise the stock assessment model, for presentation at the TRLRAG meeting in April 2017. The TRLRAG agreed that if the fishery transitions to using an empirical Harvest Control Rule (eHCR) to inform the Recommended Biological Catch (RBC), then the stock assessment would only need to be conducted every three years. However until such time as this is formally adopted, the stock assessment model is being used to inform the RBC.

The data updates include the latest (Nov 2016) pre-season survey results, the catch total for 2016 and revision for 2015, and revisions and updates to the commercial CPUE (TVH & TIB) data series. The Reference case model presented here is fitted to the TVH CPUE Main Effects Int1 option and the standardised Seller+QA CPUE TIB series as described in Campbell *et al.* 2016a,b. More recent updates to the commercial catch-at-age data have also been included in a revised version of the model. The full details of the stock assessment model are also provided in this report.

The model suggested a RBC(2017) of 495t [90% CI 315-676t] [75% CI 369-622t] which was adopted by the TRLRAG. The resource spawning biomass is estimated to be currently at approximately the 1973 level (used as a proxy for carrying capacity *K* although the stock is highly variable and fluctuates around this level), but given the variability, it is predicted that next year's spawning biomass will drop to 63% of this level.

Overall the resource is assessed to be in good condition, even though there are indications that 2017 will be a below-average year with a consequent low RBC value recommended by the TRLRAG. The Pre-season survey planned for November 2017 will be essential to cross-check this result this year, given that no midyear survey data are available and there have recently been a number of environmental anomalies.

1. Chapter 1 - Pre-season Survey 2016

Introduction

The results of the 2016 pre-season survey were presented at the TRL RAG meeting on 13 December 2016, to provide stakeholders with the updated stock assessment and the revised recommended biological catch for 2017. This paper provides updates on abundance and size/age distribution of the 2016 recently-settled (0+) and recruiting (1+) lobster year-class and long-term seabed habitat monitoring with discussions on impacts on the TRL population.

The 2016 pre-season (November) survey of the Torres Strait lobster population was conducted during 2 -15 November 2016 by four CSIRO staff, using the vessel M.V. *Flying Fish V* (Blue Planet Marine). A total of 77 sites (Figure 1) were surveyed by divers and each site was re-located accurately using portable GPS. Measured belt transects (500 m by 4 m) were employed as the primary sampling unit, as they were found to give the greatest precision (p=SE/Mean) of lobster abundance. Transect distance was measured, to the nearest metre using a Chainman® device. At the completion of each transect divers recorded: the number of lobsters caught, the number and age-class of those observed but not caught, depth, visibility, distance swum, numbers of pearl oyster (*Pinctada maxima*), crown of thorns starfish and holothurian species observed, and percent covers of standard substratum and biota (including seagrass and algae species) categories. The sampled lobsters were measured (tail width in mm), sexed and moult staged to provide fishery-independent size-frequency data.

A requirement to obtain a Marine Parks Permit for some sites within the Great Barrier Marine Park Zone in the SE region of the fishery restricted the take of lobsters at 6 sites. Restrictions included: collection of no more than 30 juvenile lobster (< 90mm carapace length) from the 6 sites per year and no more than 5 collected per site per year. Fortunately these restrictions did not affect our sample collection as lobster densities were below the permit limitations.

We repeated the photo-transects that were initially conducted at eight reef-edge sites during the 2015 pre-season survey (Figure 1) to monitor coral cover given the coral bleaching event in April/May 2015. This involved photographing the reef-edge habitat in three 50 m transects following the completion of the lobster census. In addition, the percent bleached coral and live coral was recorded as a component of the ongoing habitat monitoring initiated in 1994. The likely short-term and longer-term impacts of the 2015 bleaching event on the TRL fishery are discussed below.

Results

TRL distribution and abundance

The distributions of recently-settled (0+) and recruiting (1+) lobsters (Figure 2) were similar to those recorded during previous pre-season surveys (eg. Appendices A & B show 2015 & 2016 distributions of 0+ and 1+ lobsters respectively). However, recruiting lobsters were significantly less abundant throughout all sampling stratums; particularly at several of the southern sites which had very high abundances in 2015. Recently-settled lobsters were observed mainly along the western margin of the fishery, as per previous pre-season surveys. Fished lobsters were rarely observed, as the vast majority of fished lobsters would have emigrated from Torres Strait during August/September to undertake the breeding migration.

As the 2015 and 2016 pre-season surveys involved a reduced number of transects (77) from previous surveys (>130), four alternative methods were used to calculate annual indices of abundance between 2005 and 2016. This enabled an assessment of the likely impact of the reduced sampling on accuracy and precision of the indices. The four options are described in Table 1. The resulting indices are shown in Figure 3, which highlights that the long-term trends using data from the mid-year only (74) transects are generally consistent with trends using data for all sites and sub-sets of sites. As discussed previously, this strongly indicates that transitioning to smaller scale pre-season surveys will not interrupt the time series collected to date. Nevertheless, as promoted at the TRL RAG meetings, additional industry-run surveys would increase precision of the estimates and provide even greater confidence in the estimates of annual recruitment and recently–settled lobster strength. This is highlighted by the increased precision of the abundance indices generated using all sites in comparison to the mid-year only indices (Figure 4).

The 2016 index of recruit abundance was one of the lowest recorded in recent years, only slightly higher than the 2005 and 2008 indices and about 40% of the 2015 index. The low index was a reflection of low densities observed in all survey regions (Figure 5). This was in contrast to 2015 when lobsters showed high variations of abundance across the study area.

Fishers reported sand incursions in several regions in 2015, and this was corroborated during the 2015 pre-season survey. Nevertheless the mean percent covers of the habitat variables recorded were consistent with longer term trends suggesting the incursions were localised rather than broad scale. Likewise in 2016 seabed habitat at the survey sites was consistent with previous years, and did not appear to explain the anomalous low lobster abundance. Seabed habitat trends are discussed below.

The densities of recently-settled (0+) lobsters have been consistent and above average during 2014-2016. The pattern of densities of recently-settled (0+) lobsters amongst stratums recorded in 2016 (Figure 7) was similar to that observed during previous years; highest in the western stratums. Further, the abundance of 0+ lobsters was again highest in the Mabuiag stratum, in contrast to the low abundance recorded in 2015.

The population surveys were initially designed to provide accurate and precise indices of 1+ and 2+ lobster abundance, and 0+ lobsters were rarely observed during mid-year surveys as they only settle in June. Hence, refined sampling would likely provide better estimates of 0+ abundance. Although all 0+ lobsters observed during the pre-season surveys are recorded, it is not known how many are missed due to their small size and cryptic behaviour. Nevertheless, if the percentage of lobsters observed has remained constant throughout the study period, the density indices should be a reliable indicator of relative recruitment strength one year in advance. As for recruiting lobsters, additional future industry-run surveys could provide greater certainty about strength of the 0+ year-classes, and even earlier forecasting of stock size and TAC.

The persistent low abundance of 1+ lobsters in the northern strata is of concern for the local fishers, and particularly if the cause of the low abundance persists. The Mabuiag stratum is a key habitat for recently-settled lobsters and future recruitment and stock would be impacted by persistent poor habitat. However, the recovery of 0+ lobsters there in 2016 provided an encouraging sign that the impacts of the recent sand incursions and seagrass die backs are relatively transient.

The 2015 coral bleaching event may also have had an impact on the seabed habitats in western Torres Strait, particularly the reef-edge communities. The possible flow on impacts of this event are discussed briefly below.

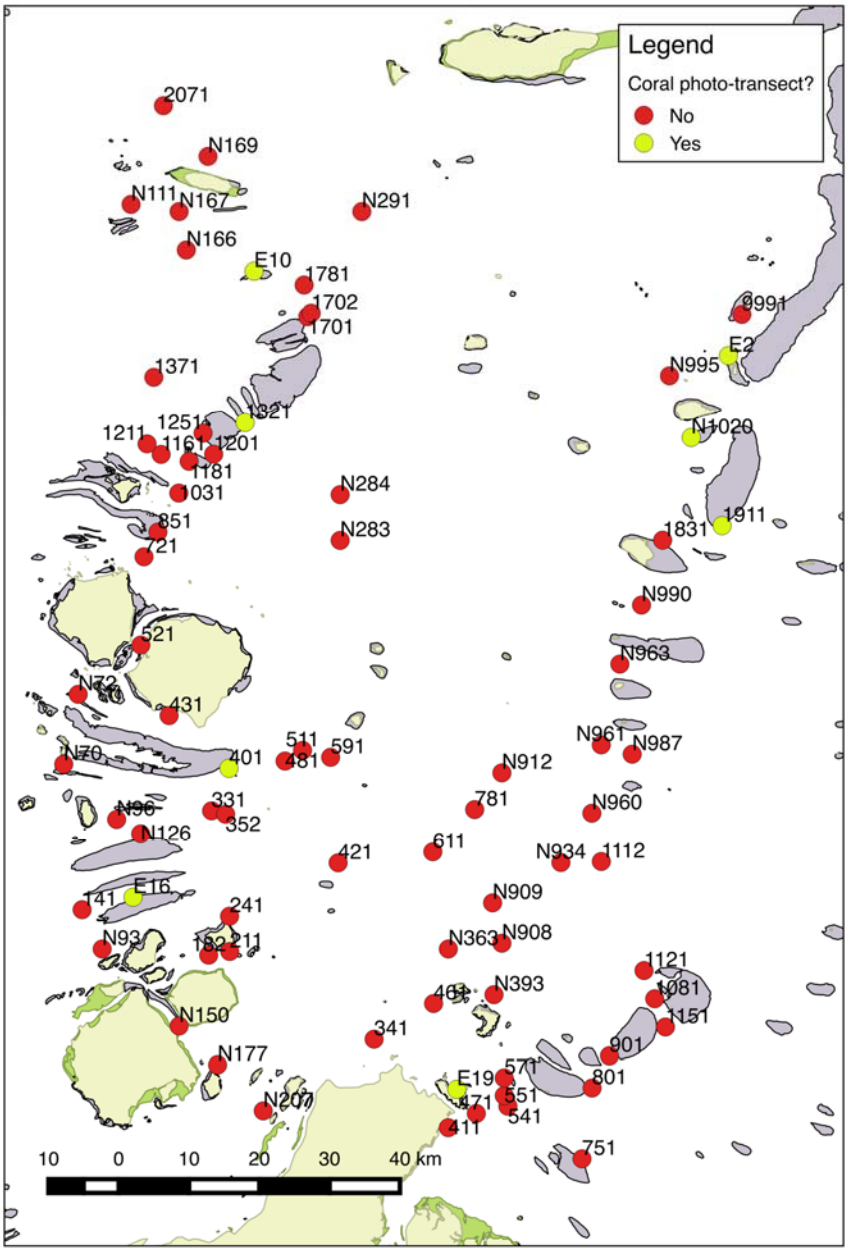


Figure 1-1. Map of western Torres Strait showing sites surveyed during the 2016 TRL pre-season population survey. Sites where coral monitoring photo-transects were conducted in 2015 and 2016 are marked yellow.

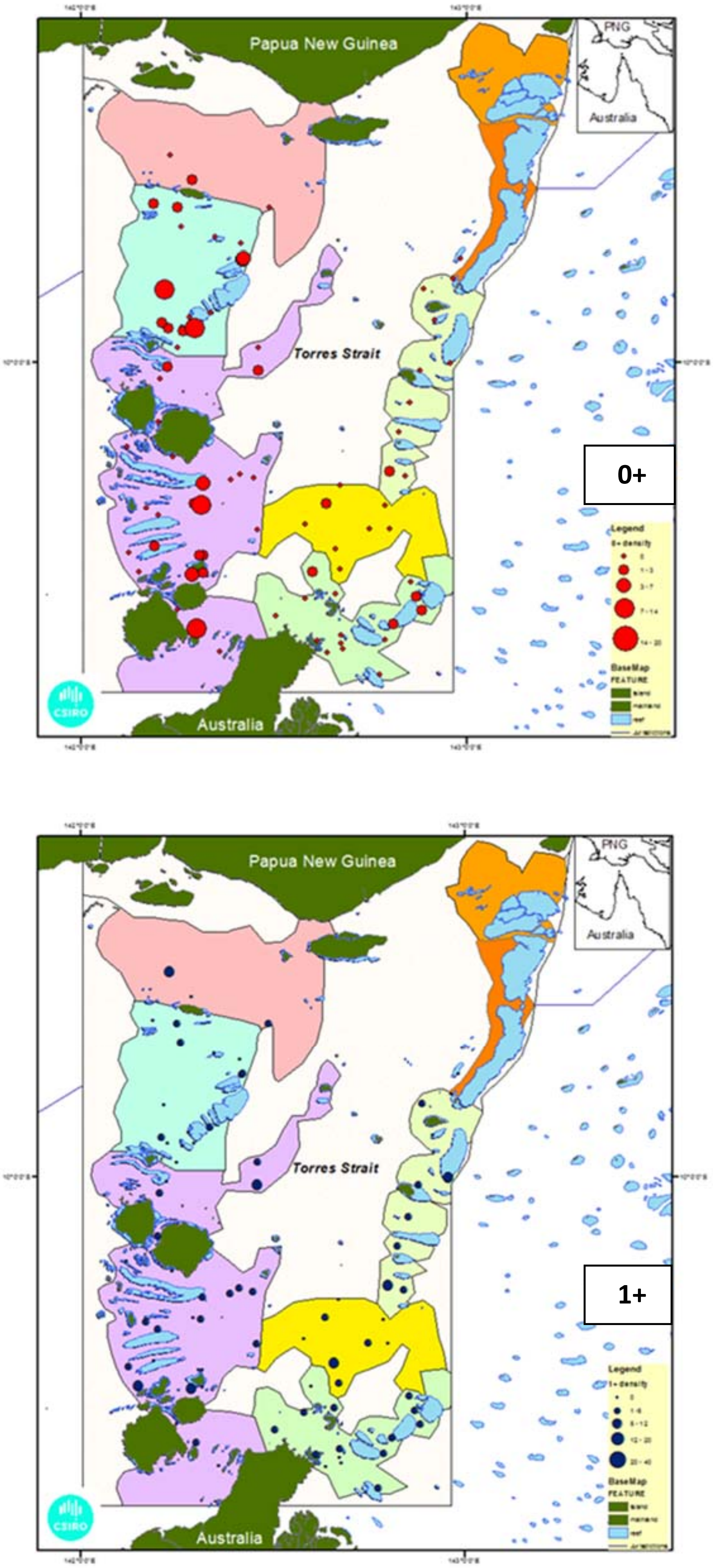


Figure 1-2. **Density of recently-settled (0+) and recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during the 2016 pre-season population survey in western Torres Strait. 2+ lobsters were observed at only seven sites as the surveys are conducted after the annual breeding migration.**

Table 1-1. **Description of the four options used to estimate ornate rock lobster (*Panulirus ornatus*) abundance indices from pre-season population surveys conducted in Torres Strait between 2005 and 2015.**

Pre-season Index Option	Number of Strata	Description
1a. ALL SITES	7	All transects for all years utilised
1b. ALL SITES excluding Buru	6	All transects for all years utilised, excluding those from the Buru stratum
2a. MID_YEAR ONLY SITES	7	All mid-year transects (74) utilised
2b. MID_YEAR ONLY SITES-common across all years	6	All common transects utilised; equal number in each year

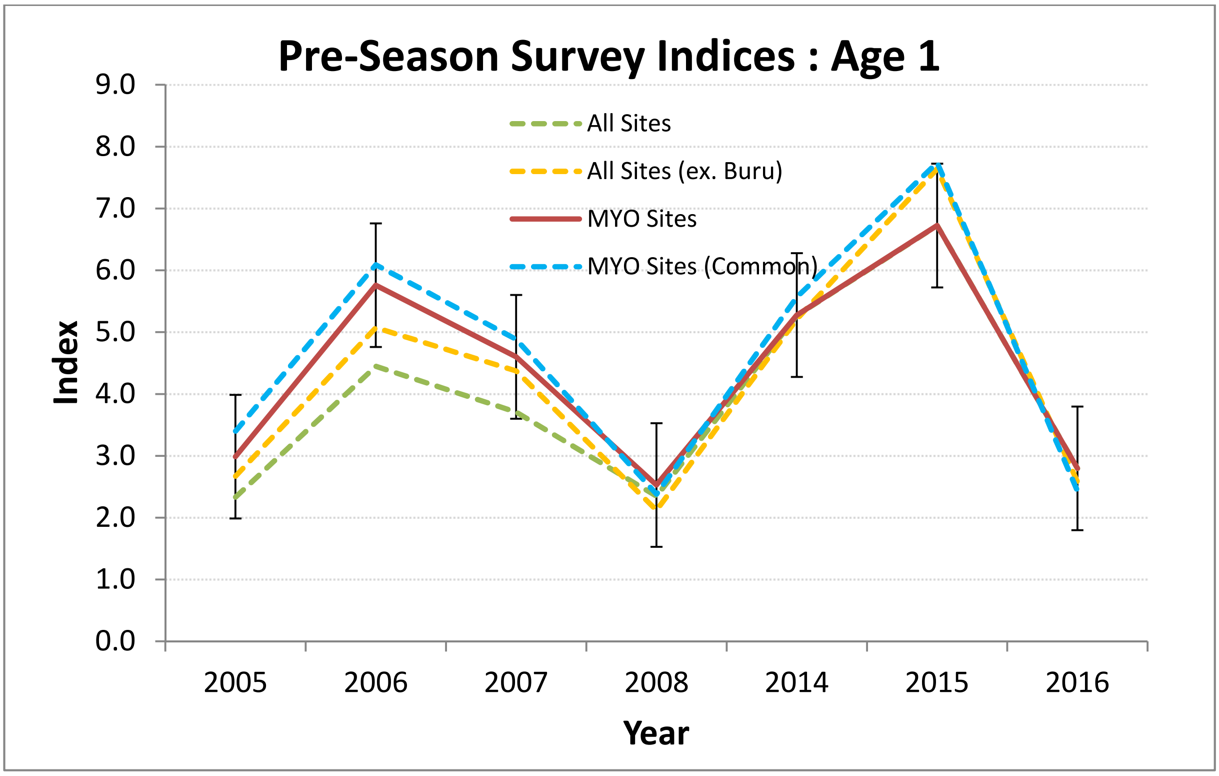


Figure 1-3. **Four comparative indices of abundance of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season surveys in Torres Strait between 2005 and 2016 (note surveys were not done during 2009-2013). Error bars of MYO indices represent standard errors.**

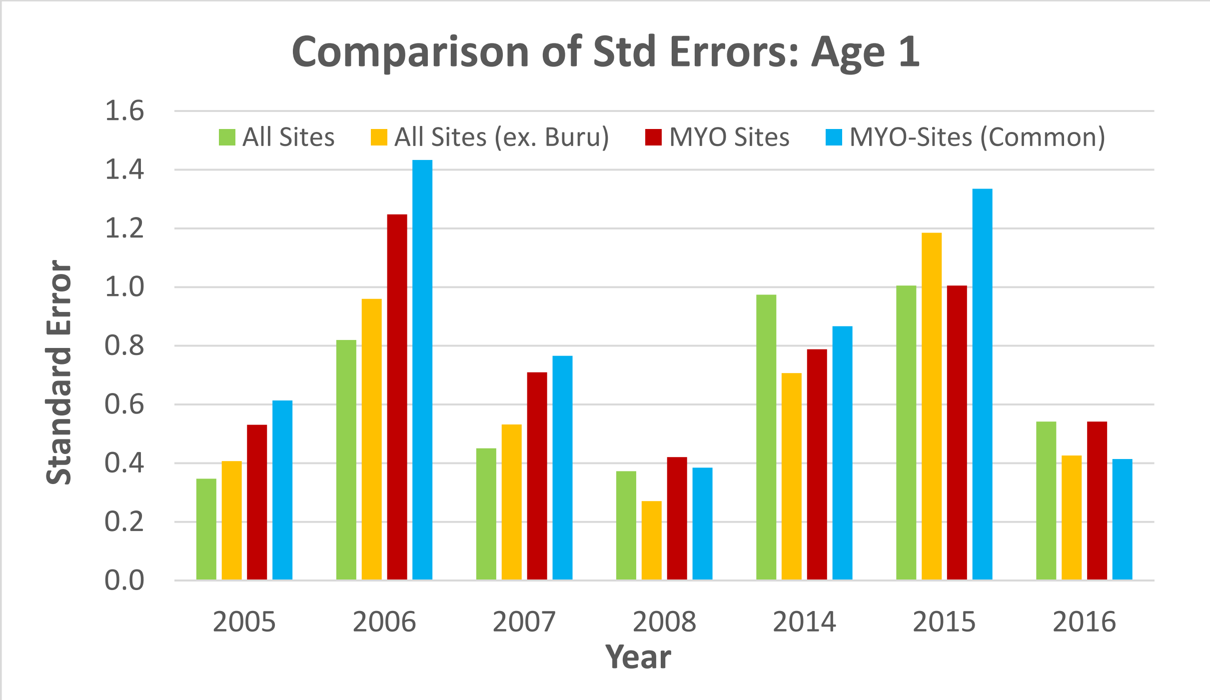


Figure 1-4. **Comparative standard errors for four indices of abundance of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season surveys in Torres Strait between 2005 and 2016 (note surveys were not done during 2009-2013).**

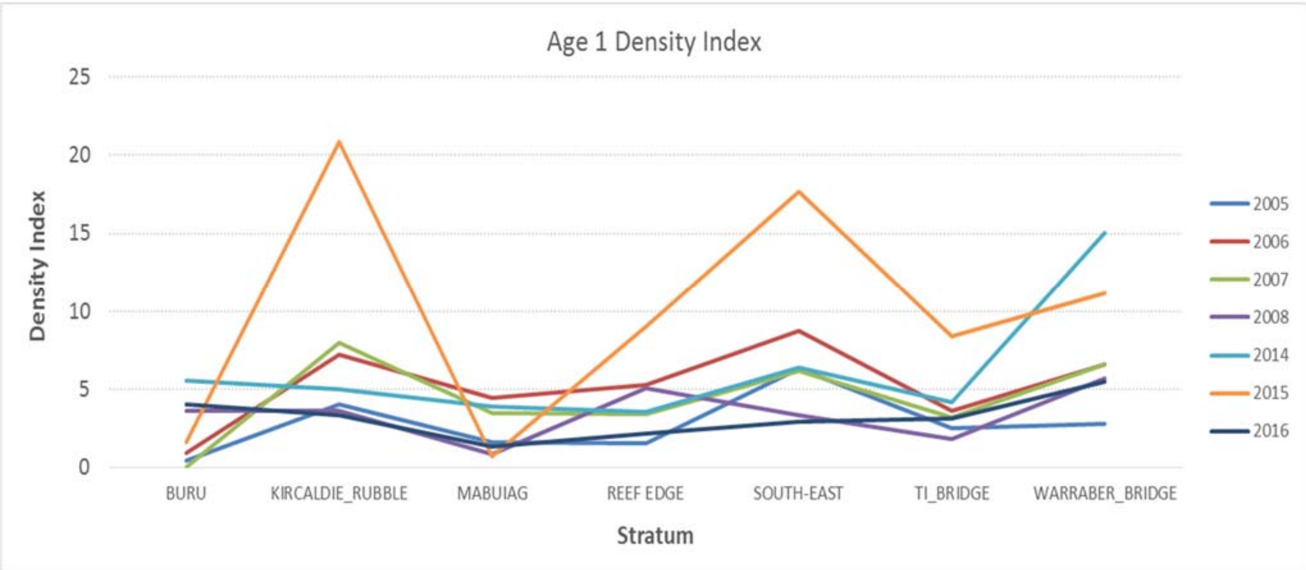


Figure 1-5. **Comparative indices of abundance of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded in each sampling stratum during pre-season surveys in Torres Strait between 2005 and 2016 (note surveys were not done during 2009-2013).**

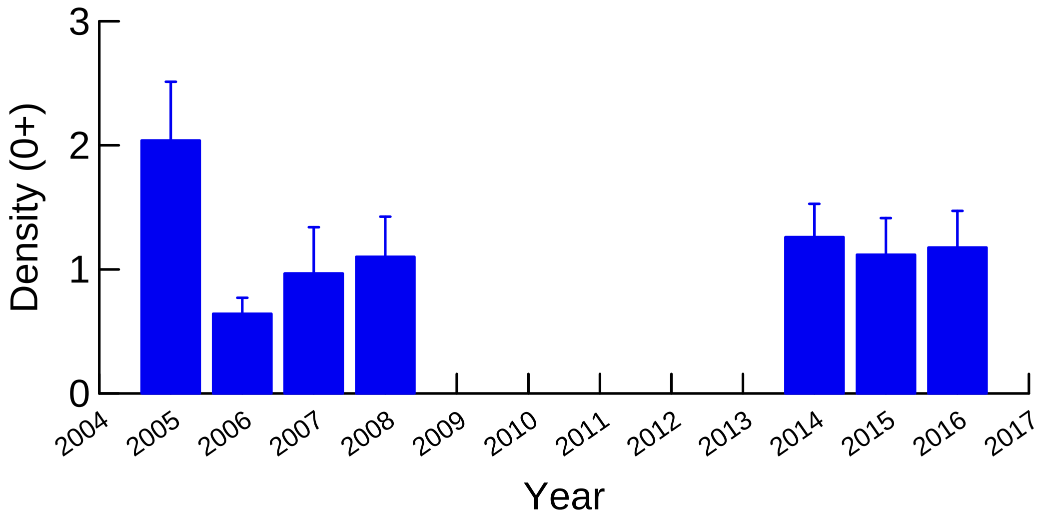


Figure 1-6. Density of recently-settled (0+) ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season population surveys in western Torres Strait between 2005 and 2016 (note surveys were not done during 2009-2013).

Comparison of abundance indices

As the fishery transitions to a QMS it is important to monitor the effectiveness of new population survey protocols in continuing the 27 year stock status time series established since 1989.

The relationship between recruiting (1+) lobster indices recorded from mid-year and pre-season surveys in the same years is shown in Figure 8. Although comparisons are only available for five years it is not surprising that the relationship is highly significant (R^2=0.97), given that the surveys were conducted only four months apart (June and November). Nevertheless, it is important that this relationship is maintained as management moves to a QMS reliant on indices from a pre-season population survey only.

The phasing out of mid-year surveys, in favour of pre-season surveys conducted closer to the fishing season opening has meant that no fishery-independent index of fished (2+) lobster abundance will be available. However, the availability of comprehensive TVH catch and effort data since 1994 has allowed comparison of the survey and CPUE indices in the same years (Figure 9). The relationship between these indices is highly significant (p=0.000) providing confidence that for future stock assessments the CPUE data will be a reliable proxy for 2+ and subsequently breeding stock abundance. Further, the recent data (>2010) has provided a range of stock sizes (most notably 2011) and the long-term significant relationship holds. TIB catch and effort data are available for more recent years and similarly provide an index of abundance for 2+.

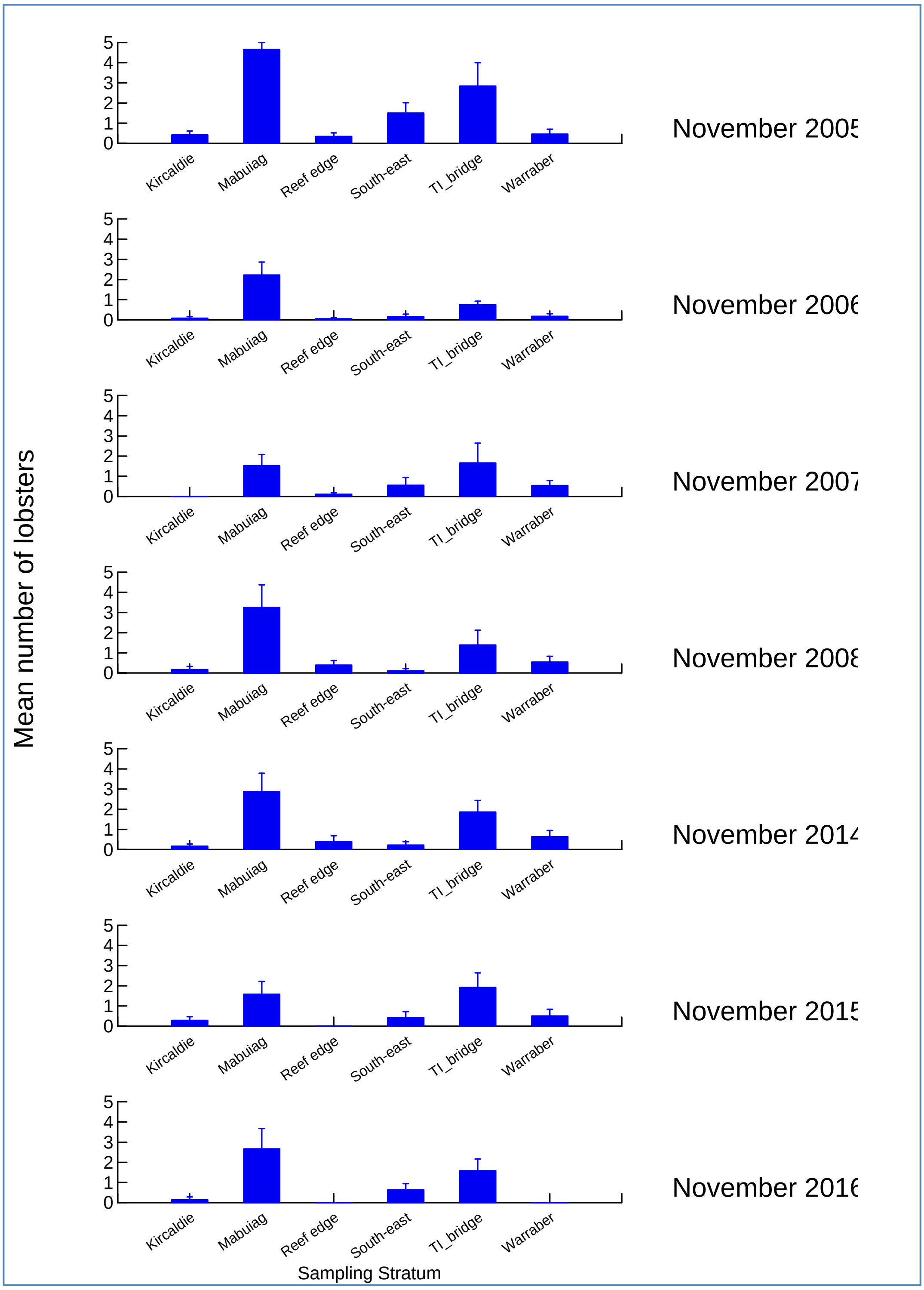


Figure 1-7. Density of recently-settled (0+) ornate rock lobsters (*Panulirus ornatus*) recorded in each sampling stratum during pre-season population surveys in western Torres Strait between 2005 and 2016.

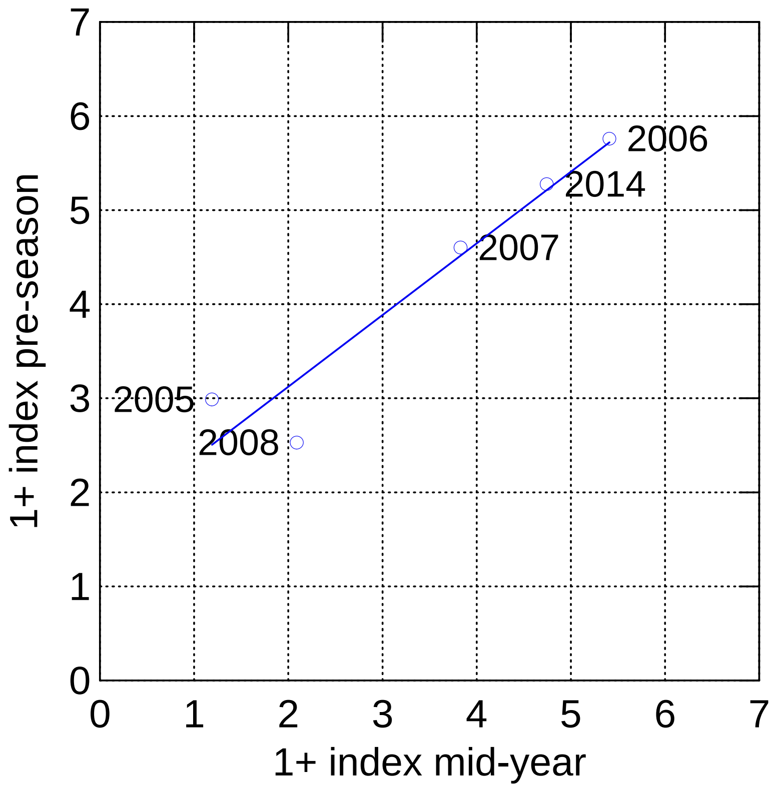


Figure 1-8. **Relationship between recruiting (1+) lobster abundances indices recorded from mid-year and pre-season surveys for years 2005-2008 and 2014. Line denotes the linear regression (R^2=0.97).**

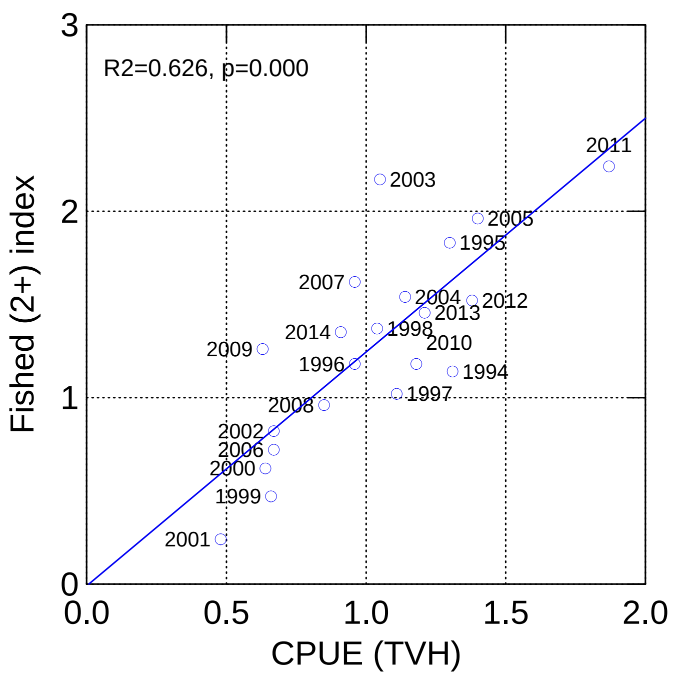


Figure 1-9. Relationship between CPUE indices for the TVH sector and fished (2+) indices recorded from mid-year surveys for years 1994 to 2014. Line denotes the linear regression (R^2=0.626).

Size/Age Distribution of Sampled Lobsters

The size distribution of lobsters sampled during the 2016 pre-season survey was similar to those recorded in previous years (Figure 10), comprising mainly 1+ lobsters. Since 2014 there have been very few legal size lobsters in the sampled population. Further, the modal size of recruiting (1+) lobsters recorded since 2014 has been generally decreasing, although comparable mean size was recorded in 2007.

The reason/s for the reduced size of lobsters in recent surveys are difficult to determine as both settlement timing and growth influence size distribution of the population. Climate change impacts have been implicated for other Australian lobster fishery impacts, both positive and negative. For TRL the recent high water temperatures are unlikely to impact growth negatively, but habitat changes may have affected lobster prey items (eg. demersal shell beds) and indirectly affected growth.

Long-term Torres Strait Seabed Habitat Monitoring

The seabed habitat monitoring recorded during the previous mid-year surveys provided the longest time series of habitat trends. The trends in percent cover of seabed substrates recorded during mid-year population surveys between 1994 and 2014 showed a relatively consistent composition of sand/mud (Mean 56 %), declining composition of rubble (Mean 13%) and an increasing composition of hard substrate which includes consolidated rubble and limestone pavement (Mean 29 %, Figure 11). Seagrass cover increased steadily during 2000 to 2010, and remained above the long-term average. Interestingly algal cover showed a steady decline throughout the period studied from ~20% to ~10%.

Overall the distribution of seabed habitats remained remarkably consistent throughout the study period, and apart from seagrass and algae, most habitats showed no declining or increasing trends indicative of longer term regional changes that might affect lobster abundance.

The consistency of seabed habitat distributions recorded during the benchmark 1989 and 2002 surveys further illustrated the consistency in habitat distribution in the medium term. However, recent bleaching events and high water temperatures events suggest that this consistency may not continue and lobsters will be required to adapt to changing environmental conditions.

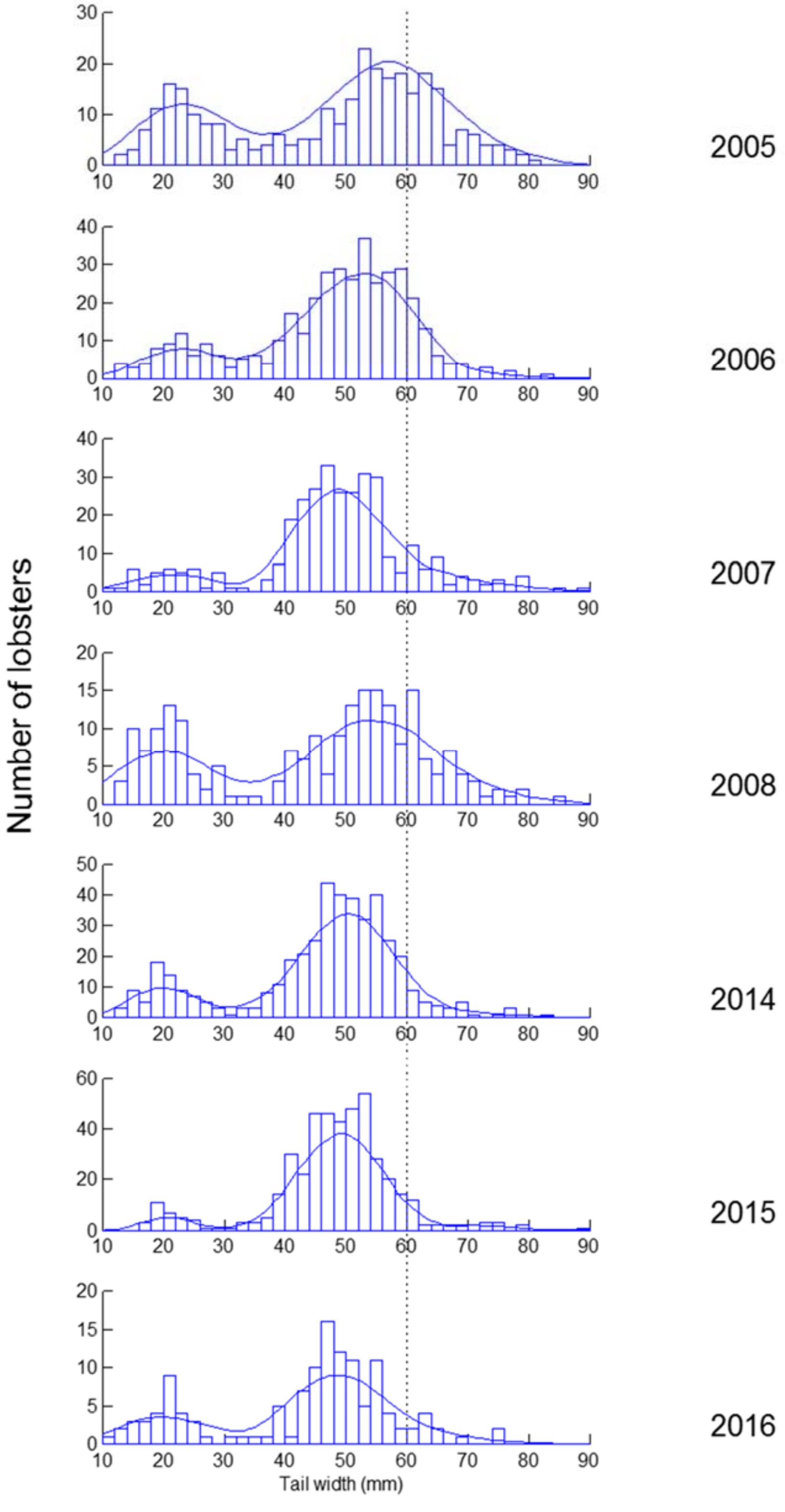


Figure 1-10. Length frequency distributions of lobsters (*Panulirus ornatus*) sampled during pre-season population surveys in Torres Strait in 2005-2008, 2014-2016. The dotted line represents the minimum legal size (90 mm CL ≈ 60 mm tail width).

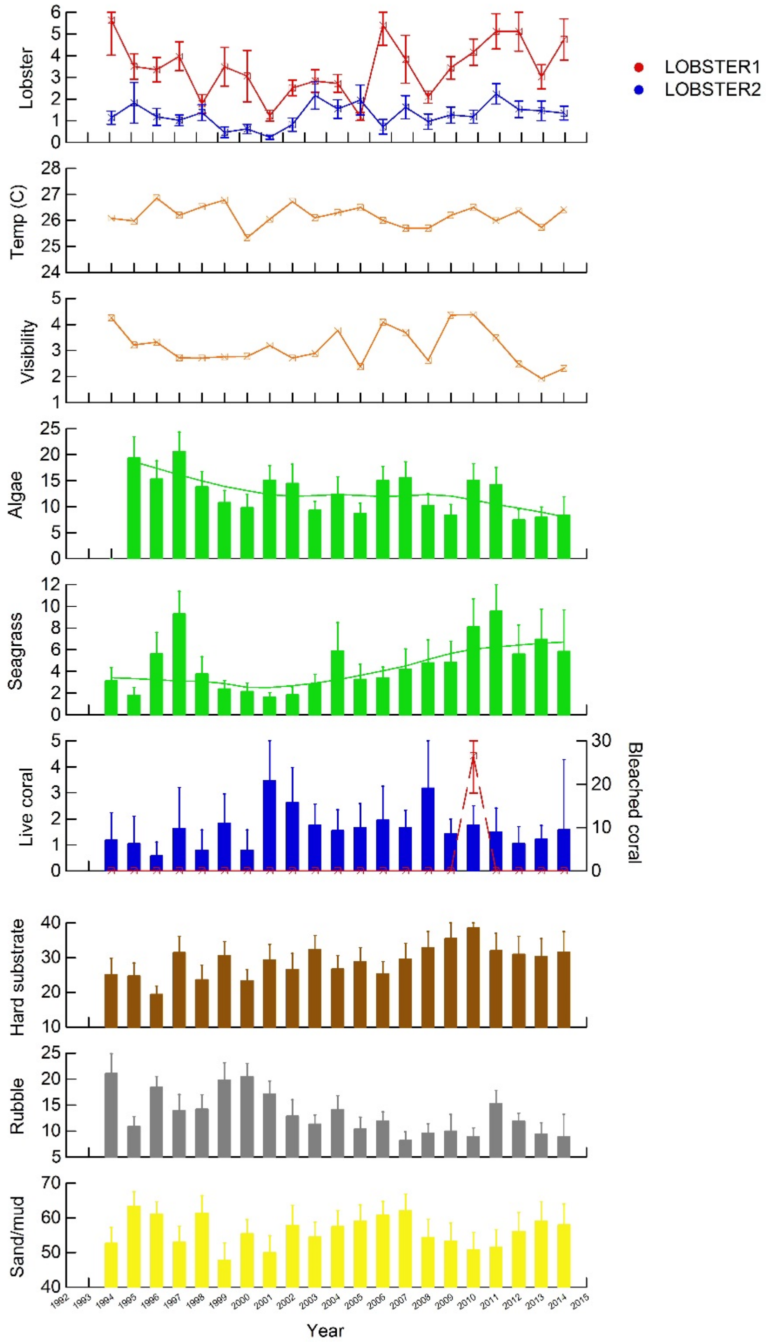


Figure 1-11. **Mean percent covers of abiotic and biotic categories and lobster (*Panulirus ornatus*) indices recorded during mid-year population surveys in Torres Strait during 1994 to 2014. Error bars represent standard errors.**

Although sand incursions were recorded at a number of transects during the 2015 pre-season population survey, the overall cover of sand at repeated sites in that year was the lowest recorded (Figure 12). The percent cover of sand returned to average level in 2016. Nevertheless, sand wave movements in Torres Strait have been rapid and continual to date and seabed communities are relatively well adapted to these incursions. Further, seagrass and algal cover estimates were above the long-term average suggesting any sand incursions had not impacted the floral communities at the transects surveyed. The habitat data recorded in 2016 suggested habitat was not to blame for low lobster abundance, noting however that the impact of major sand incursions earlier in the year may not be detected at the time of the survey.

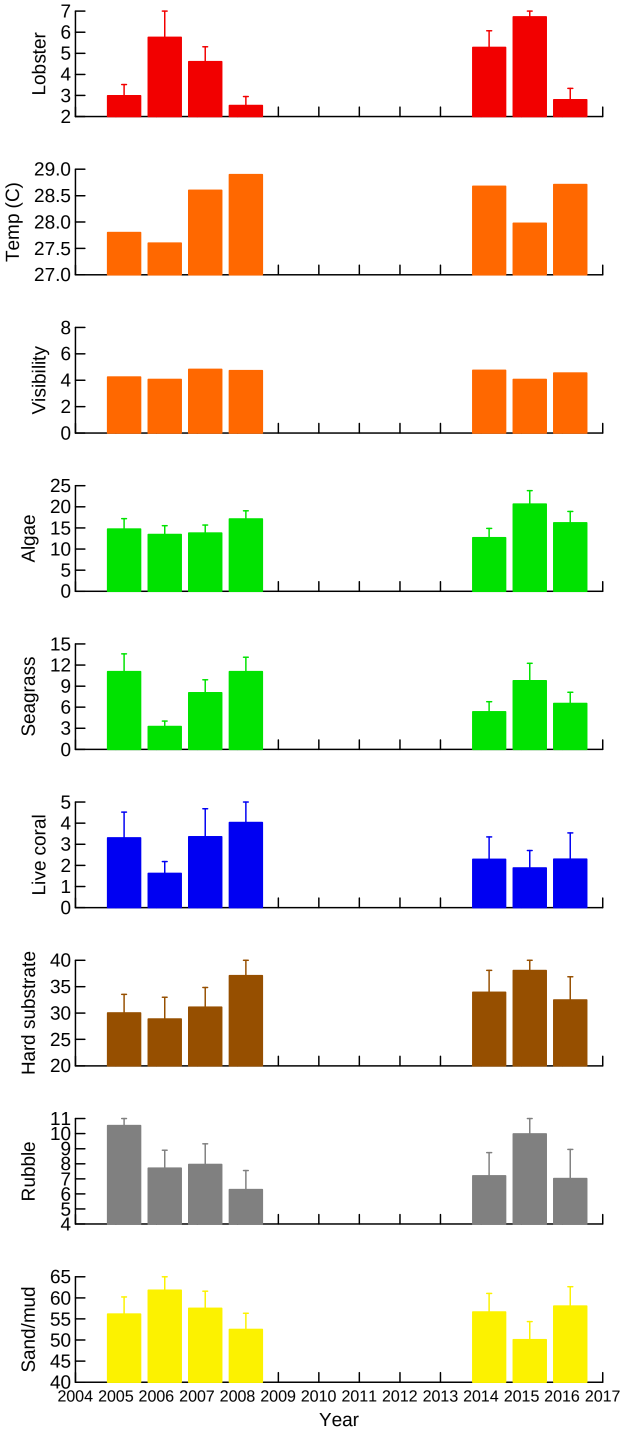
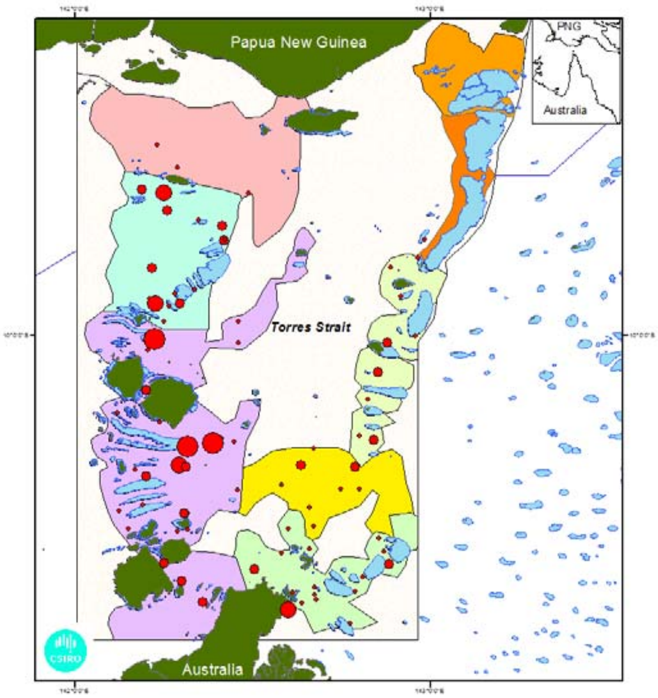


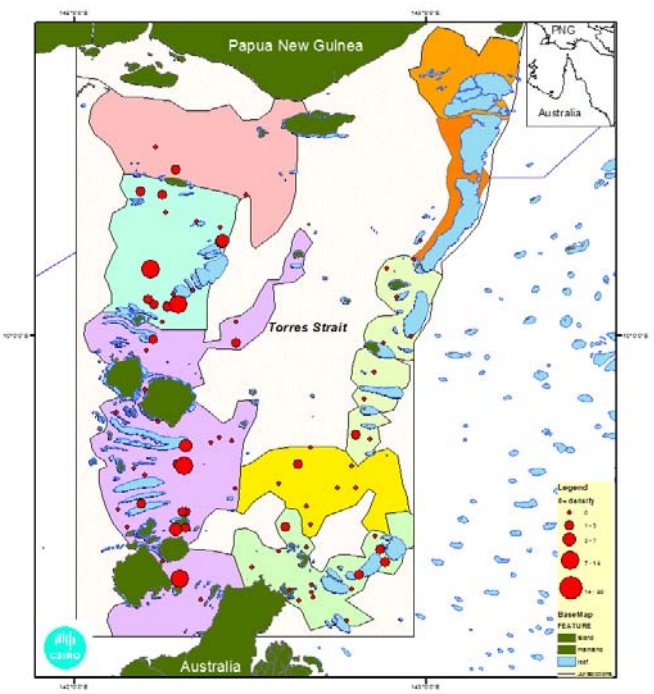
Figure 1-12. **Mean percent covers of abiotic and biotic categories and lobster (*Panulirus ornatus*) indices recorded during pre-season surveys in Torres Strait during 2005 to 2016. Error bars represent standard errors.**

Discussion

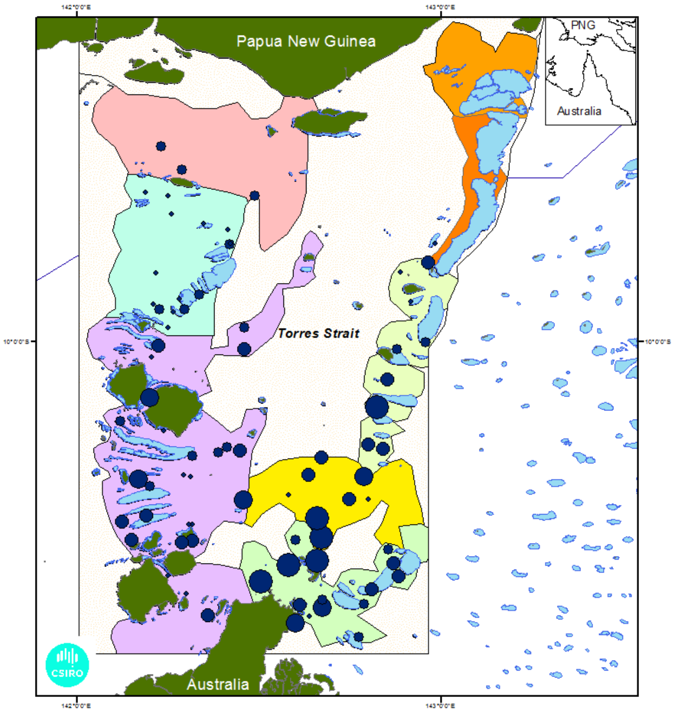
The 2016 pre-season lobster population survey was completed within the original timeframe and results of the 2016 pre-season survey were presented at the TRL RAG meeting on 13 December 2016, to provide stakeholders with the updated stock assessment and the revised recommended biological catch for 2017. Phasing out of the mid-year surveys has placed greater reliance on TVH and TiB sector CPUE in providing relative abundance data for the fished (2+) year classes. The recent research to standardise these data has improved the reliability and accuracy of the CPUE indices and the strong correlation obtained in previous work between the TVH and TiB CPUE estimates and the 2+ year class indices from the surveys suggests that CPUE data is a viable alternative for future stock assessment.

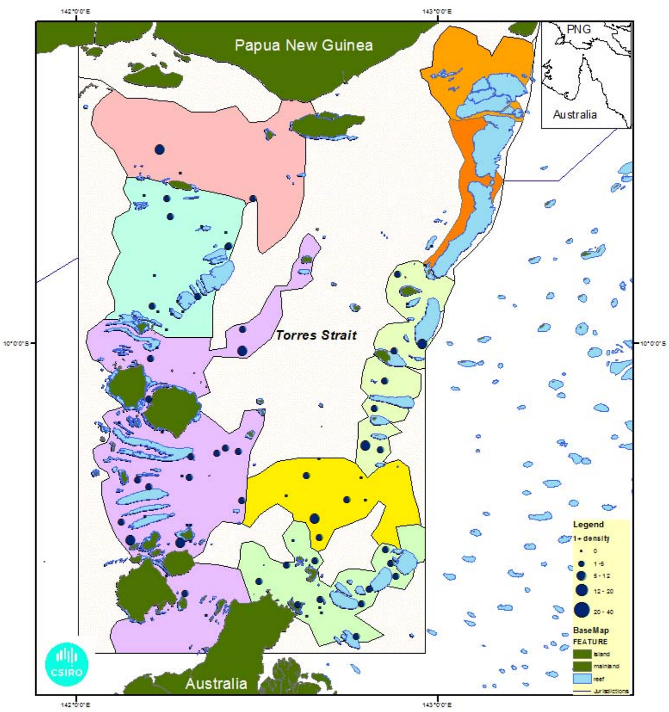
Appendix 1.1. Density of recently-settled (0+) ornate rock lobsters (*Panulirus ornatus*) recorded during the 2015 (top pane) and 2016 (bottom pane) pre-season population surveys in western Torres Strait.





Appendix 1.2. Density of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during the 2015 (top pane) and 2016 (bottom pane) pre-season population surveys in western Torres Strait.





2. Chapter 2 - 2016 Updated Assessment of the Tropical Rock Lobster (*Panulirus ornatus*) Fishery in Torres Straits following November 2016 preseason survey

Summary

This document summarises the post-Nov 2016 preseason survey update of the integrated stock assessment model presented at the December 2016 TRLRAG, as well as further work to revise the stock assessment model, for presentation at the TRLRAG meeting in April 2017. The TRLRAG agreed that if the fishery transitions to using an empirical Harvest Control Rule (eHCR) to inform the Recommended Biological Catch (RBC), then the stock assessment would only need to be conducted every three years. However until such time as this is formally adopted, the stock assessment model is being used to inform the RBC for the tropical rock lobster *Panulirus ornatus*.

The data updates include the latest (Nov 2016) pre-season survey results, the catch total for 2016 and revision for 2015, and revisions and updates to the commercial CPUE (TVH & TIB) data series. More recent updates to the commercial catch-at-age data have also been included in a revised version of the model. The full details of the stock assessment model are also provided in this report.

The model predictions for 2017 are not as optimistic as has been the case for the past couple of years because they are based mostly on the preseason survey 1+ index, which is similar to the lowest of the 6 values recorded thus far, namely 2.5 in 2008. Note that the model results presented here are fitted to the preseason survey index based on midyear sites only.

The model fits the Preseason survey data reasonably well, and most of the CPUE series, except that the model is unable to satisfactorily fit the 2015 CPUE data for TVH or TIB sectors. The potential reasons for this are discussed in more detail in Plagányi et al. (2015a,b). Anomalous environmental changes almost certainly caused a change in catchability in 2015, but there is also likely to have been an impact of changes in lobster habitat on their survival and productivity, but there are no data available to assist in separating the effect of changes in catchability and survival on the overall catches for 2015 (noting that the total catch was higher than initially expected due to trawling catches). The model assumes constant annual natural mortality, and hence cannot straightforwardly model the change in catchability and/or survival without additional information, and hence the Reference Case model has not included any *ad hoc* adjustments, but these could be further investigated via sensitivity analyses.

The Reference case model presented here is fitted to the TVH CPUE Main Effects Int1 option and the standardised Seller+QA CPUE TIB series as described in Campbell *et al.* 2016a,b. There isn't much difference between the alternative CPUE standardisations.

The 2016 stock-recruit residual is seen to be lower than the average value, but is not as low as has been predicted to be the case for some past years.

Applying the reference case model straightforwardly with the updates as described, suggests a RBC(2017) of 495t [90% CI 315-676t] [75% CI 369-622t]. This value is lower than the RBC of 624t that would be recommended if applying the empirical Harvest Control Rule (eHCR), but note that the latter estimate falls within the 90% confidence interval. The resource spawning biomass is estimated

to be currently at approximately the 1973 level (used as a proxy for carrying capacity K although the stock is highly variable and fluctuates around this level), but given the variability, it is predicted that next year's spawning biomass will drop to 63% of this level.

Overall the resource is assessed to be in good condition, even though there are indications that 2017 will be a below-average year with a consequent low RBC value recommended by the TRLRAG. The Pre-season survey planned for November 2017 will be essential to cross-check this result this year, given that no midyear survey data are available and there have recently been a number of environmental anomalies.

Introduction

A new stock assessment model (termed the "Integrated Model") (Plagányi *et al.* 2009) was developed in 2009 for the following reasons:

- The new model facilitates the move to a quota management system, in that it integrates all available information into a single framework to output a RBC;
- The new model addresses all of the concerns highlighted in a review of the previous stock assessment approach (Bentley 2006, Ye et al. 2006, 2007);
- The new model incorporates the Pre-Season survey data as well as CPUE data available from the TVH sector;
- The growth relationships used in the model were revised;
- The new model is of a form that could be used as an Operating Model in a Management Strategy Evaluation (MSE) framework, given that the need for a MSE to support the management of the TRL fishery has been identified by the TRL RAG.

The model outputs a single RBC (with Confidence Interval) for each year, which is an integrated estimate that takes into account all available sources of information. The Integrated Model is a widely used approach for providing TAC advice with associated uncertainties. More formally, it is a Statistical Catch-at-Age Analysis (SCAA) (e.g. Fournier and Archibald 1982). This paper summarises the revised 2016 model assessment using the 2016 pre-season survey data.

The revised Reference Case includes the following specifications (see Plagányi et al. 2010):

- fitting to the CPUE data assuming a hyperstable relationship (with hyperstability parameter 0.75), and setting a lower bound of 0.15 (value selected by TRLRAG in 2013) to the variance associated with the CPUE data because it is less reliable than the survey data;
- increasing the stock recruit variance parameter from 0.3 to 0.5 to capture larger fluctuations in recruitment;
- estimating a different selectivity for the 1973-1988 period;
- using as the new Reference spawning biomass level the annual biomass of mature lobsters on 1 November each year i.e. at the start of the annual migration period;
- estimating the 2016 recruitment residual;
- the use of historic information to permit estimation of a large recruitment event that is known to have occurred in 1988, the year before the long-term surveys commenced. This is an important development as if this good recruitment is not accounted for in the model, the model tries to reconcile the subsequent dynamics by over-estimating the pristine stock size.

In addition, in response to review comments in 2012, the following changes are also implemented:

- There is no lower limit on the sigma parameter associated with fitting to the catch at age information;
- The fitting to the commercial catch-at-age information ignores the years when there are no true data;
- Given there are catch-at-age data for the pre-1989 period, recruitment residuals are estimated for all years from 1985.

More recently, the following changes have been made:

- The model is fitted to the new standardised TIB CPUE series, in an analogous manner to the method to fit the TVH CPUE data, and hence assuming a hyperstable relationship (with hyperstability parameter 0.5) and setting a lower bound of 0.15.
- The historic catch estimates have been reanalysed resulting in some changes which are incorporated in the revised model;
- The model fits to the historical midyear survey series for the two age classes separately rather than as a combined series (and including fitting to the age proportions).

Finally, the TRLRAG agreed to use as the Reference Case model a version with the main effects interaction 1 TVH CPUE data and the standardised Seller&QA scenario TIB CPUE data.

Objectives

This document describes an update of the 2016 TRL stock assessment model using the results of the preseason survey conducted in November 2016.

Methods

The model details are given in Appendix 2.1 of this document. A summary of the input catch data is shown in Table 2-1. In addition, the latest November 2016 Pre-season survey (Chapter 1) is included in the model. The historical mid-year survey data are shown in Table 2-2. The commercial catch-at-age data have been updated (with these updates not available at the time of the December 2016 assessment) and the revised series is shown in Table 2-3.

The model uses the latest revised historic catch estimates. As previously, the trawl catch has been separated from the other catches because of differences in the selectivity / targeting of the trawling sector which was focused predominantly on migrating 2+ lobsters. This is important because in the early years the trawling catch comprised 35 – 90% of the total TRL catch (Table 2-1). If recent trawling catches continue, then the model will need to similarly account for these separately to the total catch.
The TVH CPUE data input series have been revised and updated for the period 1989-2016 and TIB for 2004-2016 (Campbell *et al.* 2016a,b).

The model is fitted to additional historic information as described in Plagányi et al. (2010). An adjustment has been made to the model to allow use of a separate selectivity function to be applied to the period 1973 to 1988, prior to the introduction of a MLS of 100mm TL in July 1988. The model already accounts for the subsequent size limit change to 115mm in 2002. Background information on the above specifications is given in Plagányi et al. (2010) and this document.

The relationship between stock abundance and CPUE was explored, and found to be better represented by a hyperstable relationship, than the assumption that CPUE is proportional to stock abundance (see e.g. Harley *et al.* 2001). Based on additional sensitivity tests that were conducted, the Reference case model therefore uses a power curve with a hyperstability shape parameter of 0.75. This suggests that CPUE remains high while stock abundance declines. This is consistent also with results from considering an ecometric production function approach (Pascoe et al. 2013). In addition, the MSE and production function analyses (Pascoe et al. 2013, Plagányi et al. 2012, 2013) suggested that the TIB CPUE relationship was characterized by a greater degree of hyperstability, and hence the Reference case model uses a power curve with a hyperstability shape parameter of 0.5, and sensitivity to alternative choices of this value were tested but don't have a large effect on model outputs.

Table 2-1. Lobster catches (tonnes whole weight) landed in different jurisdictions from 1973 to 2016. Catches comprised of both whole animals and tails have been converted into units of whole mass using the conversion ratio of 1kg tail=2.677 kg live.

YEAR	AUS_DIVERS	TIB	TVH	AUS_TRAWL	PNG_DIVERS	YULE_DIVERS	PNG_TRAWL	TOTAL_TS
----------	-------	-------	---------	----------	-----------	---------	--------	--------------
1973	0	0	54	19	562	616	0	616
1974	0	0	75	83	107	182	0	182
1975	0	0	62	13	214	276	0	276
1976	0	0	48	0	262	310	0	310
1977	0	0	72	35	131	203	0	203
1978	296	0	43	3	187	526	0	526
1979	309	0	56	13	0	365	0	365
1980	328	21	94	3	589	1032	0	1032
1981	495	131	96	3	262	984	0	984
1982	669	201	102	3	399	1371	0	1371
1983	433	139	86	0	112	770	0	770
1984	331	8	86	0	29	454	0	454
1985	537	24	187	16	0	748	0	748
1986	891	21	198	62	0	1110	0	1110
1987	622	0	128	54	0	750	0	750
1988	537	0	150	5	0	687	17	704
1989	651	0	211	24	0	862	16	878
1990	490	0	158	0	0	648	8	656
1991	444	0	168	0	0	612	4	616
1992	423	0	134	0	0	557	12	569
1993	506	0	166	0	0	672	6	678
1994	578	123	0	247	0	0	825	15
1995	557	101	0	257	0	0	814	63
1996	584	227	0	228	0	0	812	57
1997	653	275	0	241	0	0	894	51
1998	661	330	0	201	0	0	862	74
1999	410	95	0	163	0	0	573	128
2000	418	129	0	235	0	0	653	150
2001	121	52	69	0	173	0	5	299
2002	216	68	148	0	327	0	43	586
2003	484	123	361	0	211	0	5	700
2004	716	235	481	0	182	0	0	898
2005	903	358	545	0	228	0	0	1131
2006	288	152	135	0	142	0	0	430
2007	529	260	269	0	228	0	0	757
2008	284	184	100	0	221	0	0	505
2009	227	136	91	0	161	0	0	388
2010	426	143	283	0	293	0	0	719
2011	704	201	504	0	165	0	0	869
2012	523	153	370	0	174	0	0	697
2013	496	134	362	0	108	0	0	604
2014	421	149	273	0	151	0	110	682
2015	327	174	153	0	236	0	0	563
2016	445	207	238	0	127	0	0	572

Table 2-2. Mid-year survey data summary for the period 1989-2014. Indices reflect abundance.

	Age 1+	S.E.	Age 2+	S.E.
1989	0.059	0.243	0.093	0.305
1990	0.619	0.787	0.077	0.277
1991	0.294	0.542	0.118	0.344
1992	0.585	0.765	0.449	0.670
1993	0.238	0.488	0.108	0.329
1994	2.637	1.624	0.092	0.303
1995	0.349	0.591	0.891	0.944
1996	0.314	0.560	0.15	0.387
1997	0.453	0.673	0.062	0.249
1998	0.186	0.431	0.129	0.359
1999	0.799	0.894	0.059	0.243
2000	1.411	1.188	0.05	0.224
2001	0.061	0.247	0.009	0.095
2002	0.124	0.352	0.096	0.310
2003	0.271	0.521	0.41	0.640
2004	0.169	0.411	0.184	0.429
2005	0.033	0.182	0.471	0.686
2006	0.87	0.933	0.113	0.336
2007	1.21	1.100	0.287	0.536
2008	0.079	0.281	0.125	0.354
2009	0.274	0.523	0.139	0.373
2010	0.372	0.610	0.09	0.300
2011	0.659	0.812	0.217	0.466
2012	0.823	0.907	0.143	0.378
2013	0.309	0.556	0.206	0.454
2014	0.903	0.950	0.102	0.319

Table 2-3. Summary of commercial catch at age information from 1989 to 2016.

Year	Nb 1+	Nb 2+
1989	5.2	83.9
1990	7.6	60.9
1991	16.6	50.1
1992	14.2	43.6
1993	14.8	56.1
1994	25.3	72.0
1995	18.4	66.8
1996	23.2	68.5
1997	28.2	71.0
1998	14.7	72.4
1999	19.8	44.3
2000	-	-
2001	-	-
2002	-	-
2003	-	-
2004	2.3	88.4
2005	1.4	111.3
2006	3.1	43.2
2007	1.2	77.5
2008	2.7	47.0
2009	0.3	42.9
2010	4.7	64.4
2011	0.8	92.4
2012	5.0	63.4
2013	2.9	49.5
2014	1.3	63.4
2015	0.9	51.1
2016	0.6	48.0

Results

MODEL FITS

The fits of the Model to all available data sources are shown in Figures 2.1 to 2.9. The results are shown primarily for the TRLRAG Reference Case, because the Revised model version that includes fitting to the revised commercial catch at age data was very similar apart from fitting to the more recent data. Hence the likelihood contribution from fitting to the expanded catch-at-age data (CAA) series was substantially improved but did not change model parameters or outputs.

The starting number of lobsters is estimated and Figure 2-1 compares the benchmark survey (Ye et al. 2004) observed total lobster abundances in 1989 and 2002 with the corresponding model estimates. The Integrated model is fitted to the survey midyear index of abundance (in terms of total numbers of 1+ and 2+ lobsters) (Figure 2-2) and the observed and model-predicted proportions in each age class are compared in Figure 2-3.

The model fits to the catch at age data are adequate (Figure 2-4). The variability in the lobster age groups is well captured and the model reflects the post-2001 (increased size limit) decrease in the relative proportion of 1+ lobsters that are caught.

There were six data points available from the Pre-season survey for the TRLRAG Reference Case, and the model was fitted to data on both 0+ and 1+ abundance, with a close fit evident (Figure 2-5). The fit is better for the 1+ age group than the 0+ age group, but incorporation of the latter assists in strengthening prediction of future lobster abundance, even given the fairly large uncertainty associated with these estimates.

Comparisons between CPUE data from the TVH sector (in kg per tender-day from 1994 to 2016) (standardised as described in Campbell *et al.* 2016a) and corresponding model-predicted estimates are shown in Fig. 2-6a (when fixing the lower bound of sigma at 0.15). Similarly, Fig. 2-6b shows the fit to the standardised CPUE TIB data as described in Campbell *et al.* 2016b. The Reference Case assumes a hyperstable relationship between biomass and CPUE (TVH) as follows (Fig. 2-6c):

$$\left(\frac{C}{E}\right)_y^{TVH} = q_{TVH}\left(B_y^{ex}\right)^{0.75}$$

And similarly for the TIB CPUE data:

$$\left(\frac{C}{E}\right)_y^{TIB} = q_{TIB}\left(B_y^{ex}\right)^{0.5}$$

Comparison between historic data and model estimates of the proportions of 1+ and 2+ lobsters in the catch is shown in Figure 2-7. The fit in the early years is reasonably good, with the later deviations in the fit partly a result of a slight conflict between these data and the catch at age data.

The fitted stock-recruit relationship from the Reference-case model version is shown in Figure 2-8, which also highlights the spawning stock biomass estimates in recent years. The stock-recruit residuals are shown in Figure 2-9, from which it is clear that recruitment has been high over the recent period but has declined substantially this year. There is considerable variation about the stock-recruit curve (as is expected), but nonetheless there is some support for an underlying stock-recruit relationship.

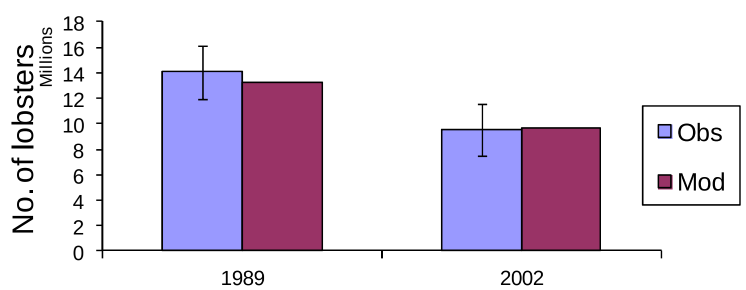
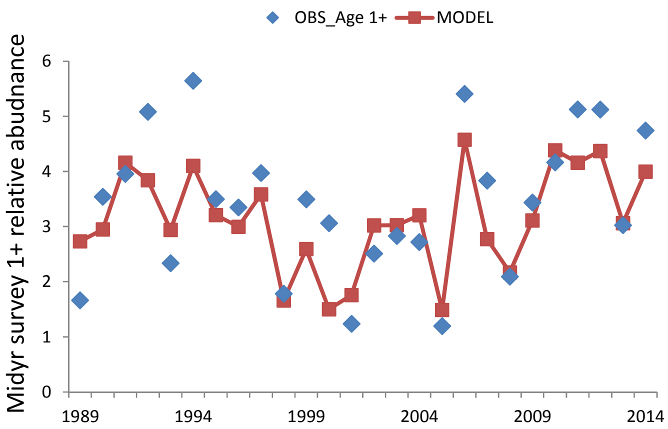
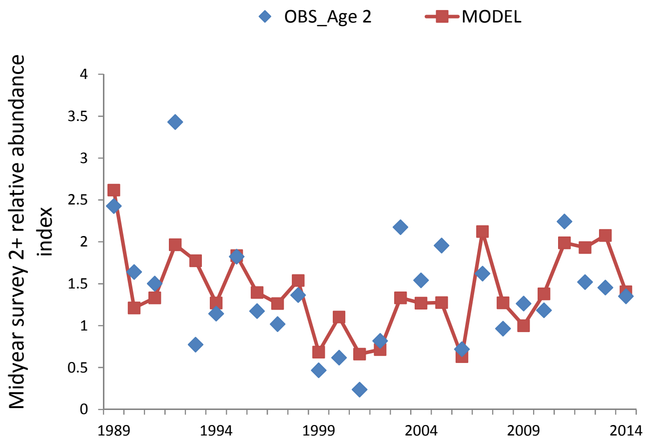


Figure 2-1. Comparison of benchmark survey observed lobster total abundance (with standard errors) and corresponding Reference Case model-estimates of abundance.





Fit shown when combining total numbers from survey

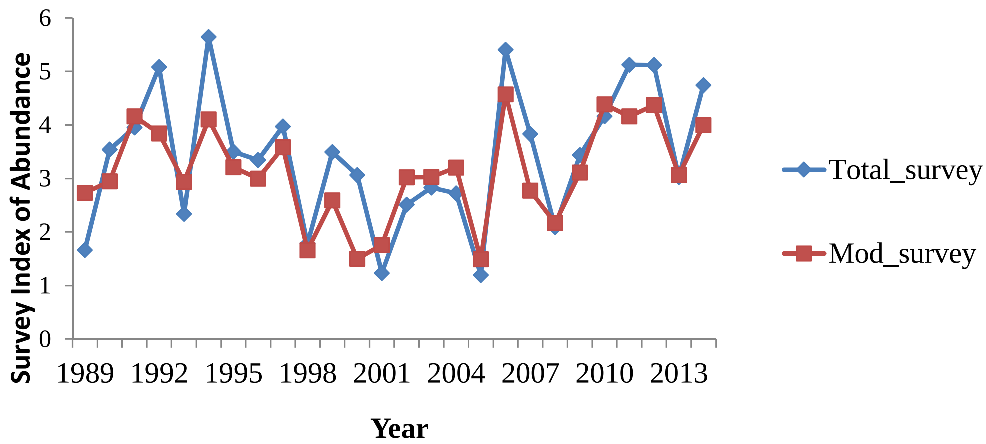


Figure 2-2. Comparison between survey midyear index of abundance (in terms of total numbers of 1+ and 2+ lobsters) compared with the corresponding model-estimated values for TRLRAG Reference Case.

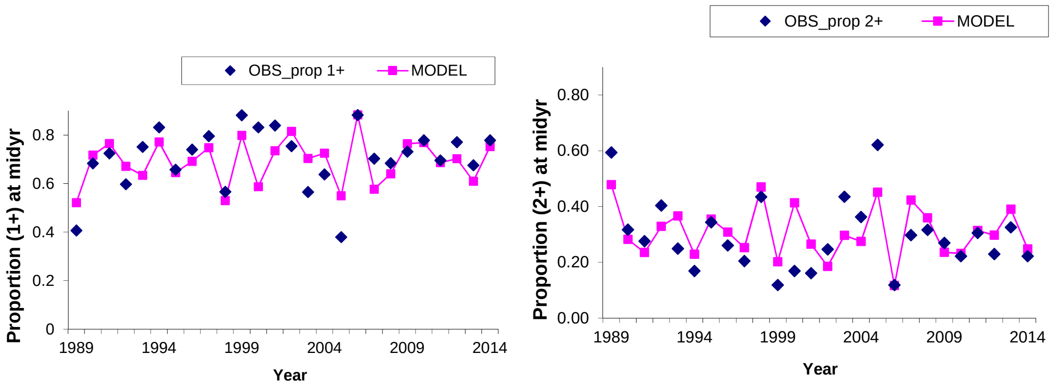


Figure 2-3. Comparison between observed and model-predicted proportions of 1+ and 2+ lobsters in the midyear survey.

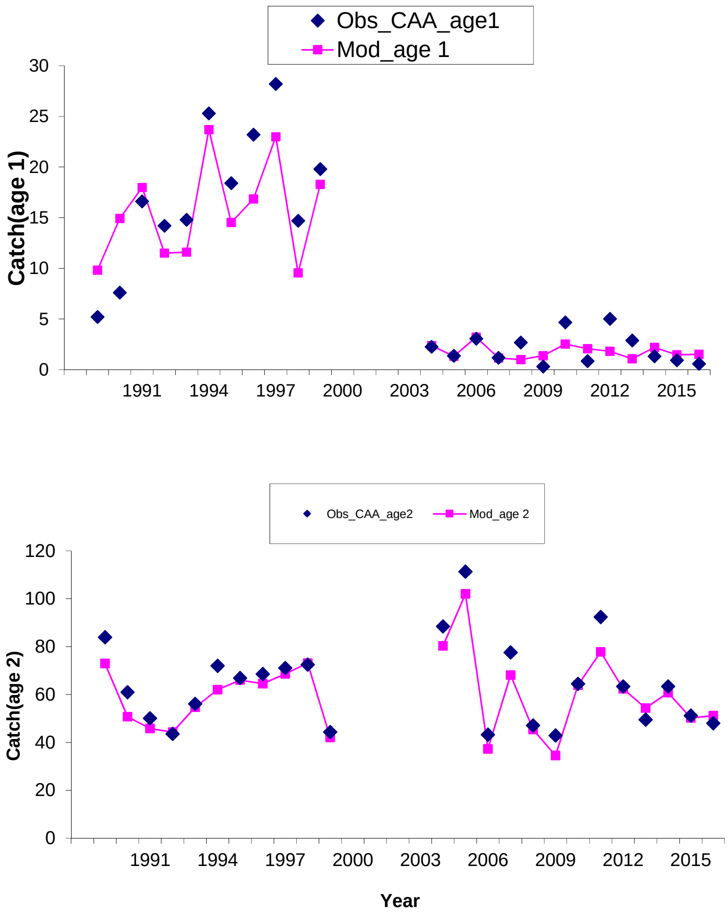
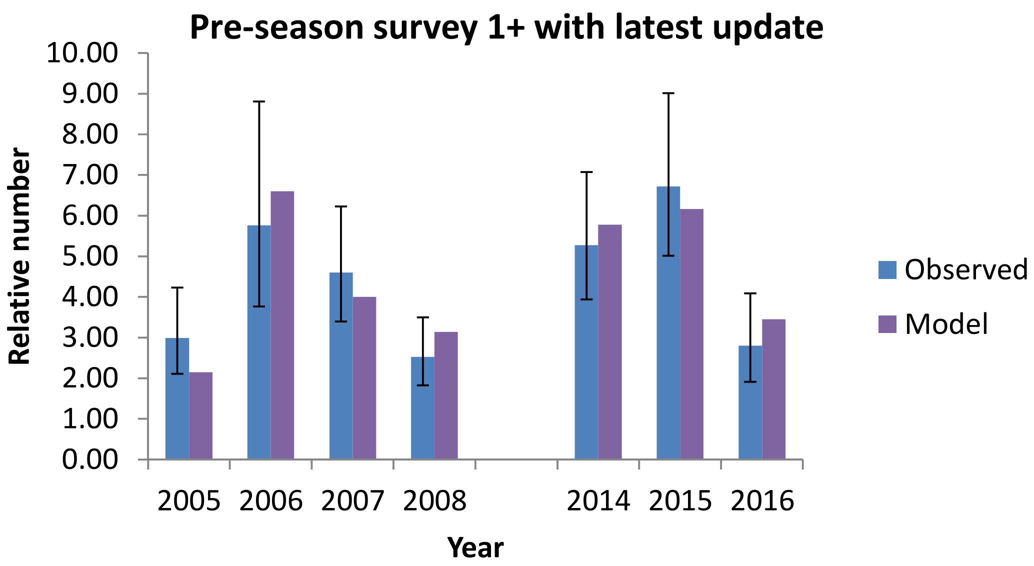


Figure 2-4. Comparison between available commercial catch-at-age data and corresponding model-predicted estimates. Similar for Reference Case model and revised model with Pre-season survey.

(A)



(B)

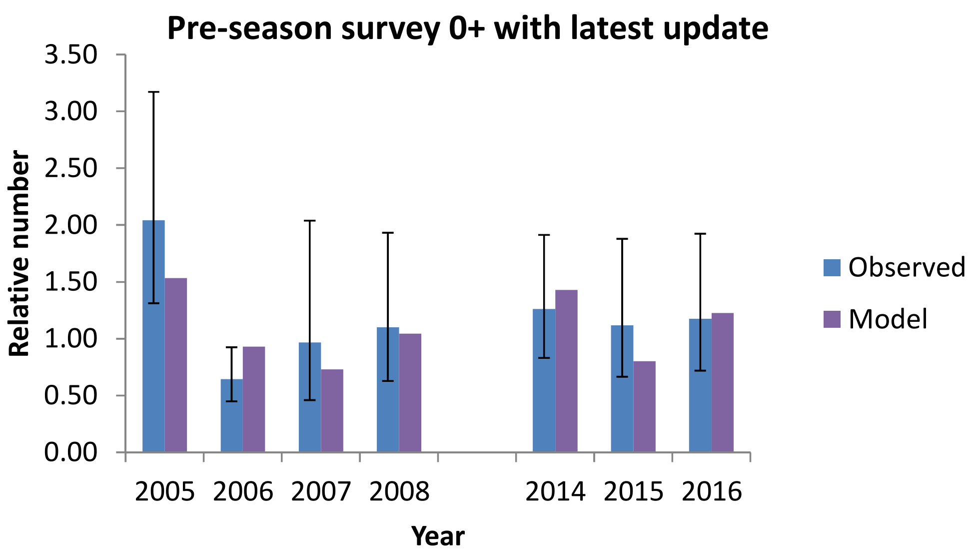
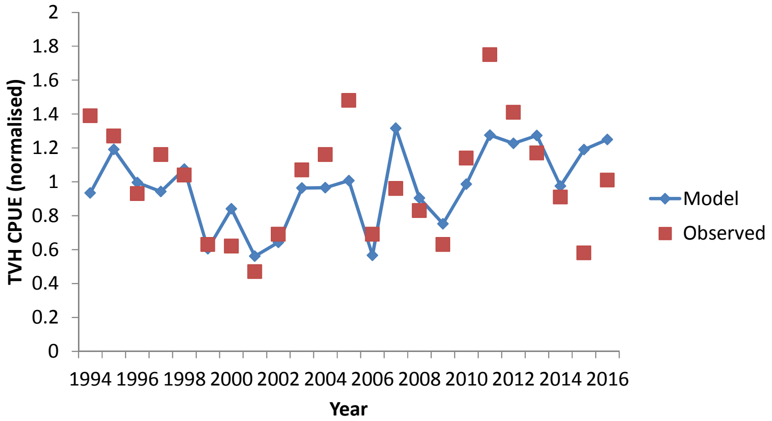
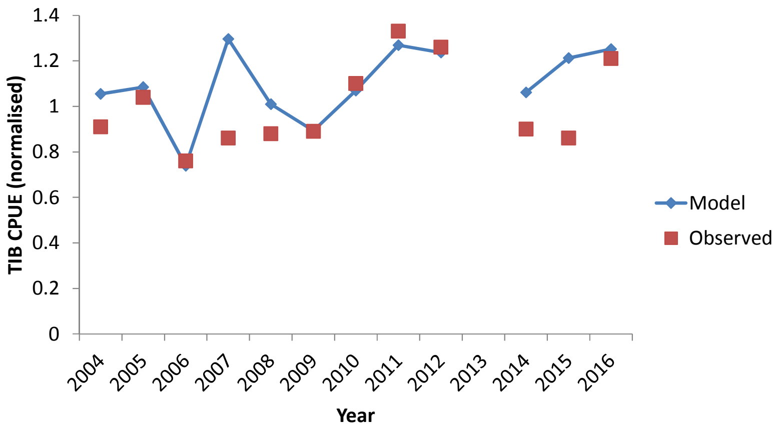


Figure 2-5. Comparison between observed Pre-season survey data (expressed in terms of number * 10^4) and corresponding (A) 1+ and (B) 0+ model-predicted estimates for TRLRAG Reference Case.

a) FIT TO TVH CPUE (sigma lower bound = 0.15); MAIN EFFECTS Int1 MODEL



b) FIT TO TIB CPUE (sigma lower bound = 0.15); TIB Seller&QA



c) HYPERSTABLE RELATIONSHIP

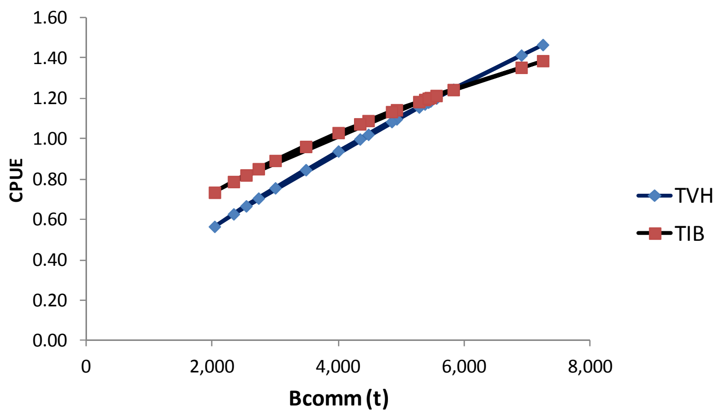


Figure 2-6. Comparison between CPUE data and corresponding model-predicted estimates. The plots are respectively a) Reference-Case fit to CPUE standardised estimates from the TVH sector with lower bound for sigma set at 0.15, b) fit to TIB CPUE standardized estimates available from 2004-2016; and c) plot of the hyperstable relationship (with power shape parameter 0.75 and 0.5 respectively) between CPUE and exploitable biomass for the TVH and TIB sectors.

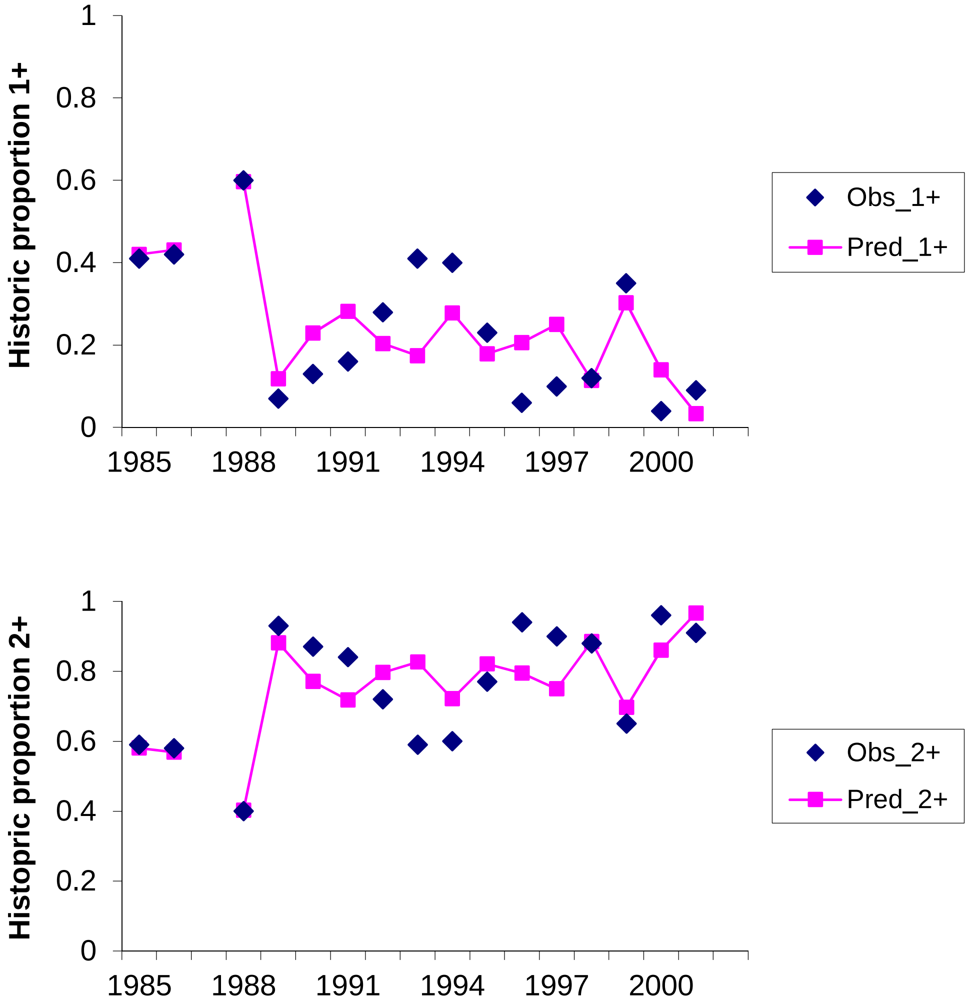


Figure 2-7. Comparison between historic data and model estimates of the proportions of 1+ and 2+ lobsters in the catch.

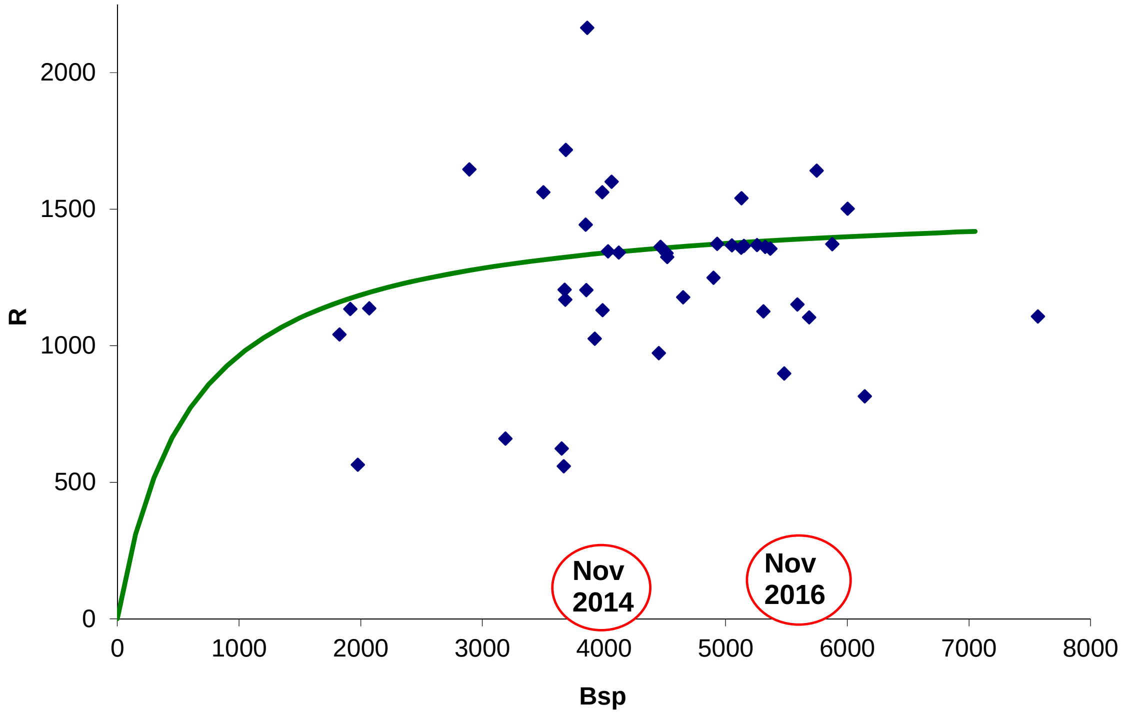


Figure 2-8. Integrated model stock recruitment relationship of the Torres Strait rock lobster fishery. Diamond symbols are output from the age-structured stock assessment model, solid line is a fitted curve, and circled years highlight spawning stock levels in those years.

Figure 2-9. Plot of stock-recruit residuals. Note the low 2016 residual.

ESTIMATES OF MODEL PARAMETERS

A full set of model parameter estimates, depletion statistics and likelihood contributions for the TRLRAG Reference Case including 2016 Pre-season survey and a sensitivity that includes the recently updated commercial catch at age information is shown in Table 2-4. In all cases the 90% Hessian-based Confidence Intervals (CI) are given alongside. The new Integrated model estimates a total of 37 parameters, namely the starting biomass $B(1973)^{sp}$, natural mortality *M*, 1+ selectivity for the 1973-1988, 1989-2001 and post-2002 periods, and 32 stock-recruit residuals. The steepness parameter *h* could not be precisely estimated as the confidence interval associated with the previous estimate is very wide hence steepness *h* is fixed in the Reference Case at 0.7, based on the median of a fisheries database (Myers et al. 1995). The natural mortality estimate of 0.69 [90% C.I. 0.56 – 0.82] year^{-1} is reasonably estimated. The pre-1989 selectivity parameter is more reliably estimated than previously due to estimating recruitment residuals for two earlier years.

Full selectivity of the 2+ age class is assumed given they are the target of the fishery and are assumed caught before the end of September, before they migrate out the Torres Straits. Selectivity of 1+ lobsters is substantially less because they are usually only susceptible to fishing after September and not all individuals will have attained the minimum legal size by that time. The selectivity coefficient for age 1+ lobsters was 0.44 for 1973-1988, 0.16 for the period of 1989-2001 and 0.02 for the remaining years. As expected, the decrease in selectivity during the recent time period is a consequence of a change in management measures having been introduced in 2002, which included an increase in the minimum legal size (to 115 mm tail length), a 4-month extension of the hookah ban (October to January) and a 2-month fishing closure (October-November) (Ye et al. 2006).

Following from the above, the level of fishing mortality on age 1+ lobsters is expected to be substantially less than that on age 2+ lobsters (Figure 2-10), with a decreasing trend evident following the implementation of the new management measures in 2002. The fishing mortality rate for age 2+ lobsters ranged from 0.09 year^{-1} to 0.27 year^{-1} (Figure 2-10), with a historic average (from 1989) of 0.15 year^{-1}. The target fishing mortality rate is 0.15 year^{-1}. The 2015 catch of 562t was assessed to have been below the target fishing mortality rate (0.10).

The fishing mortality estimates above refer to the combined estimate when lumping all TRL catches in the Torres Straits, except the trawling sector (Australian and PNG combined) catches. The latter are assumed to target 2+ lobsters only and were substantial in the early years (1973 – 1984) Figure 2-11, with small catches taken during the period (2001-2003) and zero values for all other years, except for some recent reports that are under discussion by the TRLRAG.

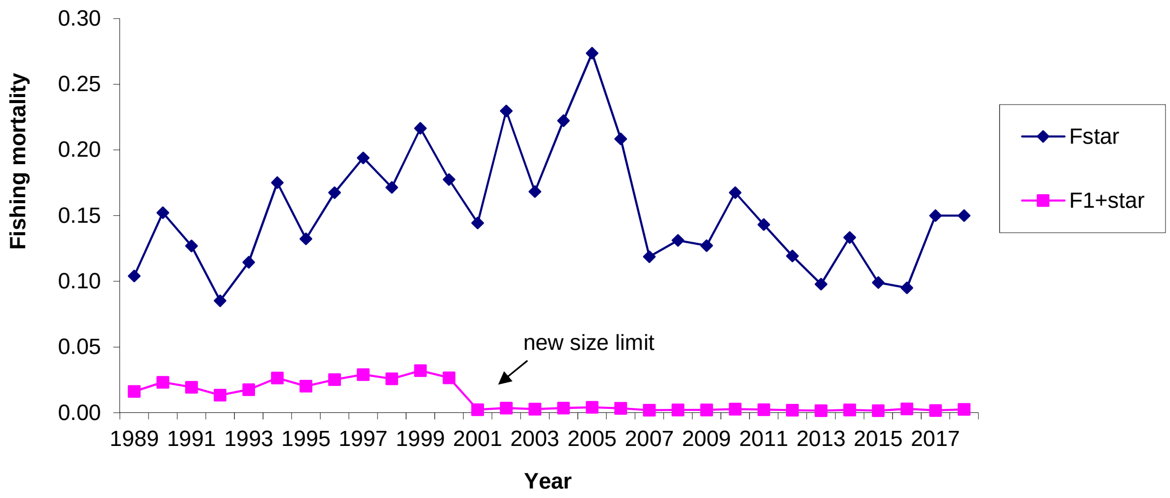


Figure 2-10. Model-estimated fishing mortality trends for 1+ (F 1+star) and 2+ (F 2+ star) lobsters. The 2002 change in size limit is highlighted and the 2015 fishing mortality set equal to the target value of 0.15.

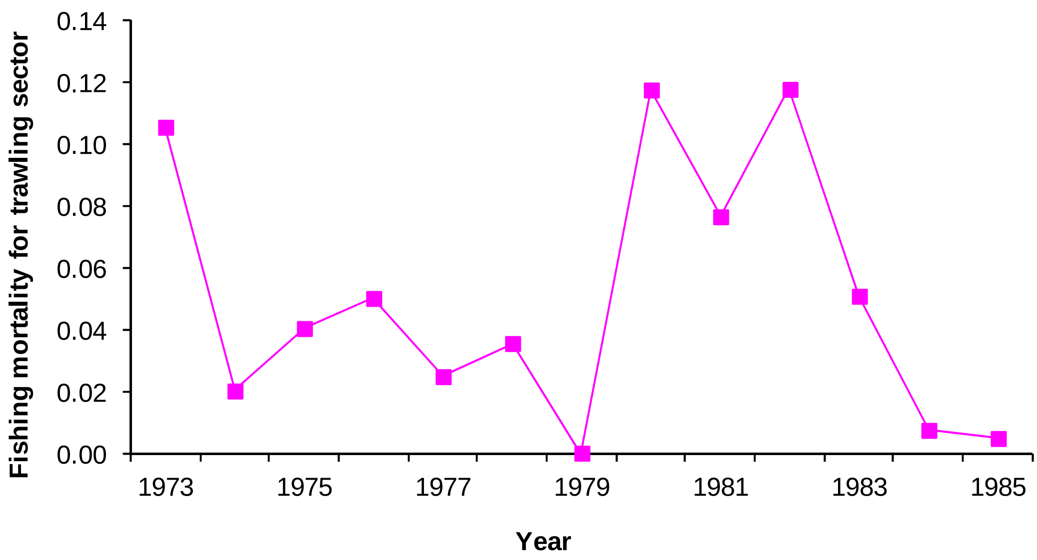


Figure 2-11. Model-estimated trawling sector fishing mortality trends for the early period of the fishery from 1973 - 1985.

Table 2-4. Summary of model parameter estimates for the RAG Reference Case and a subsequent update including recent commercial catch at age data (see text for details)

	(a) Reference Case			(b) Update with CAA data		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**
B(1973) ^{sp} *(tons)*	4947	3497	6397	4947	3499	6396
M	0.69	0.56	0.82	0.69	0.56	0.82
h	fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.44	0.24	0.63	0.44	0.24	0.63
Sel (age 1+) 1989-2001	0.16	0.14	0.19	0.16	0.14	0.19
Sel (age 1+) post2002	0.02	0.00	0.03	0.02	0.00	0.03
Recruitment residuals (1985-2016)		32 parameters			**32 parameters**	
Model estimates and depletion statistics						
B(2016) ^{sp} *(tons)*	5877	3671	8083	5872	3668	8077
RBCprelim(2017) model	495	315	676	495	315	675
RBCforecast(2018) model	758	546	970	757	545	970
Current Depletion (Nov)						
B(2016) ^{sp} */ B(1973)sp*	1.19	0.84	1.55	1.19	0.84	1.55
Bexp(2016) (tons)	6306	4179	8432	6300	4175	8424
No. parameters estimated	37			37		
'-lnL:overall	**-182.974**			-189.056		
AIC	**-291.948**			-304.112		
Likelihood contributions		**Sigma**	**q**		Sigma	q
'-lnL:CAA	-53.93	0.05		-60.38	0.05	
'-lnL:CAAsurv	-19.17	input from data		-19.17	input from data	
-lnL:CAA historic	-21.77	0.13		-21.77	0.13	
-lnL:Survey Index 1+	-24.53	input from data	3.761E-07	-24.31	input from data	3.780E-07
-lnL:Survey Index 2+	-13.20	input from data	3.935E-07	-13.04	input from data	3.953E-07
-lnL:Survey benchmark	-3.14	input from data		-3.14	input from data	
'-lnL:PRESEASON	-8.28	input from data	7.262E-07	-8.22	input from data	7.305E-07
-lnL:PRESEASON 0+	-5.79	input from data	8.436E-08	-5.82	input from data	8.504E-08
-lnL:CPUE (TVH)	**-26.02**	0.20	1996.0000	-26.02	0.20	1996.0000
-lnL:CPUE (TIB)	**-13.31**	0.20	2006.0000	-13.31	0.20	2006.0000
'-lnL:RecRes	6.15	0.50	(input sigma 0.5)	6.13	0.50	(input sigma 0.5)

Table 2-5. Summary of TRLRAG Reference Case TAC

TAC/Catch (t)	2012	2013	2014	2015	2016	2017
Forecast TAC (90% CI)	532 (282-782)	769 (485-1053)	767 (518-1016)	751 (556-945)	719 (515-923)	677 (489-866)
Preliminary TAC (90% CI)	964 (497-1432)	871 (445-1298)	616 (294-938)	894 (571-1217) TIB: 328 t TVH: 251 t PNG: 285 t	704 (510-897) Aug 2015 Dec 2015 update	495 (315-676) TIB: 188 t TVH: 144 t PNG: 163 t
Preliminary TAC allocation* (lower 75th percentile)	637	573	391	668 TIB: 254 t TVH: 194 t PNG: 220 t	568t TIB: 216 t TVH: 165 t PNG: 187 t	
Final TAC	964	871	616	Mar 2015 (revision with preseason survey = 769t)	796	Dec 2016
Catch	697t	604t	682t	562t	572t	-

MODEL TRAJECTORIES

The model-predicted numbers of 1+ and 2+ lobsters for the entire model period are shown in Fig. 2-12. There is considerable inter-annual variability in stock size, with the extent of the variability consistent with that observed from field studies.

The lobster spawning biomass (t) trajectory is given in Fig. 2-13. The stock is currently estimated to be roughly at the pristine (1973) spawning biomass level but is expected to fluctuate widely about the average target spawning biomass level, and to decline in 2017.

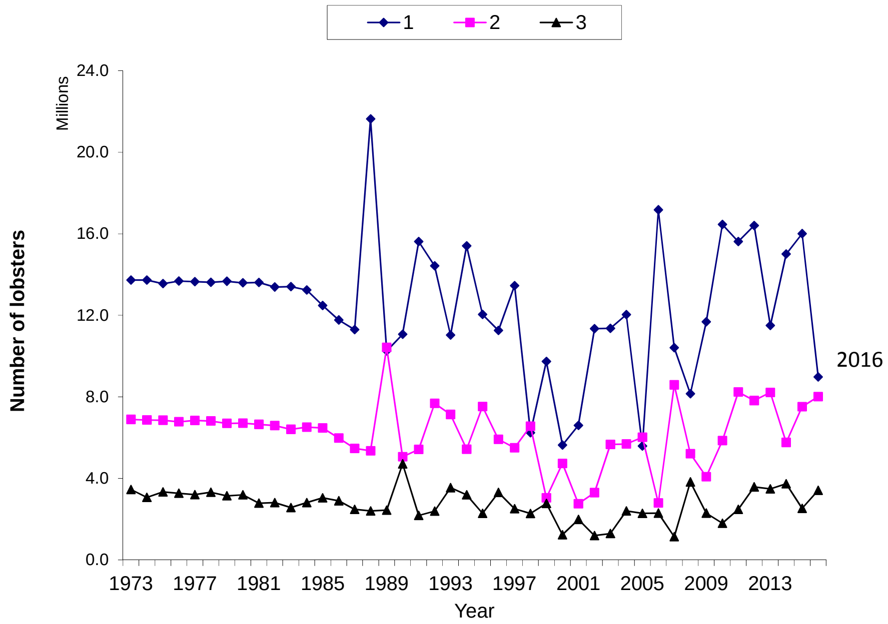


Fig. 2-12. Model trajectories of the annual numbers of lobsters in each age class at the start of each of years 1973 to 2016. The increased variability from 1985 onwards is because the model estimates stock recruit residuals for years from 1985 to 2016.

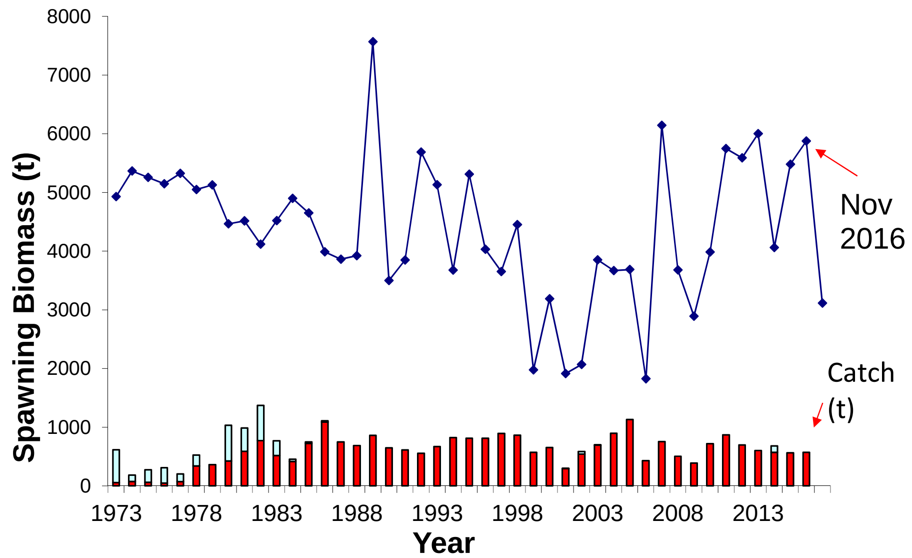


Fig. 2-13. Model trajectories of the lobster spawning biomass (t) over the model period shown together with annual catches by the trawling and other sectors combined.

The model-predicted spawning biomass trajectory is shown in Figure 2-14. The November 2016 spawning biomass for the TRLRAG Reference Case is estimated to be 5877 t [3671; 8083] (Table 5-4). Figure 2-15 shows the model-predicted commercially available (also termed exploitable) lobster biomass, computed as the sum of all 1+ and 2+ lobsters which are "available" to be caught each year. The current 2016 estimate is 6306t [4179; 8432], but this is predicted to decline substantially in 2017 (Figure 2-15).

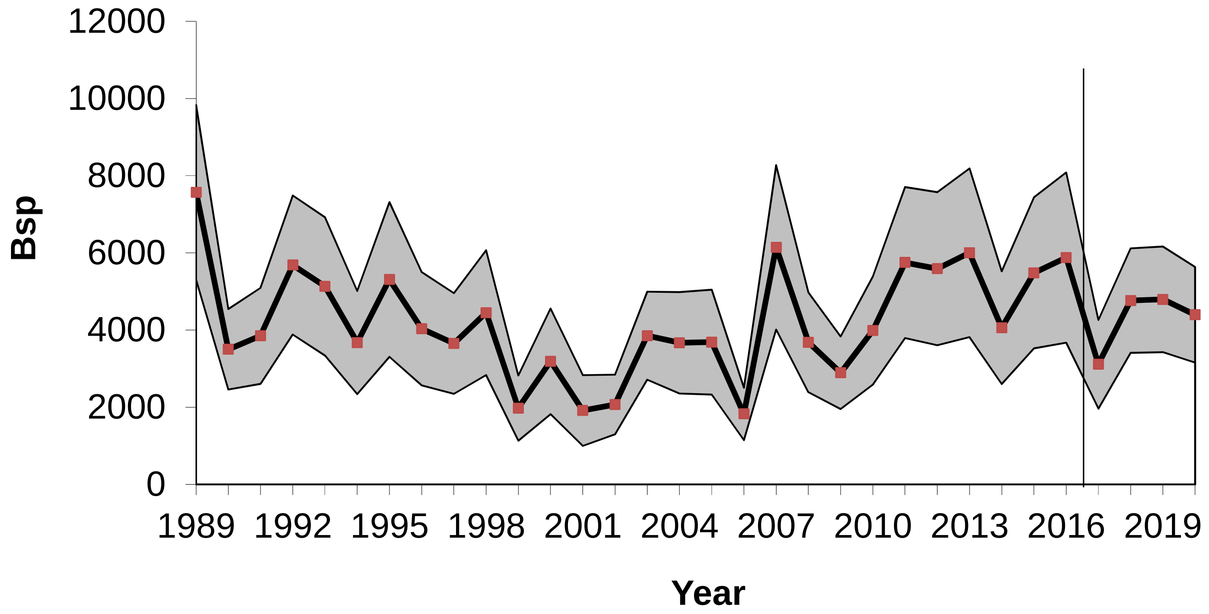


Figure 2-14. Model-predicted lobster November spawning biomass trajectory shown together with Hessian-based 90% confidence intervals. The vertical line indicates the separation between historic and predicted estimates.

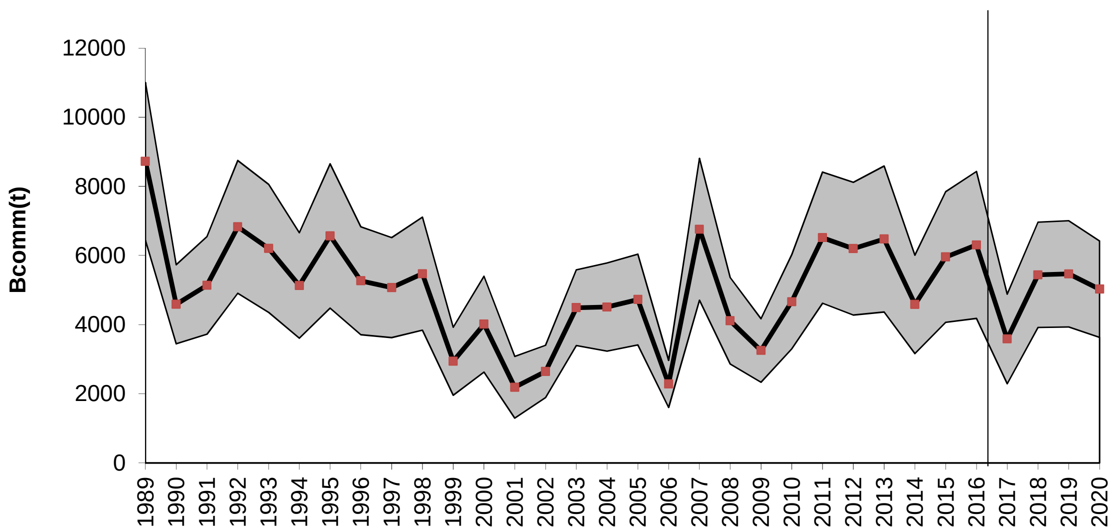


Figure 2-15. Model-predicted commercially available (also termed exploitable) lobster biomass (Bcomm), which is the sum of all 1+ and 2+ lobsters which are "available" to be caught each year. The shaded area shows the Hessian-based 90% confidence intervals. The vertical line indicates the separation between historic and predicted estimates.

SENSITIVITY TESTS

The robustness of model results were tested across a number of important sensitivity tests, including the following which were presented at the TRLRAG December 2016 meeting:

- A) Pre-RAG Reference Case
- B) Alternative CPUE TVH & TIB standardisation series (Main effects)
- C) Alternative CPUE TIB - nominal series
- D) TIB hyperstability par = 0.75 vs 0.5
- E) Higher natural (environmental) mortality rate in 2015

.

The results are summarised in Table 2-6 . Summary of results of sensitivity analyses. A range of CPUE_TVH and CPUE_TIB alternative standardisations from Campbell et al. (2016 a,b), as well as the nominal CPUE_TIB series, were used but made very little difference to the results. This was largely because the series themselves were all very similar.

Changing the assumed hyperstability parameter for the TIB CPUE series also had only a small effect on model results, with the largest difference being attributed to a change in the catchability parameter estimate for the fit to the TIB CPUE series.

Decreasing the stock-recruitment steepness parameter *h* from 0.7 to 0.6 resulted in a small improvement in the likelihood and AIC values, but only minor changes in parameter estimates as well as the model RBC recommendation.

The final scenario assumed a much higher (double) mortality rate of 2+ lobsters in 2015 due to the anomalous environmental conditions as outlined in Plagányi et al. (2015b). Although this doesn't immediately make much of a difference to any of the model parameter estimates, it will have an impact on forecasts as the number of lobsters that are assumed to survive to spawn will be substantially reduced (Fig. 2-16). There will thus be a lag effect with reduced recruitment expected a couple of years later, and hence there is a lag before this could be verified by refitting the model.

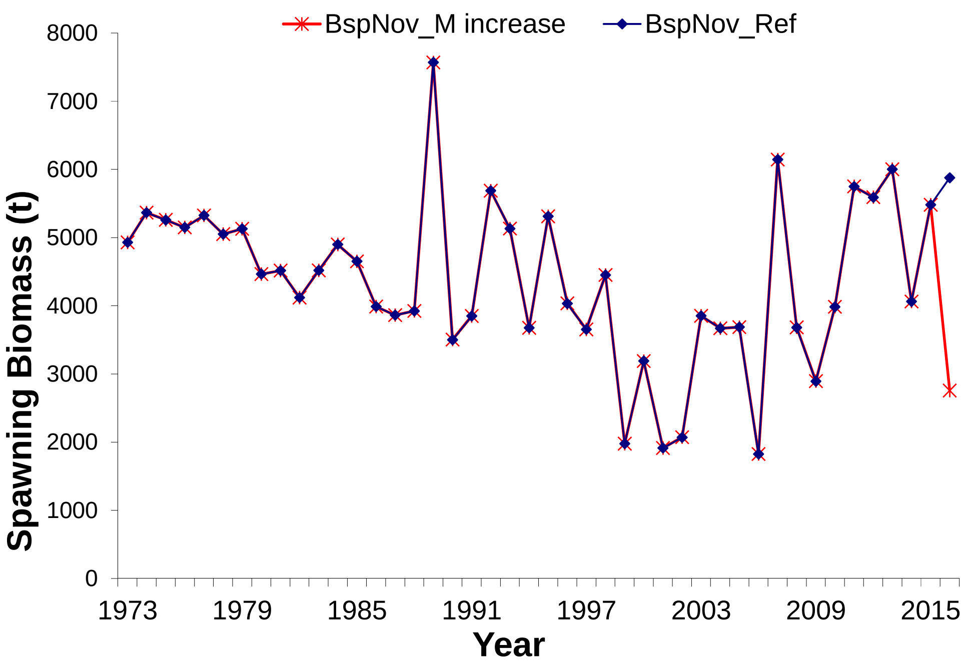


Figure 2-16. Model sensitivity test with increased mortality of 2+ lobsters assumed in 2015, compared with spawning biomass trajectory from Reference Case model.

Discussion

The revised and updated model adequately fits the available data and integrates all available information to output a RBC value as required for management. The use of a single model facilitates understanding of the way in which data inputs translate into an assessment of the status and productivity of the resource and hence an associated RBC estimate. Moreover, parameter estimates and resource trajectories are presented together with confidence intervals to illustrate the extent of uncertainty associated with model predictions.

An important assumption of the current and previous assessments is that the Torres Straits rock lobster resource is a closed population, but this is clearly not the case given they migrate eastwards out the Torres Straits (Moore and MacFarlane 1984, Skewes et al. 1994). It is not known to what extent mixing occurs with the eastern component of the stock, and hence whether these two stock components should rather be treated as a single stock in computing a spawning stock biomass. This aspect has been investigated during a related MSE project.

Overall the resource is assessed to be in good condition. The 2016 assessment that was agreed by the TRLRAG recommended a preliminary TAC of 495t (90%CI, 315-676t) for the 2017 season (Table 2-5). The forecast TAC for 2018 was recommended to be 677t (90%CI; 489-866t) (Table 2-5), to be reassessed at the TRLRAG meeting in November/December 2017.

The inherent variability of environmental influences in relatively short-lived highly variable stocks such as TRL confounds both the accuracy and precision of optimal sustainable yield estimates for the following year. As more and better surveys are added (e.g. the pre-season survey which is closer to the opening of the fishing season), it becomes possible to set less conservative TACs.

The TRLRAG is currently considering adopting a pre-tested harvest control rule that is based on the results of the pre-season survey and other data inputs to set the RBC, rather than annually running the stock assessment. The advantage of the latter approach is that it can be simulation tested and the harvest control rules agreed beforehand by all stakeholders, so that the TAC updating process is quick and efficient as is necessary given the short time between the pre-season survey completion (plus time for analysis of the data), and the opening of the fishing season.

Table 2-6 . Summary of results of sensitivity analyses

	(a) Reference Case			(B) Sensitivity - Main Effects GLM (TVH&TIB)			(C) Sensitivity - nominal TIB CPUE			(D) Sensitivity - hyps TIB=0.75			(E) Sensitivity - h=0.6			(F) Sensitivity 2015 mortality double		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Paramete**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**
$B(1973)^{sp}$ (tons)	4947	3497	6397	4947	3497	6397	4947	3497	6397	4947	3497	6397	5120	3597	6643	4947	3497	6397
M	0.69	0.56	0.82	0.69	0.56	0.82	0.69	0.56	0.82	0.69	0.56	0.82	0.69	0.56	0.82	0.69	0.56	0.82
h	fixed 0.7			fixed 0.7			fixed 0.7			fixed 0.7			**fixed 0.6**			fixed 0.7		
Sel (age 1+) 1973-1988	0.44	0.24	0.63	0.44	0.24	0.63	0.44	0.24	0.63	0.44	0.24	0.63	0.44	0.24	0.63	0.44	0.24	0.63
Sel (age 1+) 1989-2001	0.16	0.14	0.19	0.16	0.14	0.19	0.16	0.14	0.19	0.16	0.14	0.19	0.16	0.14	0.19	0.16	0.14	0.19
Sel (age 1+) post2002	0.02	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.03
Recruitment residuals (1985-2016)		32 parameters			**32 parameters**			32 parameters			32 parameters			32 parameters			32 parameters	
Model estimates and depletion statistics																		
$B(2016)^{sp}$ (tons)	5877	3671	8083	5877	3671	8083	5877	3671	8083	5877	3671	8083	5931	3708	8154	2756	1526	3986
RBCprelim(2017) model	495	315	676	495	315	676	495	315	676	495	315	676	499	318	681	494	313	674
RBCforecast(2018) mode	758	546	970	758	546	970	758	546	970	758	546	970	780	561	999	755	543	967
Current Depletion (Nov)																		
$B(2016)^{sp}$ / B(1973)sp	1.19	0.84	1.55	1.19	0.84	1.55	1.19	0.84	1.55	1.19	0.84	1.55	1.16	0.80	1.51	0.56	0.36	0.75
Bexp(2016) (tons)	6306	4179	8432	6306	4179	8432	6306	4179	8432	6306	4179	8432	6359	4216	8501	3188	2034	4342
No. parameters estimated	37			37			37			37			37			37		
'-lnL:overall	**-182.974**			**-182.974**			**-182.974**			**-182.974**			**-183.042**			**-182.969**		
AIC	**-291.948**			**-291.948**			**-291.948**			**-291.948**			**-292.084**			**-291.938**		
Likelihood contributions		**Sigma**	**q**		Sigma	q		**Sigma**	**q**		Sigma	q		Sigma	q		Sigma	q
'-lnL:CAA	-53.93	0.05		-53.93	0.05		-53.93	0.05		-53.93	0.05		-53.89	0.05		-53.93	0.05	
'-lnL:CAAsurv	-19.17	input from data		-19.17	input from data		-19.17	input from data		-19.17	input from data		-19.15	input from data		-19.17	nput from data	
-lnL:CAA historic	-21.77	0.13		-21.77	0.13		-21.77	0.13		-21.77	0.13		-21.75	0.13		-21.77	0.13	
-lnL:Survey Index 1+	-24.53	input from data	3.761E-07	-24.53	input from data	3.761E-07	-24.53	input from data	3.761E-07	-24.53	input from data	3.761E-07	-24.66	input from	3.750E-07	-24.54	nput from dat	3.760E-07
-lnL:Survey Index 2+	-13.20	input from data	3.935E-07	-13.20	input from data	3.935E-07	-13.20	input from data	3.935E-07	-13.20	input from data	3.935E-07	-13.11	input from	3.921E-07	-13.20	nput from dat	3.935E-07
-lnL:Survey benchmark	-3.14	input from data		-3.14	input from data		-3.14	input from data		-3.14	input from data		-3.14	input from data		-3.14	nput from data	
'-lnL:PRESEASON	-8.28	input from data	7.262E-07	-8.28	input from data	7.262E-07	-8.28	input from data	7.262E-07	-8.28	input from data	7.262E-07	-8.29	input from	7.221E-07	-8.27	nput from dat	7.261E-07
-lnL:PRESEASON 0+	-5.79	input from data	8.436E-08	-5.79	input from data	8.436E-08	-5.79	input from data	8.436E-08	-5.79	input from data	8.436E-08	-5.75	input from	8.354E-08	-5.79	nput from dat	8.436E-08
-lnL:CPUE (TVH)	**-26.02**	0.20	0.0018	-26.02	0.20	0.0018	**-26.02**	0.20	0.0018	-26.02	0.20	0.0018	-26.02	0.20	0.0018	-26.02	0.20	0.0018
-lnL:CPUE (TIB)	**-13.31**	0.20	0.0158	-13.31	0.20	0.0158	**-13.31**	0.20	0.0158	-13.31	0.20	**0.0020**	-13.31	0.20	0.0158	-13.31	0.20	0.0158
'-lnL:RecRes	6.15	0.50	(input sigma 0.5)	6.15	0.50	(input sigma 0.5)	6.15	0.50	(input sigma 0.5)	6.15	0.50	(input sigm	6.03	0.50	(input sigma 0.5	6.15	0.50	nput sigma 0.5

Appendix 2.1 - STOCK ASSESSMENT EQUATIONS

INTRODUCTION

Torres Strait rock lobsters emigrate in spring and breed during the subsequent summer (November-February) (Moore and MacFarlane, 1984; MacFarlane and Moore, 1986). Therefore, the number of age 2+ lobsters at the middle of the breeding season (December) should represent the size of the spawning stock (Figure A2-17). A schematic summary timeline underlying the new Integrated model is presented in Figure A2-17. To simplify computations, the new model assumes catches, migration and spawning occur at discrete times, with quarterly updates to the dynamics of each age class. Catches of 2+ individuals are assumed taken as a pulse at midyear, with individuals migrating out of the Torres Straits at the end of the third quarter, and a spawning biomass being computed at the end of the year. Catches of 1+ lobsters are assumed taken at the end of the third quarter, when a proportion of this age class have grown large enough to be available to fishers.

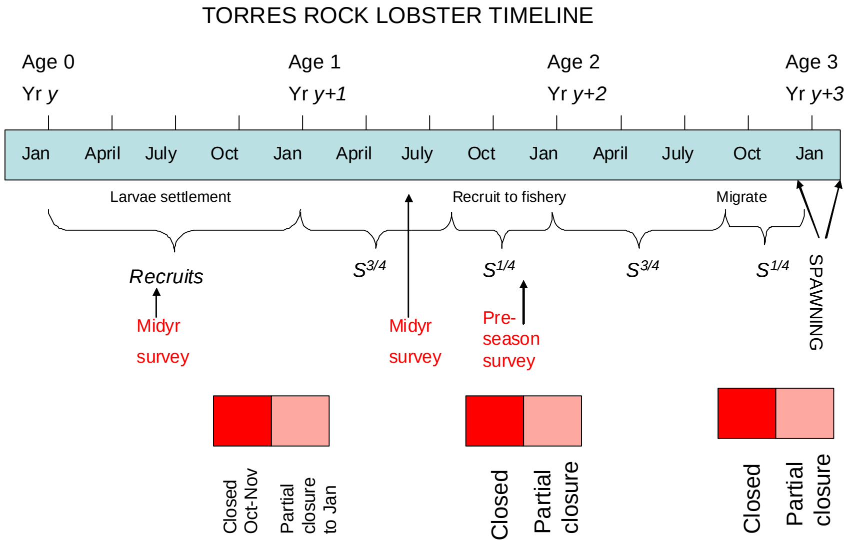


Figure A2-17. Summary timeline for Torres Strait Rock Lobster model.

P. ornatus is an unusually fast growing lobster and hence analyses are expected to be sensitive to changes in assumption regarding growth rate (length vs age) and mass-at-length. Previous modelling studies used the Trendall et al. (1988) relationship:

$$CL_m = 177\left(1 - e^{-0.386(m/12-0.411)}\right)$$

where *CL* is carapace length (mm) and *m* is age in months for aspects of the computations. However, after converting length to mass using the morphometric relationship:

TOTWT=0.00258*(CL^2.76014)

the Trendall et al (1988) relationship translates into average individual masses that are less than the observed average mass of lobsters caught in the fishery. The Integrated model thus uses the Phillips et al. (1992) male growth relationship:

$$CL = L_{\infty}\left(1 - e^{-kt}\right)$$

where $L_{\infty} = 165.957 \quad mm$;

$\kappa = -0.0012$; and

t is age in DAYS.

THE INTEGRATED MODEL

An age-structured model of the Torres Rock Lobster population dynamics is developed and fitted to the available abundance indices by maximising the likelihood function. The model equations and the general specifications of the model are described below, followed by details of the contributions to the log-likelihood function from the different sources of data available. Quasi-Newton minimization is used to minimize the total negative log-likelihood function (the package AD Model Builder™ (Fournier et al. 2012) is used for this purpose.

LOBSTER POPULATION DYNAMICS

Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,1} = R_{y+1} \qquad 1$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-3M_a/4} - C_{y,a}\right)e^{-M_a/4} \qquad \text{for } a=1 \qquad 2$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right)e^{-M_a/2} \qquad \text{for } a=2 \qquad 3$$

where

$N_{y,a}$ is the number of lobsters of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 1-year-old lobsters) at the start of year *y*,

M_a denotes the natural mortality rate on lobsters of age *a*,

$C_{y,a}$ is the predicted number of lobsters of age *a* caught in year *y*, and

m is the maximum age considered (taken to be 3).

These equations simply state that for a closed population, with no immigration and emigration, the only sources of loss are natural mortality (predation, disease, etc.) and fishing mortality (catch). They reflect Pope's form of the catch equation (Pope, 1972) (the catches are assumed to be taken as a pulse at midyear for the 2+ class and at the start of the third quarter for the 1+ class) rather than the more customary Baranov form (Baranov, 1918) (for which catches are incorporated under the assumption of steady continuous fishing mortality). Pope's form has been used in order to simplify computations.

Recruitment

The number of recruits (i.e. new 1-year old lobsters – it is simpler to work with 1- rather than 0-year old lobsters as recruits) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature lobsters) by a modified Beverton-Holt stock-recruitment relationship (Beverton and Holt, 1957), allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B^{sp}_{y-1}}{\beta + \left(B^{sp}_{y-1}\right)^{\gamma}} e^{(\varsigma_y - (\sigma_R)^2/2)} \qquad 4$$

where

α, β and γ are spawning biomass-recruitment relationship parameters (note that cases with γ > 1 lead to recruitment which reaches a maximum at a certain spawning biomass, and thereafter declines towards zero, and thus have the capability of mimicking a Ricker-type relationship),

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process. Estimating the stock-recruitment residuals is made possible by the availability of catch-at-age data, which give some indication of the age-structure of the population.

B^{sp}_y is the spawning biomass at the start of year *y*, computed as:

$$B^{sp}_y = w^{st}_3 \cdot N_{y,3} \qquad 5$$

where

w^{st}_3 is the mass of lobsters of age 3 (i.e. in December during the spawning season).

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness", *h*, of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass:

$$\beta = \frac{\left(K^{sp}\right)^{\gamma}\left(1 - 5h0.2^{\gamma}\right)}{5h - 1} \qquad 6$$

and

$$\alpha = \frac{\beta + \left(K^{sp}\right)^{\gamma}}{SPR_{virg}} \qquad 7$$

where

$$SPR_{virg} = w^{st}_3 N^{virg}_3 \qquad 8$$

with

$$N^{virg}_1 = 1 \qquad 9$$

$$N^{virg}_a = N^{virg}_{a-1} e^{-M_{a-1}} \qquad \text{for } 2 < a \le m \qquad 10$$

Total catch and catches-at-age

The catch by mass in year *y* is given by:

$$C_y = w_1^{land} N_{y,1} e^{-3M_a/4} S_{y,1} F_y^{1+} + w_2^{mid} N_{y,2} e^{-M_a/2} S_{y,2} F_y^{2+} \quad (11)$$

Where

w_a^{land} denotes the mass of lobsters of age *a* that are landed at the end of the third quarter,

w_a^{mid} denotes the mid-year mass of lobsters of age *a*,

$S_{y,a}$ is the commercial selectivity (i.e. vulnerability to fishing gear) at age *a* for year *y*; and

F_y is the fished proportion (of the 1+ and 2+ classes) of a fully selected age class.

The model estimate of the exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mass-at-age (using the individual weights of the 1+ lobsters assumed landed at the end of the third quarter, and the 2+ lobsters assumed landed at midyear):

$$B_y^{ex,1+} = w_1^{land} S_{y,1} N_{y,1} e^{-3M_a/4} \quad (12)$$

$$B_y^{ex,2+} = w_2^{mid} S_{y,2} N_{y,2} e^{-M_a/2} \quad (13)$$

and hence:

$$B_y^{ex} = B_y^{ex,1+} + B_y^{ex,2+} \quad (14)$$

The 2010 model version computes the catch by mass separately for the trawling sector, which is assumed to target 2+ lobsters only. The exploitable component of biomass for this sector is thus based on Equation (13) only and assumes full selectivity of the 2+ age group.

The model estimates of the midyear numbers of lobsters are:

$$N_y^{mid} = N_{y,1} e^{-M_1/2} + \left(N_{y,2}\, e^{-M_2/2} - C_{y,2}\right) \quad (15)$$

i.e.

$$N_{y,1}^{mid} = N_{y,1} e^{-M_1/2} \quad (16)$$

$$N_{y,2}^{mid} = N_{y,2}\, e^{-M_2/2} - C_{y,2} \quad (17)$$

Similarly, the model estimate of numbers for comparison with the Pre-Season November survey are as follows:

$$N_{y,1}^{pre} = \left(N_{y,1} e^{-3M_1/4} - C_{y,1}\right) e^{-M_1/6} \quad (18)$$

$$N_{y,2}^{pre} = N^{mid}{}_{y,2}\, e^{-5M_2/12} \quad (19)$$

The proportion of the 1+ and 2+ age classes harvested each year (F_y^{1+}) are given respectively by:

$$F_y^{1+} = C_y^{1+} \;/\; B_y^{exp,1+} \tag{20}$$

$$F_y^{2+} = C_y^{2+} \;/\; B_y^{exp,2+} \tag{21}$$

where C_y^{1+} and C_y^{2+} are the catch by mass in year *y* for age classes 1 and 2, such that:

$$C_y^{1+} = p_{y,1+} C_y \tag{22}$$

and

$$C_y^{2+} = (1 - p_{y,1+}) C_y \tag{23}$$

with $p_{y,1+}$ representing the 1+ proportion of the total catch.

Given different fishing proportions for the two age classes, the numbers-at-age removed each year from each age class can be computed from:

$$C_{y,1} = S_{y,1} F_y^{1+} N_{y,1} e^{-3M_a/4} \quad \text{for } a = 1\text{, and} \tag{24}$$

$$C_{y,2} = S_{y,2} F_y^{2+} N_{y,2} e^{-M_a/2} \quad \text{for } a = 2 \tag{25}$$

The fully selected fishing proportion (*F*) is related to the annual fishing mortality rate (*F**) as follows:

$$1 - F = e^{-F^*} \tag{26}$$

Initial conditions

Although some exploitation occurred before the first year for which data are available for the lobster stock, this is considered relatively minor and hence the stock is assumed to be at its pre-exploitation biomass level in the starting year and hence the fraction (θ) is fixed at one in the analysis described here:

$$B_{y_0}^{sp} = \theta \cdot K^{sp} \tag{27}$$

with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \quad \text{for } 1 \le a \le m \tag{28}$$

where

$$N_{start,1} = 1 \tag{29}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{a-1}} \quad \text{for } 2 \le a \le m-1 \tag{30}$$

THE (PENALISED) LIKELIHOOD FUNCTION

Model parameters are estimated by fitting to survey abundance indices, commercial and survey catch-at-age data as well as standardised CPUE data in some cases. A penalty function is included to permit estimation of residuals about the stock-recruitment function. Contributions by each of these to the negative of the log-likelihood (- $\ell \mathrm{n} L$) are as follows.

Survey abundance data

The same methodology is applied for the midyear and pre-season surveys, except that for the former there are indices for both the total 1+ and 2+ numbers, whereas for the pre-season the fit is only to the 1+ lobsters as most of the older lobsters will have migrated out of the region by November. The likelihood is calculated assuming that the observed midyear (and pre-season) survey abundance index is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell \mathrm{n}\left(I_y^i\right) - \ell \mathrm{n}\left(\hat{I}_y^i\right) \qquad 31$$

where

I_y^i is the scaled survey abundance index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}_s \hat{N}_y^{survey}$ is the corresponding model estimate, where $\hat{N}_y^{survey}$ is the model estimate of midyear numbers, given by equation 16 and 17 for the midyear survey, and for the pre-season survey it is given by equation 18.

$\hat{q}_s$ is the constant of proportionality (catchability) for the survey, and

ε_y^i from $N\left(0,\left(\sigma_y^i\right)^2\right)$.

The contribution of the survey data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell \mathrm{n}\, L^{Surv} = \sum_i \sum_y \left[\ell \mathrm{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \qquad 32$$

where $\left(\sigma_y^s\right)^2 = \ln\left(1+\left(CV_y\right)^2\right)$ and the coefficient of variation (CV_y) of the resource abundance estimate for year *y* is input.

The survey catchability coefficient $\hat{q}_s$ is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}_s = 1/n_i \sum_y \left(\ln I_y^i - \ln N_y^{ex}\right) \qquad 33$$

Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an “adjusted” lognormal error distribution is given by:

$$-\ell \mathrm{n} L^{CAA} = \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{com}\right)^2\right] \qquad 34$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of lobsters caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of lobsters caught in year *y* that are of age *a*, where

$$\hat{C}_{y,1} = N_{y,1}\, e^{-3M_a/4}\, S_{y,1}\, F_y^{1+} \qquad 35$$

$$\hat{C}_{y,2} = N_{y,2}\, e^{-M_a/2}\, S_{y,2}\, F_y^{2+} \qquad 36$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \qquad 37$$

The same approach is applied when fitting to the historic catch proportion data.

Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation 25) where:

$p_{y,a} = C_{y,a}^{surv} / \sum_{a'} C_{y,a'}^{surv}$ is the observed proportion of lobsters of age *a* in year *y*,

$\hat{p}_{y,a}$ is the expected proportion of lobsters of age *a* in year *y* in the survey, given by:

$$\hat{p}_{y,a} = N_{y,a} \Big/ \sum_{a'=1}^{2} N_{y,a} \qquad 38$$

Benchmark Survey Estimates of Absolute Abundance

The absolute abundance of lobsters is estimated by fitting to data from two benchmark midyear surveys. The total 2002 population estimate, together with 95% confidence interval, was T_{89} = 9.0 (±1.9) million lobsters, and for 1989, T_{89} = 14.0 (±2.9) million lobsters (Pitcher et al. 1992). The 2+ year class was estimated at 1.77 (±0.38) million in 2002, and the 1+ year-class was at 5.2 (±1.5) million.

The approach is similar to that described above for the survey relative abundance index. The contribution of the survey data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell n\, L^{Bench} = \ell n\left(\sigma_{89}\right) + \left(\varepsilon_{89}\right)^2 / 2\left(\sigma_{89}\right)^2 + \ell n\left(\sigma_{02}\right) + \left(\varepsilon_{02}\right)^2 / 2\left(\sigma_{02}\right)^2 \qquad 39$$

where $\varepsilon_{89} = \ell n\left(T_{89}\right) - \ell n\left(\hat{N}_{1989,1}^{mid} + \hat{N}_{1989,2}^{mid}\right)$;

$\varepsilon_{02} = \ell n\left(T_{02}\right) - \ell n\left(\hat{N}_{2002,1}^{mid} + \hat{N}_{2002,2}^{mid}\right)$; and

$\left(\sigma_y\right)^2 = \ln\left(1 + \left(CV_y\right)^2\right)$ and the two coefficients of variation (CV_{89} and CV_{02}) are input.

Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed and serially correlated. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{pen} = \sum_{y=y1+1}^{y2} \left[\left(\frac{\lambda_y - \rho\lambda_{y-1}}{\sqrt{1-\rho^2}} \right)^2 \Big/ 2\sigma_R^2 \right] \qquad 40$$

where

$\lambda_y = \rho\lambda_{y-1} + \sqrt{1-\rho^2}\,\varepsilon_y$ is the recruitment residual for year *y*, which is estimated for year *y*1 to *y*2 (see equation 4),

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_R is the standard deviation of the log-residuals, which is input, and

ρ is the serial correlation coefficient, which is input.

In the interest of simplicity, equation 40 omits a term in λ_{y1} for the case when serial correlation is assumed ($\rho \neq 0$), which is generally of little quantitative consequence to values estimated.

The analyses conducted in this paper have however all assumed $\rho = 0$.

MODEL PARAMETERS

Natural mortality:

Natural mortality (M_a) is generally taken to be age independent and is estimated in the model fitting process.

In sensitivity tests where age-dependence is admitted, it is taken to have the form:

$$M_a = \mu_1 + \mu_2 / a \qquad 41$$

Fishing selectivity-at-age:

The commercial selectivity is taken to differ over the 1973-2002 and 2002+ periods. Full selectivity of the 2+ class is assumed, with a separate selectivity parameter being estimated for each period for the 1+ class.

Appendix 2.2 – Revised Model stock recruitment residual estimates

	Estimate	90% Hessian-based confider	
1985	0.05	-0.38	0.49
1986	-0.01	-0.70	0.67
1987	-0.05	-0.58	0.48
1988	0.62	0.38	0.86
1989	-0.12	-0.36	0.12
1990	-0.05	-0.28	0.18
1991	0.22	0.01	0.44
1992	0.24	0.01	0.46
1993	-0.05	-0.28	0.19
1994	0.24	-0.02	0.49
1995	0.00	-0.23	0.24
1996	-0.02	-0.24	0.19
1997	0.11	-0.12	0.34
1998	-0.63	-0.89	-0.36
1999	-0.17	-0.44	0.11
2000	-0.74	-1.09	-0.39
2001	-0.43	-0.70	-0.16
2002	0.01	-0.22	0.23
2003	0.12	-0.12	0.36
2004	0.16	-0.06	0.38
2005	-0.73	-0.95	-0.51
2006	0.40	0.18	0.62
2007	-0.10	-0.32	0.12
2008	-0.20	-0.39	0.00
2009	-0.05	-0.27	0.18
2010	0.36	0.14	0.58
2011	0.35	0.11	0.58
2012	0.34	0.09	0.60
2013	-0.06	-0.30	0.19
2014	0.21	-0.03	0.46
2015	0.27	0.01	0.53
2016	-0.26	-0.55	0.03

Glossary

AFMA	Australian Fisheries Management Authority
CPUE	Catch Per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Agency
eHCR	Empirical Harvest Control Rule
RBC	Recommended Biological Catch
TAC	Total Allowable Catch
TIB	Traditional Inhabitant Boat sector
TRL	Tropical Rock Lobster
TSSAC	Torres Strait Scientific Advisory Committee
TVH	Transferrable Vessel Holder (Licence)
TRL RAG	Tropical Rock Lobster Research Advisory Group
PNG	Papua New Guinea

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

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CSIRO Oceans and Atmosphere Flagship
Dr Éva Plagányi
Principal Research Scientist
t +61 7 38335955
e Eva.Plagányi-lloyd@csiro.au
w http://people.csiro.au/P/E/Eva-Plaganyi-Lloyd

Mark Tonks
Experimental Scientist
t +61 7 38335973
e Mark.Tonks@csiro.au
w www.csiro.au