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Torres Strait Tropical Rock Lobster Fishery Survey and Stock Assessment

Research Project RR2013/803

Final Report

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Australian Fisheries Management Authority
Thursday Island

Australian Government
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Executive Summary

Background

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 (TVH) 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 690 t live weight since 1989. 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 (*Panulirus ornatus*) population has been carried out during 1989 to 2015. The surveys were conducted mid-year (June) during 1989 to 2014, with an additional pre-season (November) survey conducted during 2005-2008 and 2014 to provide the only long-term information on the relative abundance of recruiting (1+) lobsters. A pre-season survey was conducted in 2015, with funded mid-year surveys being phased out. Prior to the introduction of mandatory logbooks in the TVH sector and subsequently the docket book system in the TiB sector the mid-year 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 and 2014, in addition to mid-year surveys, 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 were integral to the outputs of the fishery model developed to assess fishery status and to forecast stock size and TAC. Due to the delay in QMS implementation pre-season surveys were ceased in 2008 as the costs of two surveys are prohibitive and mid-year surveys were deemed of greater value to input management due to the extended time series. Pre-season surveys were re-implemented in 2014 with the development of the TRL management plan.

The significant correlation between the mid-year and pre-season abundance indices indicated that transitioning to annual pre-season surveys would not result in losing the time-series established since 1989.

The 6th annual pre-season population survey was conducted in November 2015. The sample design employed during the 2015 pre-season survey was consistent with all previous surveys. There was a significant correlation between pre-season indices calculated using all (130) sites compared with those using only the 74 mid-year survey sites. Hence, the 2015 pre-season survey included only the mid-year sites. 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 research project outcomes summarised in this report addressed the research priorities set for the Tropical Rock Lobster (TRL) fishery by the TSSAC in its five year Operational Plan: Rock Lobster 1) Providing advice for fisheries management 1a) Evaluation of alternative management strategies including harvest control rules and spatial and seasonal management controls 1b) Development of simulation operating models of the fishery to be used for the evaluation of management strategies.1c) Regular updates of stock assessments to provide estimates of stock status and reference points 1d) Improved monitoring of catch and effort in all sectors of the fishery. 2) Continuation and improvement of data collection 2a) Fishery independent surveys of resource abundance 2b) Improved monitoring of commercial catch and effort in all sectors of the fishery. 5)

Environmental impacts 5a) Collect relevant baseline information to assess environmental change impacts on lobster populations 5b) Analyse the impact of environmental change on the fishery.

Objectives

1. Recommend a TAC for the 2014 and 2015 fishing seasons based on the long-term stock assessment using the integrated fishery model with updated fishery-independent and commercial catch data.

2. Conduct a mid-year survey in May/June 2014, of the relative abundance of recruiting (1+) and fished (2+) lobsters, as well as size-frequency of the TRL population in 2014.

3. Recommend a TAC for the 2015 and 2016 fishing seasons based on the long-term stock assessment using the integrated fishery model with updated fishery-independent and commercial catch data.

4. Conduct a full-scale (140 sites) pre-season survey in November 2014 including a component to train TVH and TiB divers in the sampling protocol used during the scientific surveys

5. Recommend a TAC for the 2016 and 2017 fishing seasons based on the long-term stock assessment using the integrated fishery model with updated fishery-independent and commercial catch data.

6. Depending on the results of the review, plan accordingly a pre-season survey to be conducted in November 2015 by Industry/Islander divers and/or CSIRO operating off an industry-chartered or CSIRO chartered vessel.

7. Undertake a fieldtrip to Torres Strait to discuss changes to survey designs, as well as data gathering by Islanders.

8. Give a presentation to communities about the project at its completion

The research project “Torres Strait Tropical Rock Lobster Fishery Survey and Stock Assessment

Research (Project No. 2013/803)” included: a mid-year population survey in June 2014, a pre-season population survey in November 2014, a pre-season population in November 2015, updated stock assessments incorporating fishery-independent and commercial data, recommendations of TACs for the 2014-2017 fishing seasons, collation and error checking of commercial catch and effort data, calculations of standardised CPUE for the TIB and TVH sectors, science and stakeholder workshops in July and November 2015, preparation of a TRL survey protocol document for industry, development and testing of harvest control rules to be implemented under the TRL management plan and presentations of papers at annual TRL WG and TRL RAG meetings.

This report summarises the results of the 2015 TRL population survey, updated stock assessment and estimated RBC for the 2016 season and standardised estimates of CPUE for the TiB and TVH sectors. A draft report summarising the development of harvest control rules under quota management was submitted separately.

Torres Strait TRL 2015 Pre-season Population Survey Update

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1. Introduction

The results of the 2015 pre-season survey were presented at the combined TRL RAG & TRLWG meeting on 14 December 2015, to provide stakeholders with the updated stock assessment and the revised recommended biological catch for 2016. This section provides updates on size/age distribution of the 2015 recruiting (1+) year-class, long-term seabed habitat monitoring and long-term water temperature monitoring with discussions on impacts on the TRL population.

The 2015 pre-season (November) survey of the Torres Strait lobster population was conducted during 16 -28 November 2015 by four CSIRO staff, using the vessel M.V. *James Kirby*. A total of 78 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 pearlshell (*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.

Three additional 50 m photo-transects were conducted at eight reef-edge sites (Figure 1) to benchmark coral cover given the anticipated coral bleaching event in April/May 2016. This bleaching event has now eventuated, starting in mid-February, as a result of anomalous high water temperatures. The likely short-term and longer-term impacts on the TRL fishery are discussed below.

2. Results

TRL distribution and abundance

The distributions of recently-settled (0+), recruiting (1+) and fished (2+) lobsters (Figure 2) were similar to those recorded during previous pre-season surveys (eg. Appendices A & B show 2014 & 2015 distributions of 0+ and 1+ lobsters respectively), except recruiting lobsters were significantly more abundant at several of the southern sites. 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.

As the 2015 pre-season survey involved a reduced number of transects (78) from previous surveys (>130), four alternative methods were used to calculate annual indices of abundance between 2005 and 2015. These 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, additional industry run surveys would increase precision of the estimates and provide even greater confidence in the estimates of annual recruitment 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 2015 index of recruit abundance was the highest recorded, although not significantly higher than the 2006 and 2014 levels. The high index was mainly due to anomalous levels recorded in the Kircaldie_rubble, South-east and TI_bridge stratums (Figure 5). In contrast, a record low level of abundance was recorded in the large Mabuiag stratum and recruitment was also low in the Buru stratum. The seabed habitat at several transects in these strata had been impacted by the incursion of sand waves, and this observation was corroborated by commercial fishers. Nevertheless, the high overall abundance of recruiting (1+) lobsters suggested that the 2016 stock would again be above average.

The pattern of densities of recently-settled (0+) lobsters amongst stratums (Figure 6) was similar to that observed during all previous years, although density in the Mabuiag stratum was significantly lower than in 2014. Further, the abundance of 0+ lobsters was highest in the Mabuiag stratum in most pre-season surveys. Overall the abundance of 0+ lobsters has been similar during the past four pre-season surveys.

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. 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 low abundance of both 0+ and 1+ lobsters in the northern strata is of concern for the local fishers, and particularly if the cause of the low abundance persists. As the Mabuiag stratum has been a key habitat for recently-settled lobsters in the past, future recruitment and stock would be impacted by persistent poor habitat. However, sand incursions have caused habitat destruction, seagrass die backs and reduced lobster abundance in the past and it is hoped that the impacts are transient.

The current coral bleaching event may also 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.

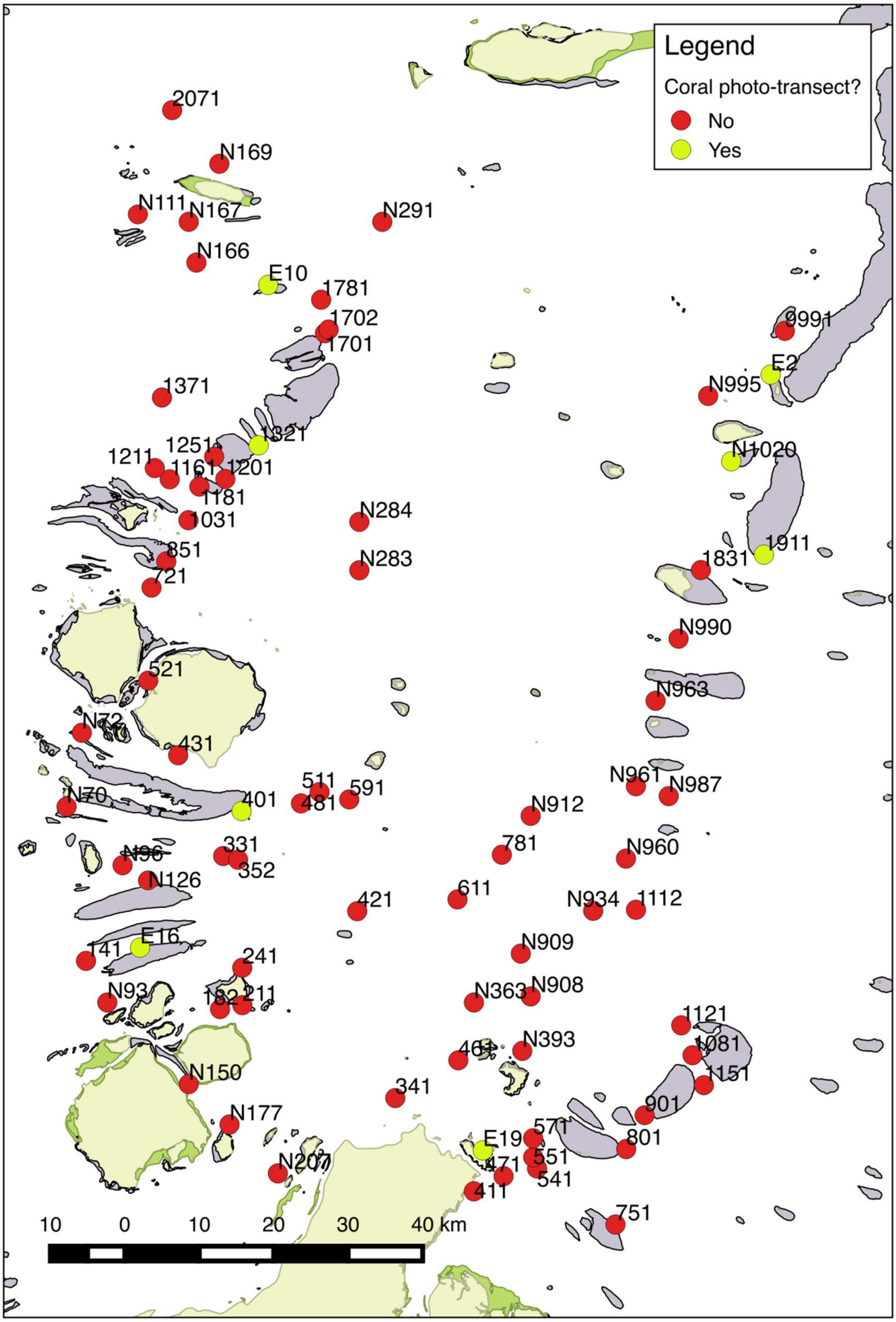

Figure 1. Map of western Torres Strait showing sites surveyed during the 2015 TRL pre-season population survey. Additional coral monitoring transects were conducted at sites marked yellow.

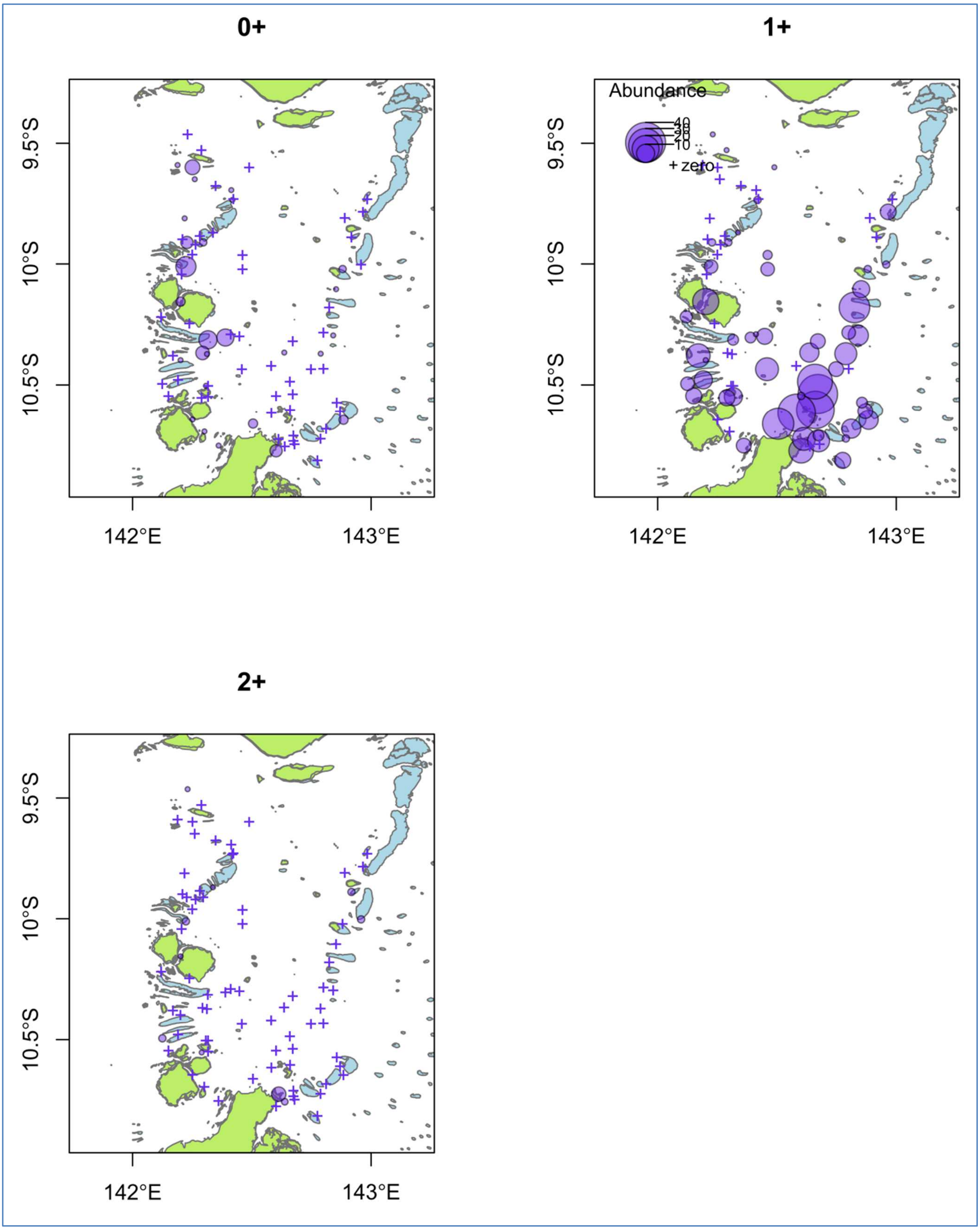

Figure 2. Density of recently-settled (0+), recruiting (1+) and fished (2+) ornate rock lobsters (*Panulirus ornatus*) recorded during the 2015 pre-season population survey in western Torres Strait.

Table 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

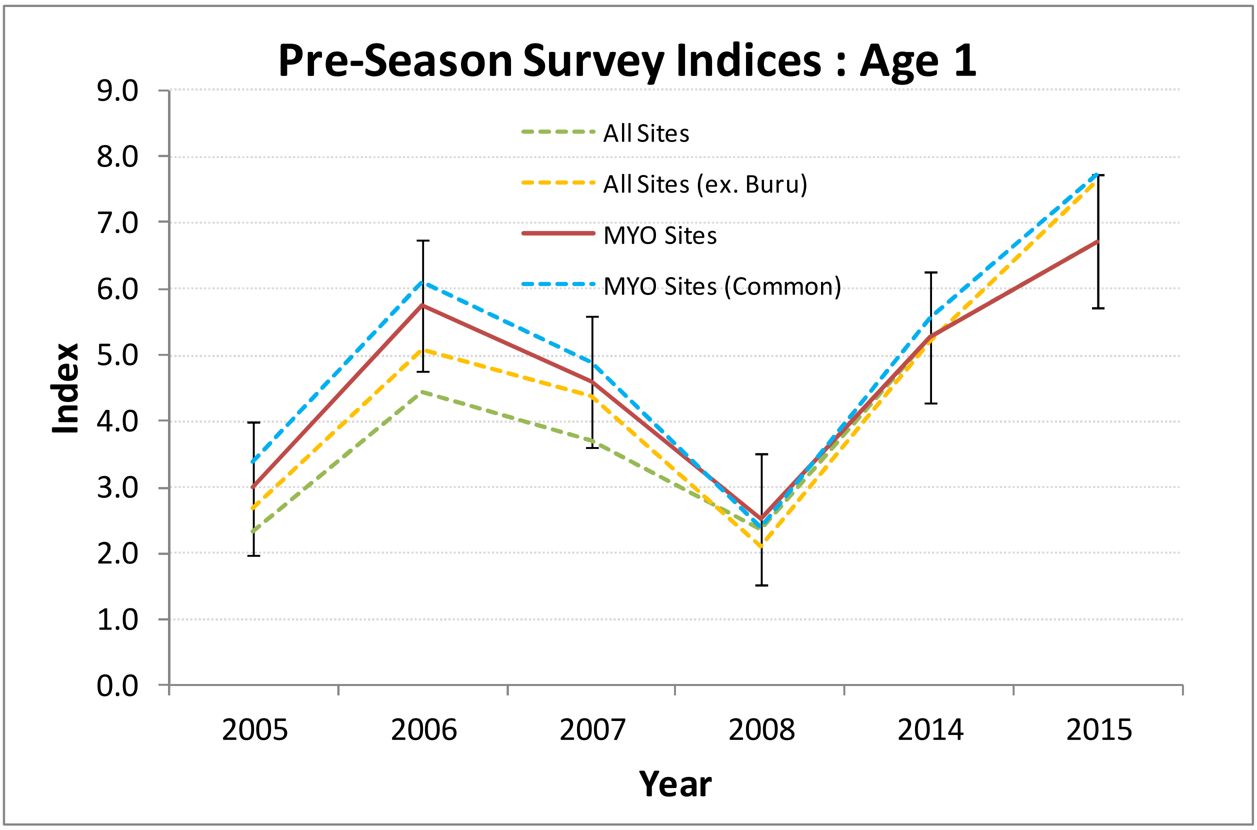

Figure 3. Four comparative indices of abundance of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season surveys in Torres Strait between 2005 and 2015 (note surveys were not done during 2009-2013). Error bars of MYO indices represent standard errors.

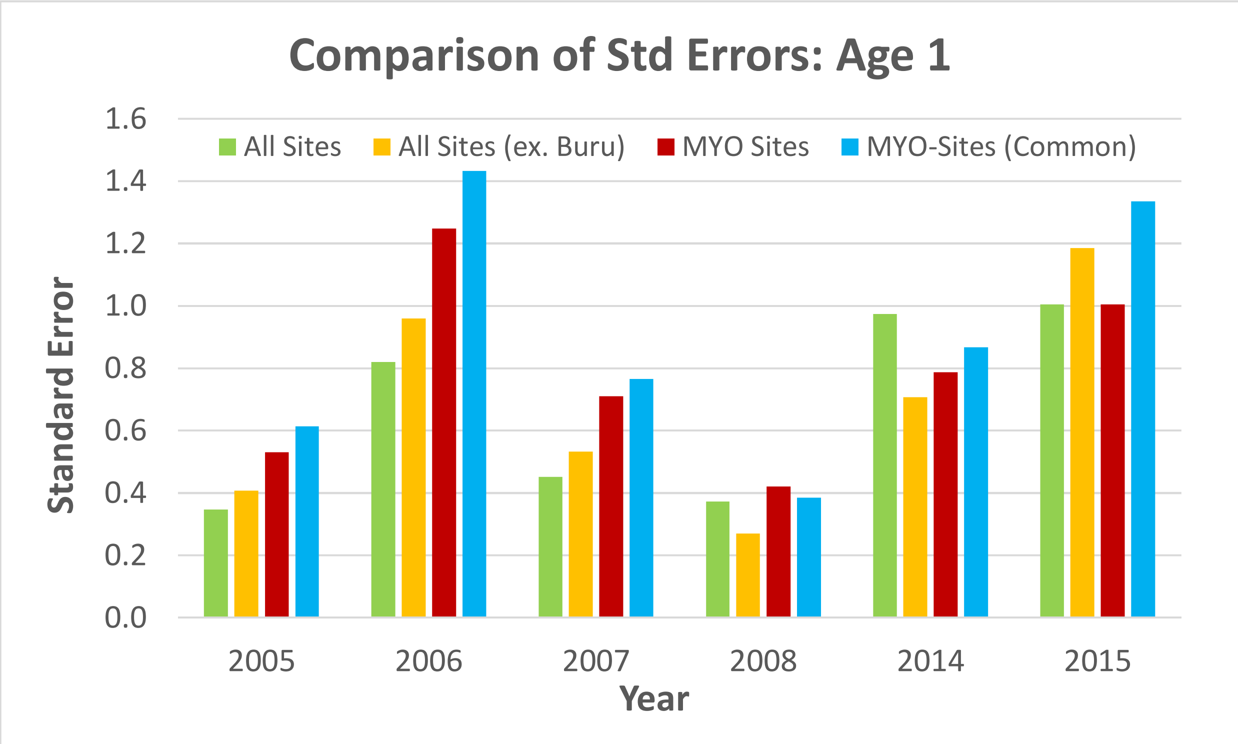

Figure 4. Comparative standard errors for four indices of abundance of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season surveys in Torres Strait between 2005 and 2015 (note surveys were not done during 2009-2013).

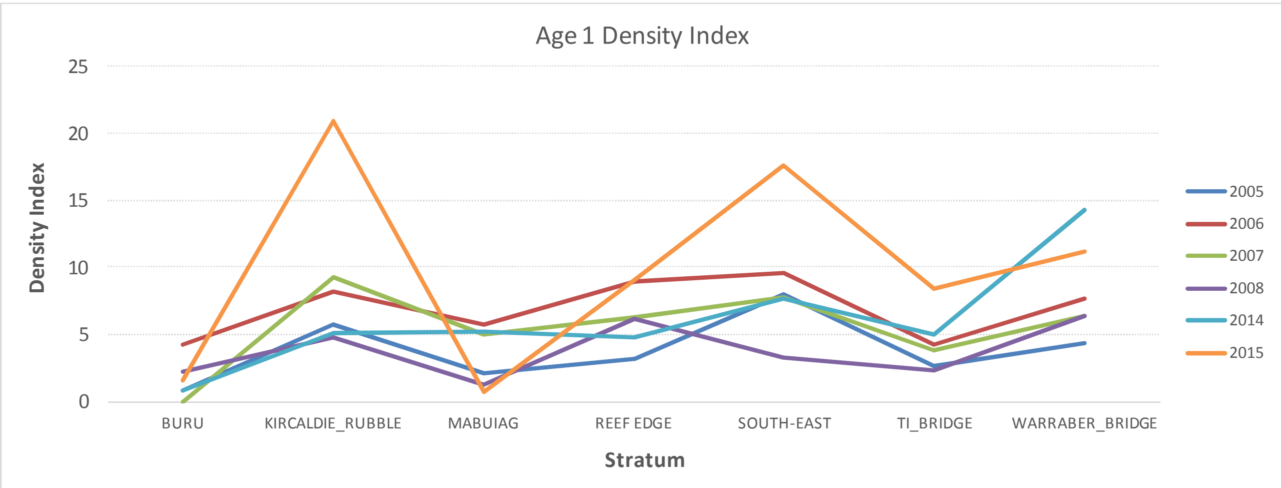

Figure 5. Comparative indices of abundance of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded in each sampling stratum during pre-season surveys in Torres Strait between 2005 and 2015 (note surveys were not done during 2009-2013).

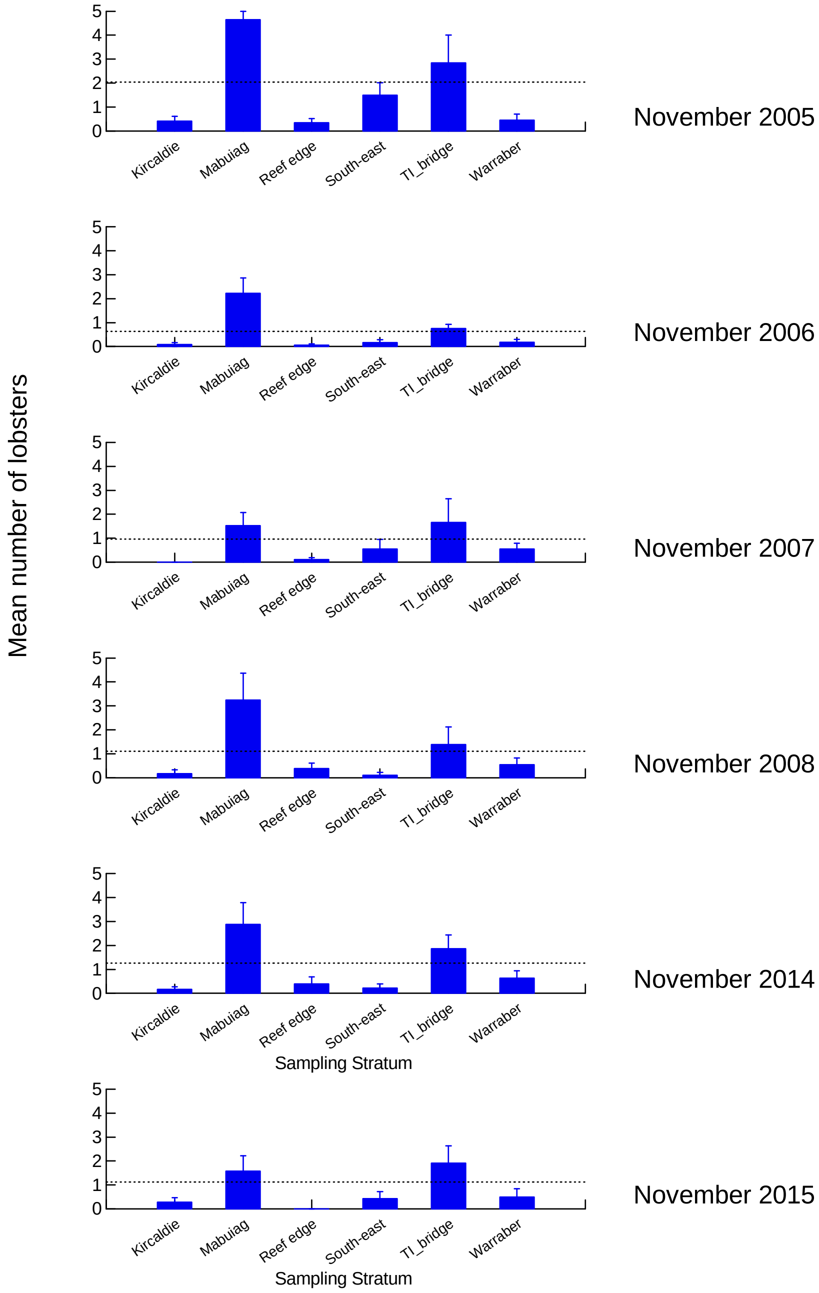

Figure 6. Density of recently-settled (0+) ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season population surveys in western Torres Strait between 2005 and 2015 (note surveys were not done during 2009-2013). Dashed lines indicate overall density of 0+ lobsters.

Comparisons 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 7. 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.

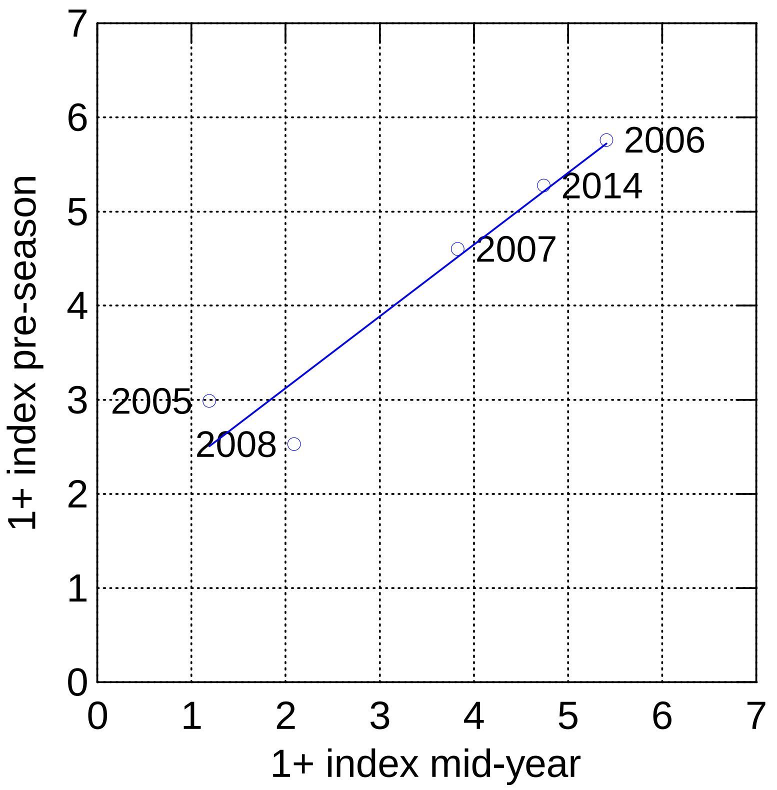

Figure 7. Relationship between recruiting (1+) lobster abundances indices recorded from mid-year and pre-season surveys for years 2005-2008 and 2014. Line denotes the linear regression (R^2=0.97).

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 8). 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.

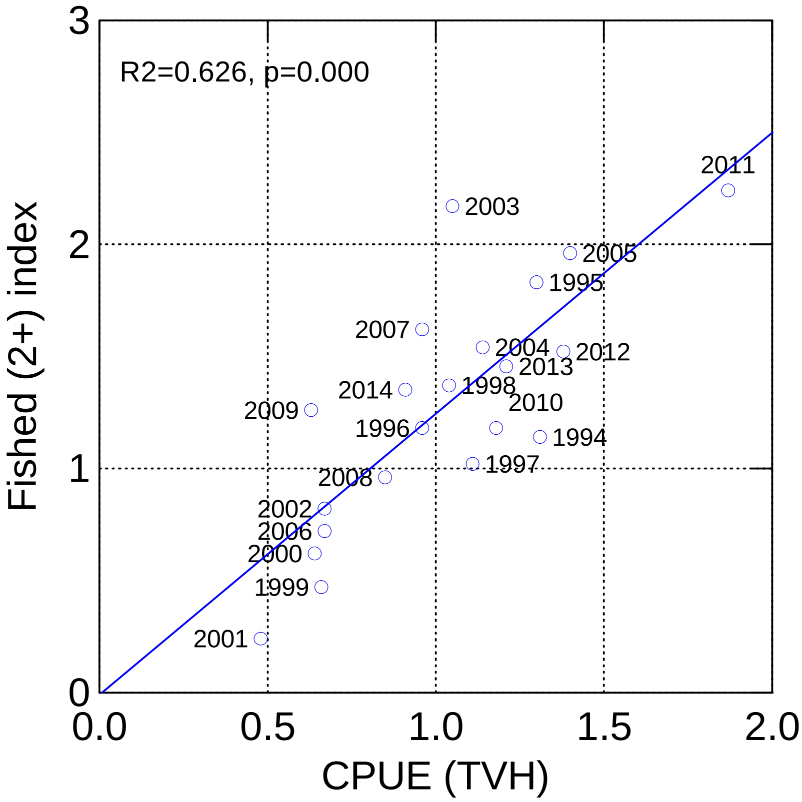

Figure 8. Relationship between CPUE indices for the TVH sector and fished (2+) indices recorded from mid-year surveys for years 1994 to 2014. Line denotes the linear regression (R^2=0.626).

Size/Age Distribution of Sampled Lobsters

The size distribution of lobsters sampled during the 2015 pre-season survey was similar to those recorded in previous years (Figure 9), except there was a decrease in the percent composition of legal-size lobsters. The modal size of recruiting (1+) lobsters recorded in 2015 was low and comparable to 2007 and 2014 levels.

Long-term Torres Strait Seabed Habitat Monitoring

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 10). Seagrass cover increased steadily during 2000 to 2010, and has remained above the long-term average since then Interestingly algal cover showed a steady decline throughout the period studied from ~20% to ~10%.

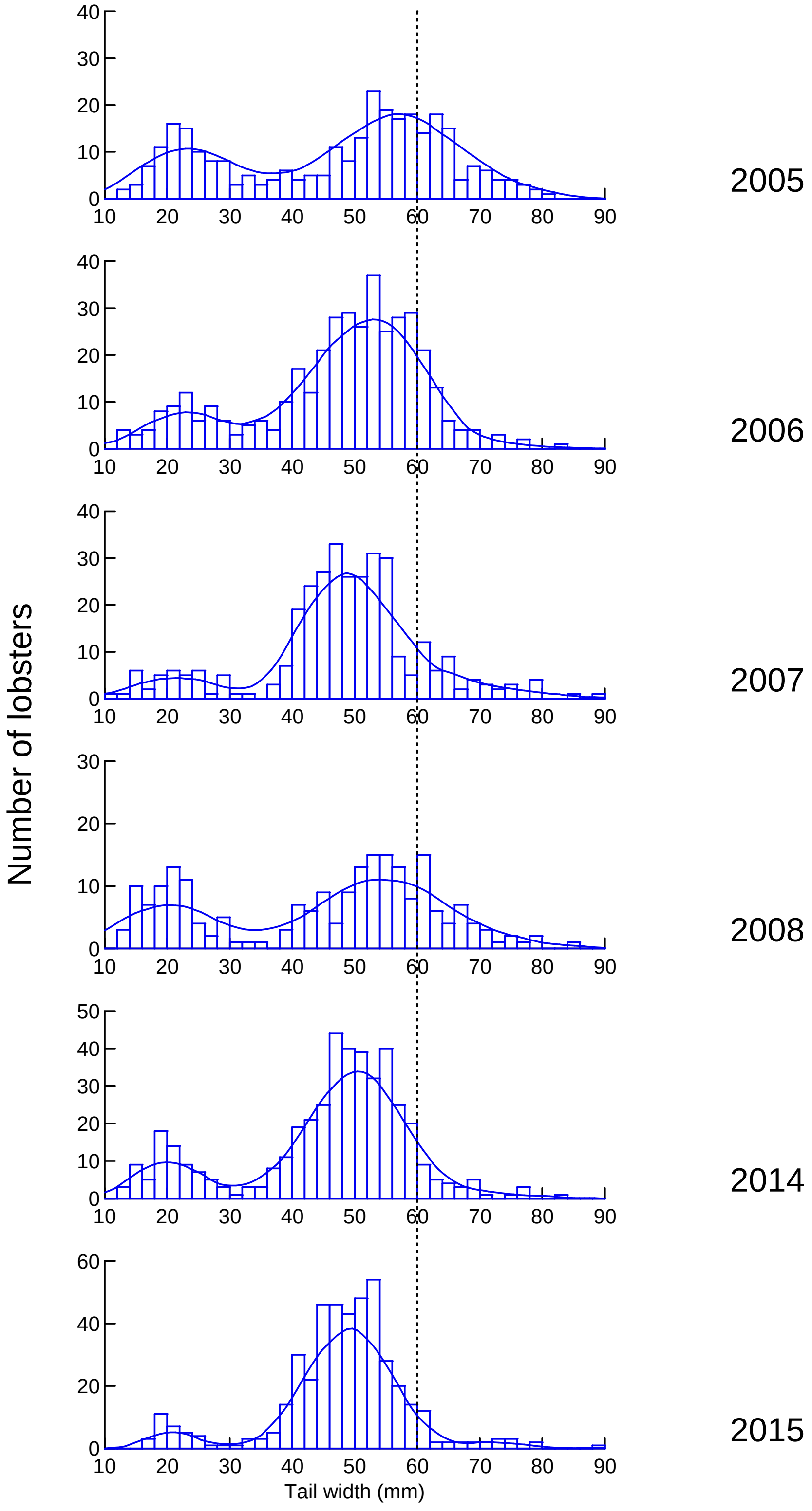

Figure 9. Length frequency distributions of lobsters (*Panulirus ornatus*) sampled during pre-season population surveys in Torres Strait in 2005-2008, 2014 and 2015. The dotted line represents the minimum legal size (90 mm CL ≈ 60 mm tail width).

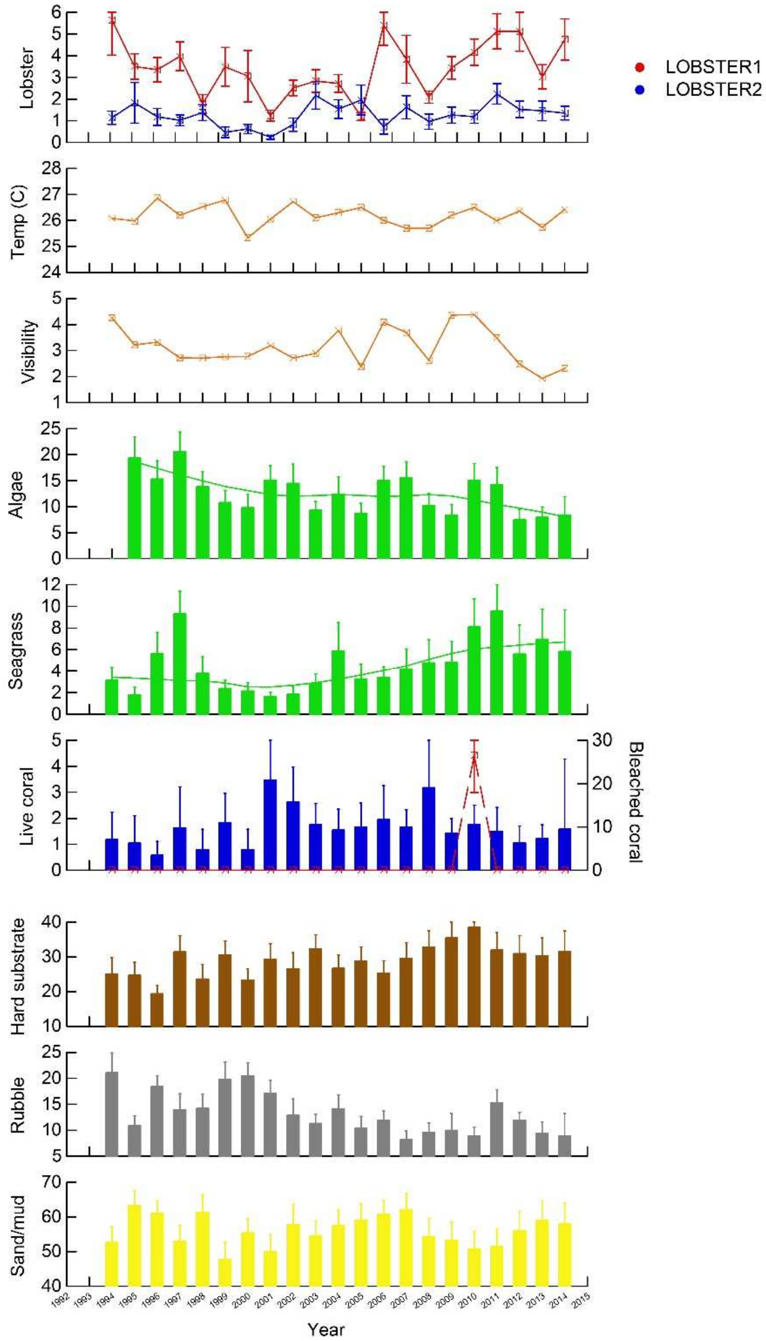

Figure 10. Mean percent covers of abiotic and biotic categories and lobster (*Panulirus ornatus*) indices recorded during mid-year population surveys in Torres Strait during 1994 to 2014. Error bars represent standard errors.

Although sand incursions were recorded at a numbers of transects during the 2015 pre-season population survey, the overall cover of sand at repeated sites was the lowest recorded (Figure 11). Further, the distribution of seabed substratums recorded in 2014 and 2015 wase similar with no clear evidence of regional incursions of sand (Appendix C). Nevertheless, sand wave movements in Torres Strait have been rapid and continual to date and seabed communities are well adapted to these incursions in any case. 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.

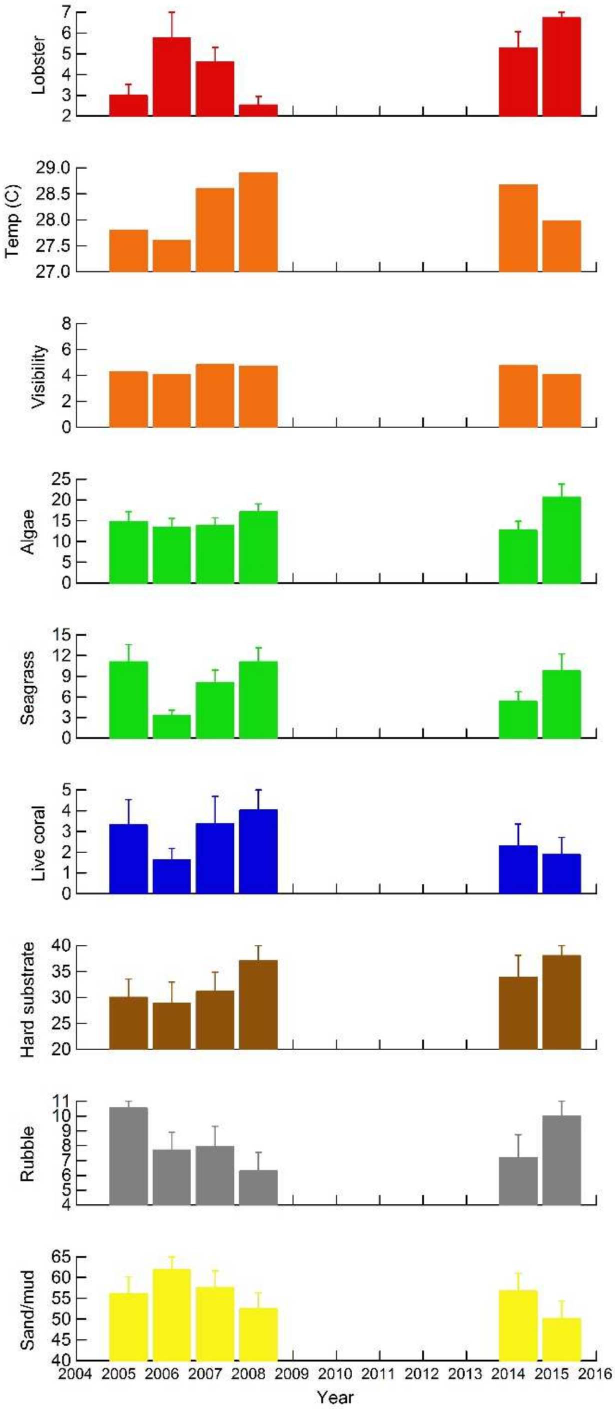

Figure 11. Mean percent covers of abiotic and biotic categories and lobster (*Panulirus ornatus*) indices recorded during pre-season surveys in Torres Strait during 2005 to 2015. Error bars represent standard errors.

Long-term Torres Strait Water Temperature Patterns

Whilst there has been considerable research on the impacts of changing climate on Australia's temperate lobster fisheries, for example the effects of warmer water temperature on western rock lobster (*Panulirus cygnus*) recruitment (de Lestang et al. 2014), little is known of the impacts on tropical lobsters. Projected climate conditions to 2030 suggest that whilst higher temperatures may increase egg production and growth of TRL, juvenile mortality will likely increase (Norman-Lopez et al. 2013). The perceived impacts are largely speculative due to the consistency of the recent climate, and hence the lack of range in impacting variables such as water temperature, sea level rise, ocean currents and rainfall. However, as per the recent dramatic decline in recruitment of *P. cygnus*, and reduced catch, changing conditions can be significant and provide valuable evidence for forecasting likely impacts on populations and catch.

The Southern Oscillation Index (SOI) has declined recently to a 10 year low in 2016 (Figure 12), continuing El Nino conditions throughout eastern Australia. As a result there was a high likelihood that eastern Australia would see above average sea temperatures, and this has occurred throughout northern Australia.

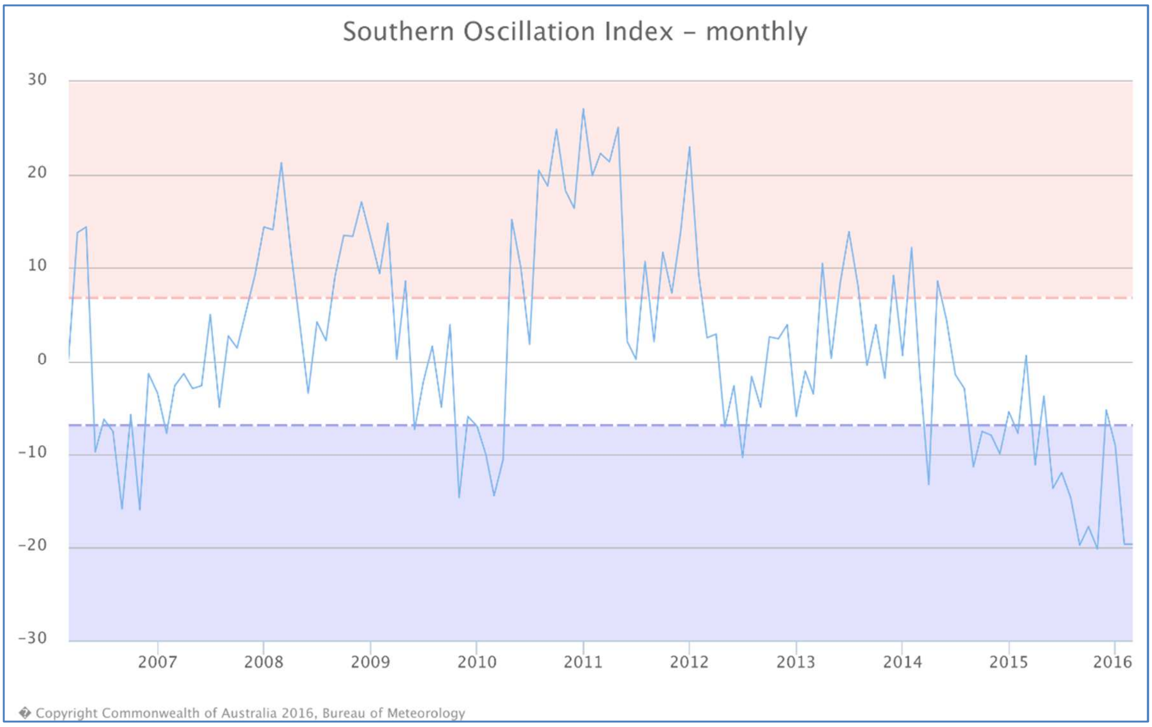

Figure 12. SOI indices recorded during 2006 to 2016; source Bureau of Meteorology.

Water temperature recorded at Thursday Island during 2012 to 2016 was generally consistent with the long-term trend (Figure 13) but since mid-February 2016 there has been a significant increase with temperatures well above average. The impacts of elevated water temperature have been exacerbated by reduced wind strength over the same period (Figure 14), which causes still conditions particularly in shallow water.

As a result of these conditions there have been reports of coral bleaching around Thursday Island, and it is likely that corals throughout western Torres Strait will be affected, as they were during the 2010 bleaching event (Appendix C). However, the impacts on the full range of key lobster habitats are less obvious.

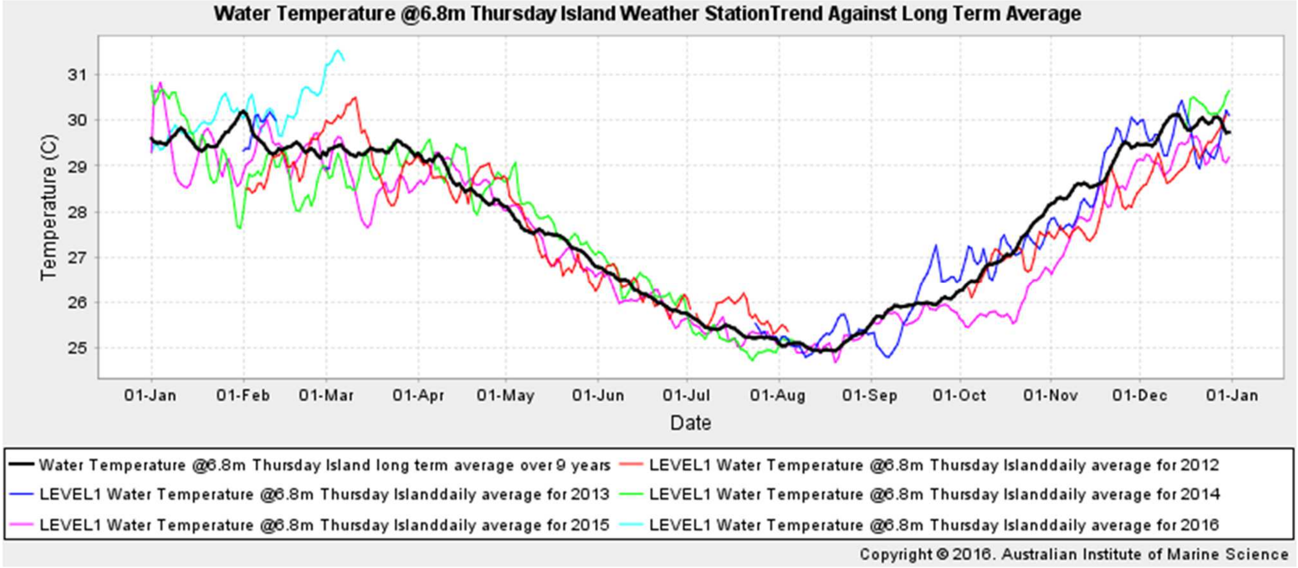

Figure 13. Water temperature recorded at 6.8m depth at Thursday Island during 2012 to 2016, against the long-term average. Source: AIMS/NERP. The black line represents the long-term average.

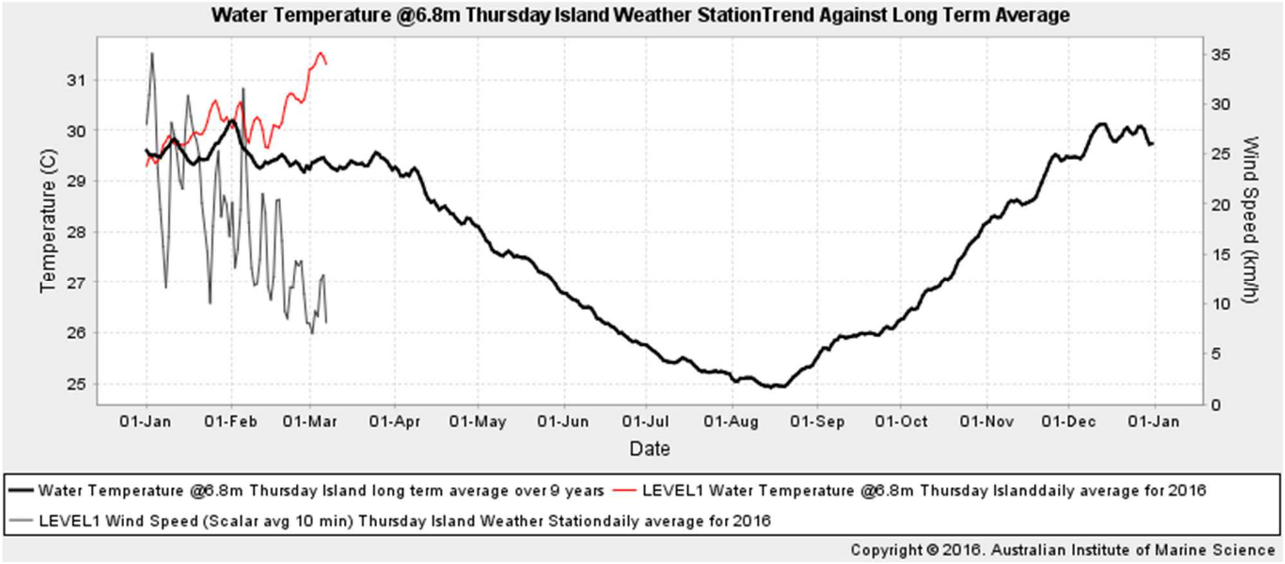

Figure 14. Water temperature and wind speed recorded at Thursday Island during 2016 against the long-term average. Source: AIMS/NERP.

As noted above, the long-term trends in water temperature in Torres Strait have been remarkably consistent with the exception of the spike observed in March 2010 (Figure 15), which resulted in the widespread coral bleaching. Fortunately, in 2010 water temperature returned to the normal seasonal cycle shortly after this spike and there was some evidence that there was minimal impact on the TRL population in that 2011 saw record catches and catch rates.

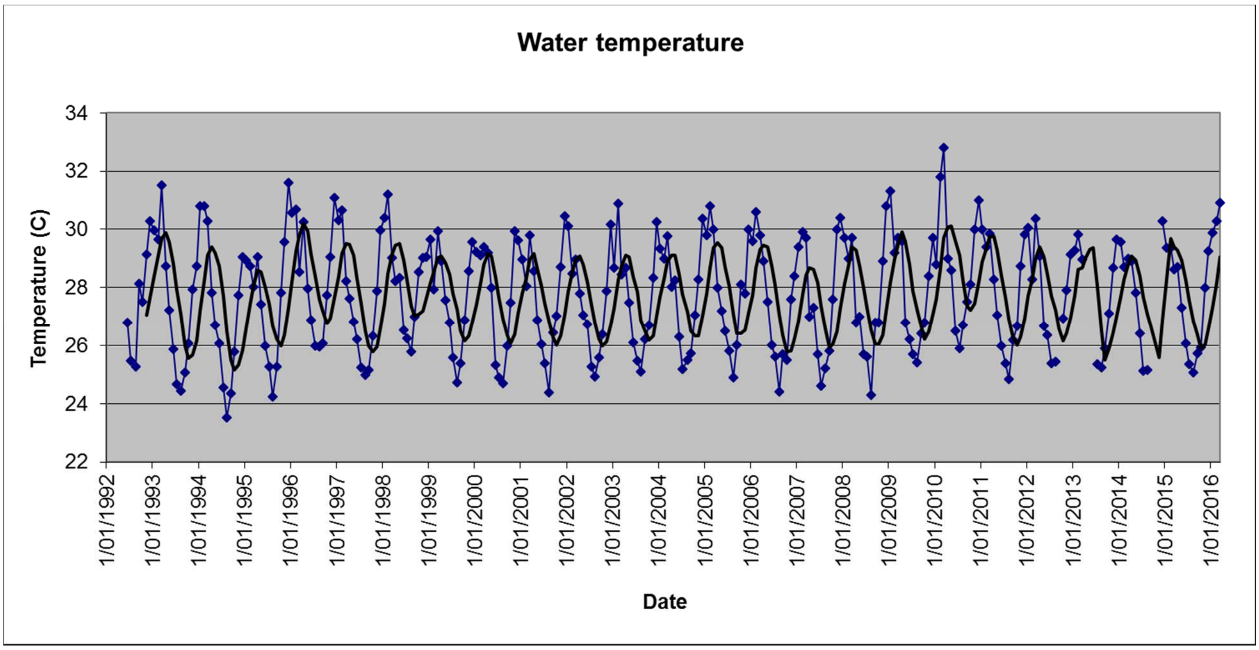

Figure 15. Water temperature recorded at Thursday Island during 1992 to 2016 from combined sources; CSIRO loggers 1992-2011, AIMS/NERP weather station 2012-2016.

Impact of elevated water temperature on held and wild lobsters

The impact of elevated water temperature on lobsters held in sea cages was clearly evident in early 2011 when high mortalities were recorded in Torres Strait, and subsequently at holding facilities. The impact was exacerbated by the high stocking densities in that year as a result of abundance well above average (eg. total Australian catch was 700 t). Notably in the previous year, when higher temperatures were recorded but catch rates were much lower (460 t), high mortality rates were not recorded in sea cages. The primary impact of elevated temperature on lobsters is the reduction in dissolved oxygen and the subsequent physiological effect on lobsters resulting in weakness and death (Paterson et al. 1997). These impacts can be ameliorated to some extent by increasing water flow, but invariably this is simply not possible and in any case high stocking densities result in increased dead space in tanks.

Ironically higher water temperatures are generally conducive for high growth rates in lobsters (Jones et al. 2001), and hence the 2016 year-class would be expected to grow faster than previous cohorts in the wild. This effect is obviously countered by density-dependent effects (for example competition for food) for years like 2016 when lobster abundance is above average. Nevertheless, given that recent high stocking density combined with high water temperature has resulted in significant mortality there is a case for reducing current fishing effort and accessing these lobsters later in the season when water temperatures are lower. This occurred to some extent in 2011 and resulted in high sustained catch rates throughout the fishing season. Further, it is possible that there may be a productivity bloom as a result of sustained high temperatures for seabed habitats including seagrass meadows and mussel beds, which may further enhance growth and survival of lobsters.

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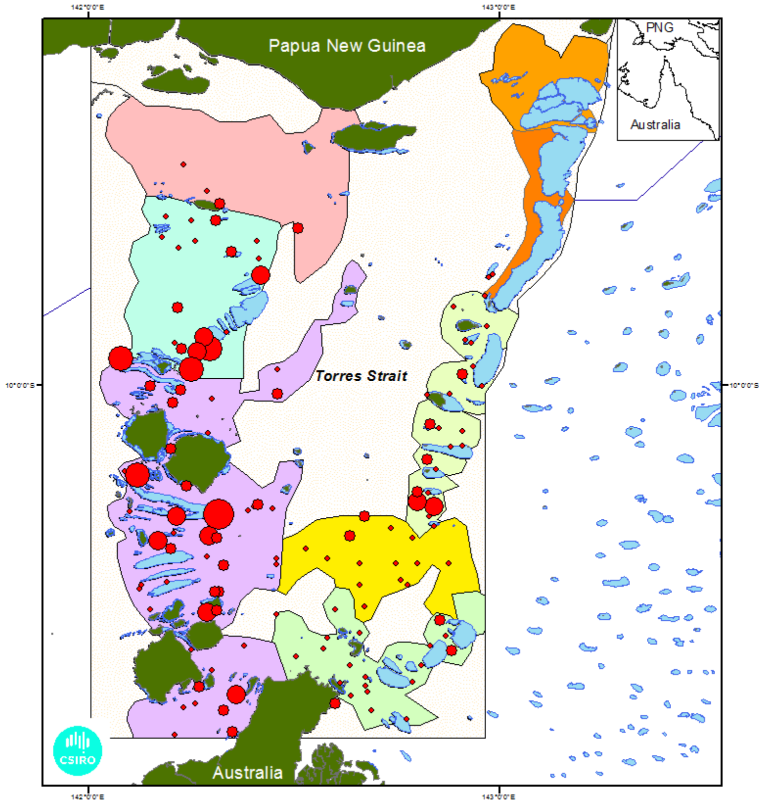
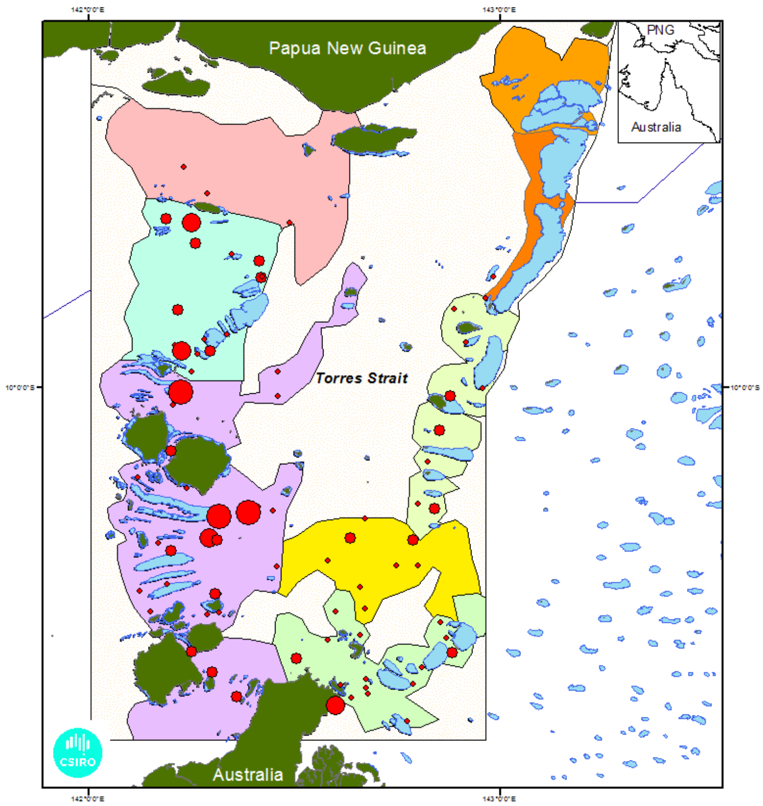
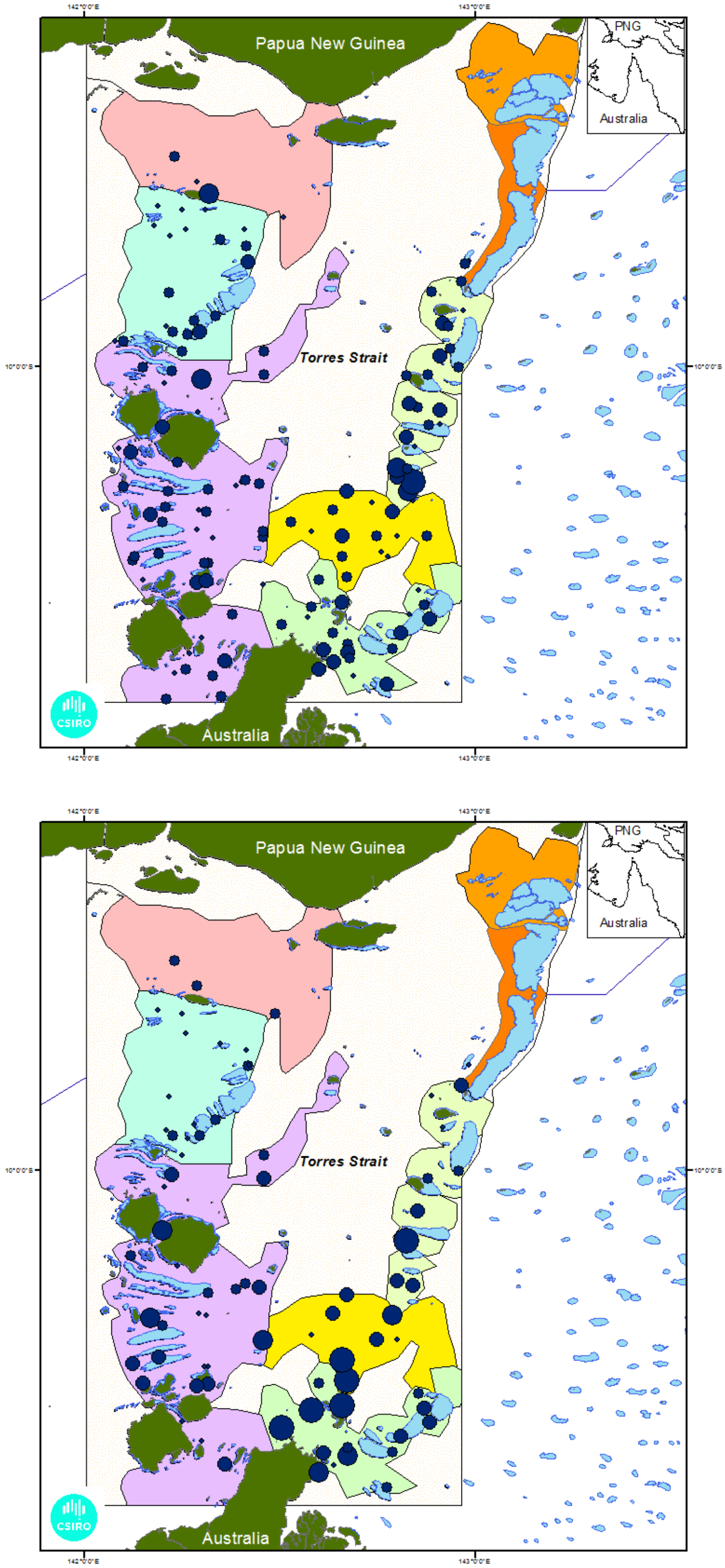
Appendix A. Density of recently-settled (0+) ornate rock lobsters (*Panulirus ornatus*) recorded during the 2014 (top pane) and 2015 (bottom pane) pre-season population surveys in western Torres Strait.

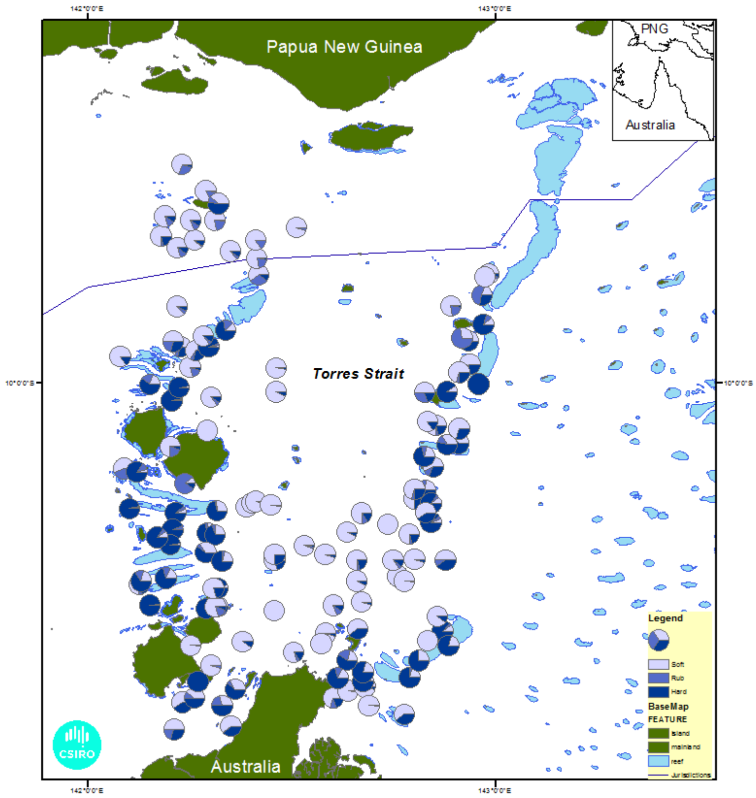


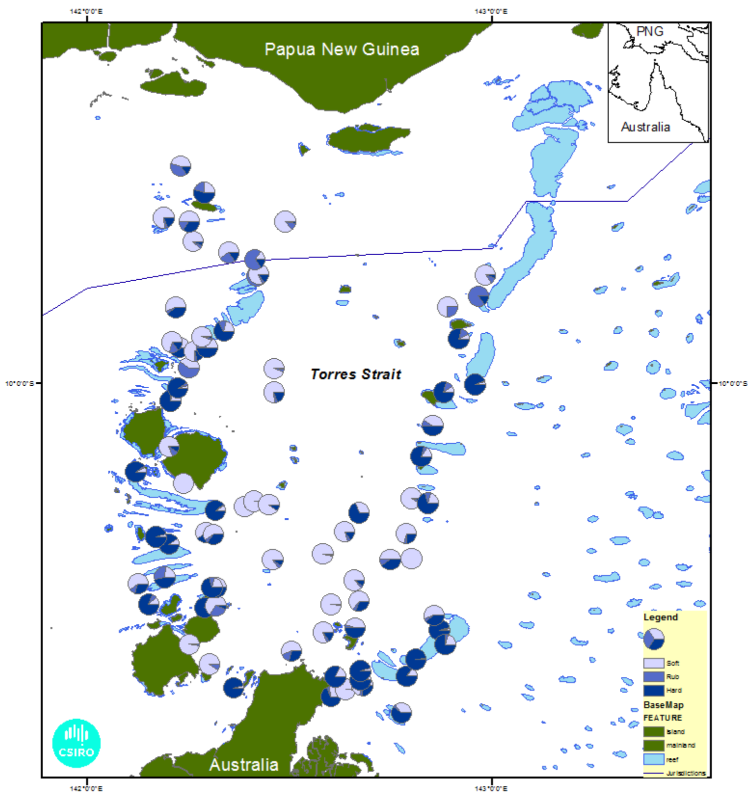


Appendix B. Density of recruiting (1+) ornate rock lobsters (*Panulirus ornatus*) recorded during the 2014 (top pane) and 2015 (bottom pane) pre-season population surveys in western Torres Strait.

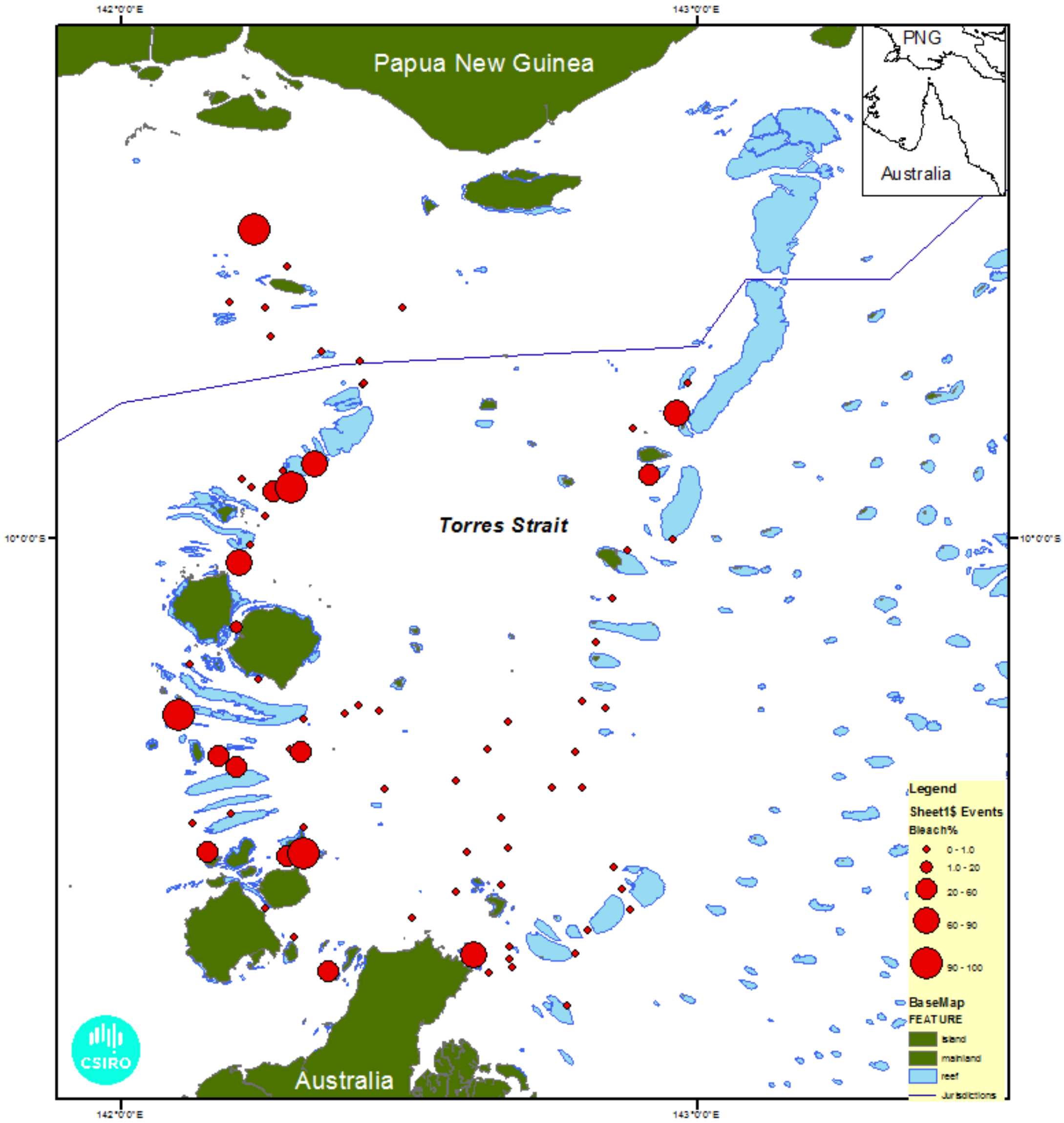


Appendix C. Distribution of seabed substratums recorded during the 2014 (top pane) and 2015 (bottom pane) pre-season population surveys in western Torres Strait.





Appendix D. Percent coral cover bleached recorded during the 2010 mid-year lobster (*Panulirus ornatus*) population survey in western Torres Strait.



2015 Updated Assessment of the Torres Strait Tropical Rock Lobster (*Panulirus ornatus*) Fishery following the November 2015 pre-season survey

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Summary

This document summarises the post-Nov 2015 preseason survey update of the integrated model. The data updates include the latest (Nov 2015) pre-season survey results (see Dennis et al. 2015), the catch total for 2015, and revisions and updates to the commercial CPUE (TVH & TIB) data series (see Campbell et al. 2015). The full details of the stock assessment model are provided in the Appendix. As there was no midyear survey conducted in 2015, the preliminary Recommended Biological Catch (RBC) based on the stock assessment update presented at the TRLRAG meeting in August was not considered reliable as there was no firm basis for estimating the size of the recruiting age-class. Hence the TRLRAG agreed that the same model would be updated when the results of the preseason survey became available as a basis for setting the RBC for 2016.

Applying the reference case model straightforwardly with the updates as described, suggests a RBC(2016) of 796t [90% CI 524-1067t] [75% CI 660-931t] (Table 1). This value is slightly larger than the August model prediction of 704t (preliminary allocation 568t) (Table 2). A key sensitivity test recommended by the TRLRAG was to change the hyperstability parameters for the TVH and TIB CPUE relationships to 1 from 0.75 and 0.5 respectively. This changes the RBC(2016) to 782t [90% CI 519-1046t] (Table 1).

The model predictions are optimistic for 2016 because they are based mostly on the preseason survey 1+ index (Fig. 1-4). A record number of recruiting lobsters were observed during the survey (Dennis et al. 2015), suggesting that there will be high numbers of fished lobsters in 2016. However, the overall high index of recruit abundance was attributable largely to anomalously high levels recorded in the Kircaldie_rubble, South-east and TI_bridge strata, in contrast to very low levels observed in the Mabuiag and Buru strata (Dennis et al. 2015). The stock assessment model does not account for these spatial differences, and further discussion is needed as to the implications of this spatial variability when setting a TAC.

Of greater concern is that the 2015 total catch of 495t is substantially less than expected. Potential reasons for this are discussed in more detail in Plagányi et al. (2015b). The 2015 catch corresponded to a fishing proportion F of 0.08 (assuming constant natural mortality) in the August model, but with the subsequent revision this is changed to 0.12, compared with the target level of 0.15. The 2014 catch is estimated retrospectively to correspond to F=0.19 (Fig. 2). 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 low overall catches for 2015 (noting that the total catch estimate is not considered 100% reliable either). The model assumes constant annual natural mortality, and hence cannot straightforwardly model the change in catchability and/or survival without additional information, and further discussion is needed as to how best to account for the 2015 difference between the catch and prediction. Preliminary model simulations were done to try

and estimate the change in selectivity and/or survival, but this could not be reliably estimated in the model without further information or work, so this is not presented in this document.

The Reference case model presented here is fitted to the TVH CPUE Main Effects and the nominal CPUE TIB data as described in Campbell *et al.* 2015b (Fig. 5). There isn't much difference between the alternative CPUE standardisations, but one example is shown using the Int2A series for TVH CPUE and Main effects standardised series for TIB (Table 1, Fig. 6).

There is some conflict in the model between the 2014 preseason survey predicting a large fished cohort in 2015 (Fig. 1), and the actual observation of a poor catch year and corresponding low CPUE (Fig. 5). The model therefore trade-offs the fit between the survey and CPUE data, and does not exactly fit the full extent of the recent downturn in the CPUE indices. This is important because in the absence of a midyear survey, the CPUE data need to serve as an index of spawning stock biomass, and it's possible that the spawning biomass is lower than the model estimate (Table 1, Fig. 3). In order to fit the CPUE trends, the model trade-offs the fit to the 2014 midyear survey, and a large deterioration is seen in the fit to the 2014 midyear survey data (Fig. 7), highlighting the current anomalous events. The model outputs thus need to be interpreted with caution.

Note that the model results presented here are fitted to the preseason survey index based on midyear sites only, as discussed in Campbell et al. (2015). A single sensitivity test is shown using the alternative series with all sites (Table 1). The different series have different associated variances, and this will affect the weight the model accords to the preseason survey data, and hence this aspect needs to be investigated further in future work and survey design considerations.

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 TAC estimate;
- 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 new model outputs a single TAC estimate (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 report summarises the December 2015 model assessment update based on the latest update of the Pre-season survey data from November 2015.

The revised Reference Case includes the following specifications (see Plaganyi 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;
- 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 TIB CPUE series (both nominal and new standardized 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;
- In response to a review suggestion, the model fits to the midyear survey series for the two age classes separately rather than as a combined series (and including fitting to the age proportions);

This year's August TRLRAG assessment differs from previous years because no midyear survey was done in 2015, after a continuous survey series of 26 years. The annual midyear surveys provided relative abundance indices for two lobster age-classes; sub-legal recruiting lobsters aged about 1.5 years (1+) and legal lobsters aged about 2.5 years (2+). The 2+ abundance indices, as measured before migration, provide data on the relative size of the spawner stock. As the CPUE data also index the size of the spawner stock, these data can substitute to some extent for the 2+ index. In November 2014 and 2015 a preseason survey was re-instigated, adding to the previous surveys which were conducted for the years 2005-2008. The rationale for a survey at the end of year was that it was closer to the season opening in December. As the survey was closer to the opening season it provided a higher level of accuracy and certainty in forecasts of stock in the following year (Dennis et al. 2015). This further improves prediction of the TRL stock size as there is substantial inter-annual variability in recruitment, driven by environmental factors, some of which are not well understood. Dennis et al. (2015) showed that including both independent fishery surveys returned a positive net present value over a 20 year timeframe even when randomly varying biomass, accounting for increasing survey costs, lower gross margins, and lower lobster prices. The availability of both midyear and preseason data in 2014 allowed further investigation of the extent to which the assessment is modified following the addition of a preseason survey (Plaganyi et al. 2015). This document describes the December 2015 update of the assessment using the updated and analysed CPUE data from 2015, as well as the 2015 Preseason survey data.

Methods

The model details are given in Appendix 2. A summary of the input catch data is shown in Table 1. In addition, the latest (Nov 2015) preseason survey results are included in the model. There is no midyear survey conducted in 2015 and hence the model fits to these data up until 2014 (Table 2).

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 1).

The TVH CPUE data input series have been revised and updated for the period 1989-2015 (Campbell *et al.* 2015). In addition, the model is also fitted to the revised nominal TIB CPUE data series for the period 2004-2015 (no data for 2013), and a standardized series is used as well in sensitivity runs.

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 Plaganyi 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. 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.

Results

- ### MODEL FITS

The fits of the new Integrated Model to all available data sources is shown in Figures 1 to 7. The starting number of lobsters is estimated and Figure 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) and fits to the catch at age data are adequate (Plaganyi et al 2015). 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.

The model predictions are optimistic for 2016 because they are based mostly on the preseason survey 1+ index (Fig. 1-4). A record number of recruiting lobsters were observed during the survey (Dennis et al. 2015), suggesting that there will be high numbers of fished lobsters in 2016. However, the overall high index of recruit abundance was attributable largely to anomalously high levels recorded in the Kircaldie_rubble, South-east and TI_bridge strata, in contrast to very low levels observed in the Mabuiag and Buru strata (Dennis et al. 2015). The stock assessment model does not account for these spatial differences, and further discussion is needed as to the implications of this spatial variability when setting a TAC.

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Discussion

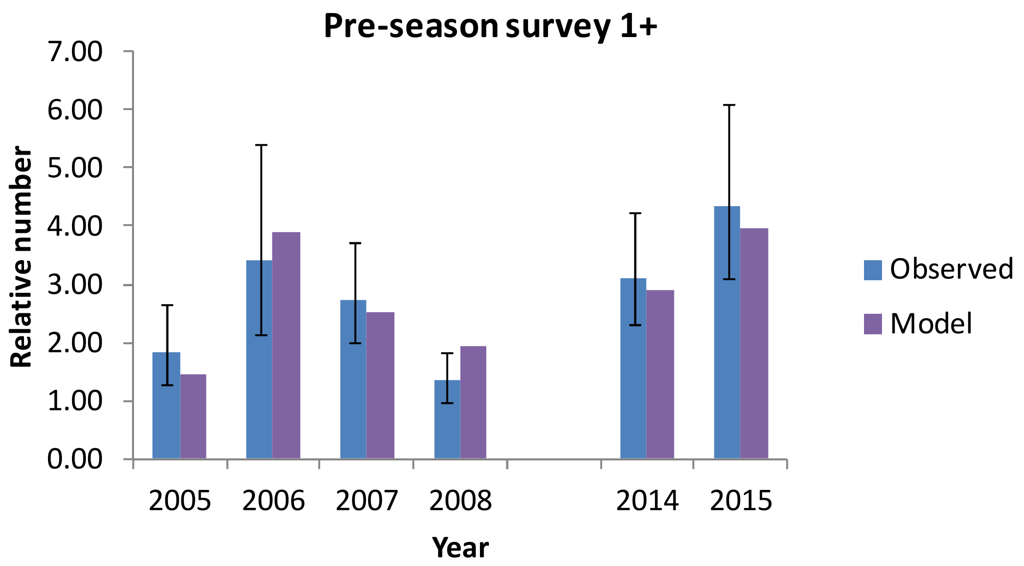
The revised and updated model adequately fits the available data and integrates all available information into a single framework to output a RBC value as required for a change to a quota management system. The use of a single model facilitates understanding of the way in which data inputs translate into an assessment of the status and productivity of the resource and hence an associated TAC 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, and work is continuing on how this might be taken into consideration in the assessment. There is also a need to investigate whether there is a benefit in moving towards a spatial assessment model (for example, the spatial operating model used in the MSE) or at least better accounting for marked spatial differences in abundance and catch.

Applying the reference case model straightforwardly with the updates as described, suggests a RBC(2016) of 796t [90% CI 524-1067t] [75% CI 660-931t] (Table 1). This value is slightly larger than the August model prediction of 704t (preliminary allocation 568t) (Table 2). A key sensitivity test recommended by the TRLRAG was to change the hyperstability parameters for the TVH and TIB CPUE relationships to 1 from 0.75 and 0.5 respectively. This changes the RBC (2016) to 782t [90% CI 519-1046t] (Table 1).

Acknowledgements

This research project was co-funded by the Australian Fisheries Management Authority and CSIRO to provide annual Torres Strait Tropical Rock Lobster surveys and stock assessment for effective management of the TRL fishery. Thanks to James Cook University for continued support of the diving surveys through the charter of the MV *James Kirby* and valued assistance of the master. Thanks to staff of M.G. Kailis Pty Ltd for continued support in providing size data from commercial catches and seasonal price data – concurrent activities undertaken by this project.



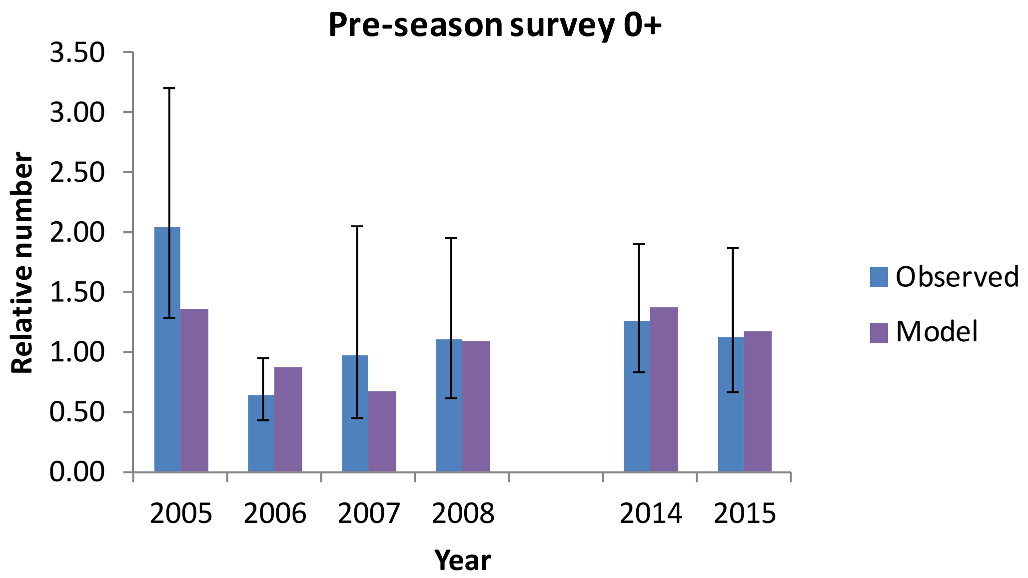


Figure 1. Comparison between observed Pre-season survey data (expressed in terms of number * 10^4) and corresponding model-predicted estimates.

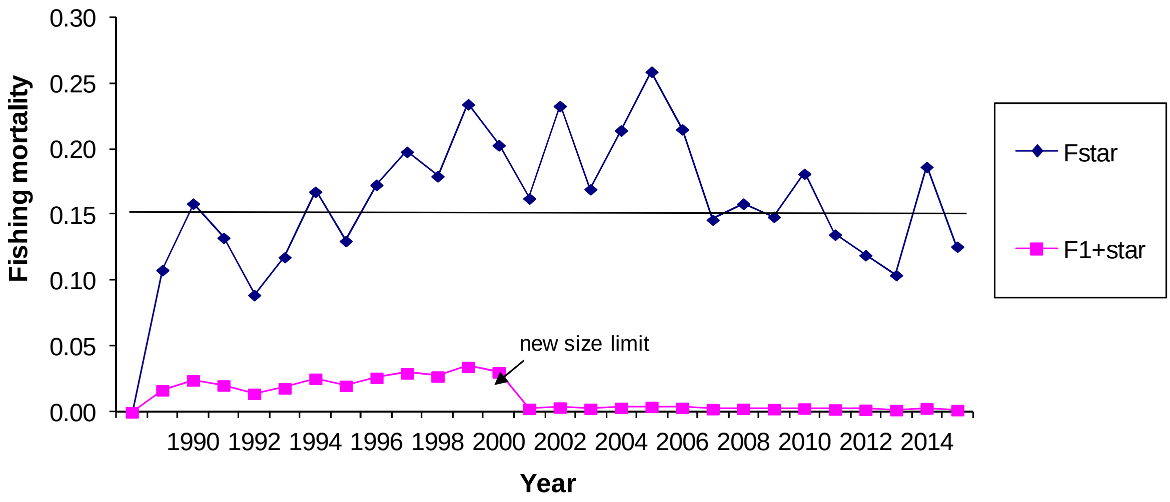


Figure 2. Model-estimated fishing mortality trends for 1+ (F 1+star) and 2+ (F 2+ star) lobsters. The 2002 change in size limit is highlighted and the 2016 fishing mortality set equal to the target value of 0.15.

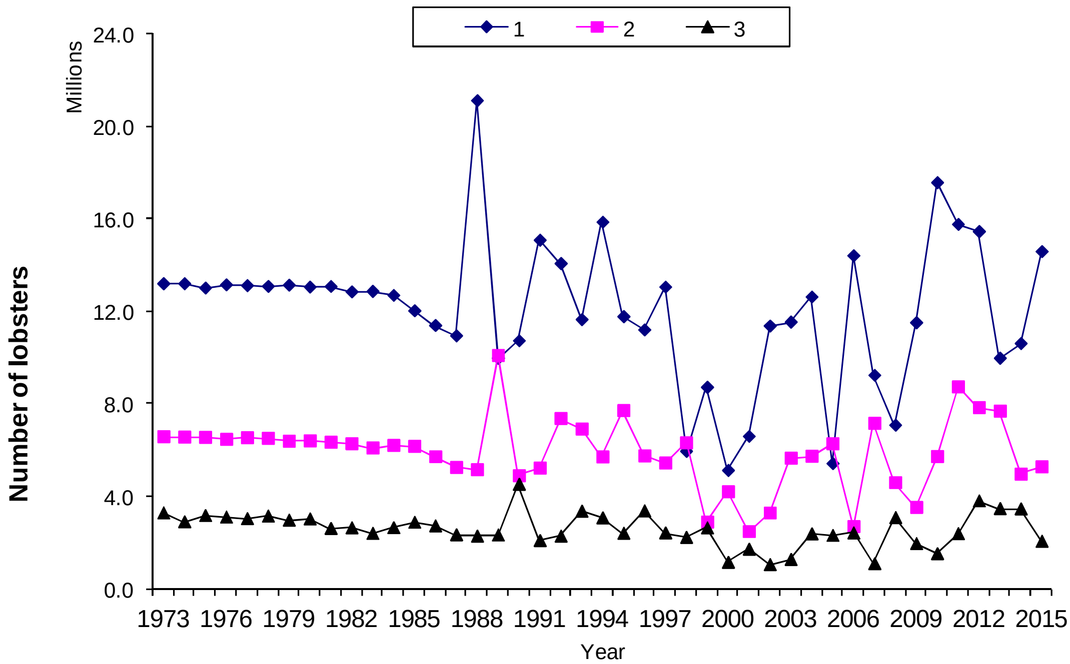


Fig. 3. Model trajectories of the annual numbers of lobsters in each age class at the start of each of years 1973 to 2015. The increased variability from 1985 onwards is because the model estimates stock recruit residuals for years from 1985 to 2014.

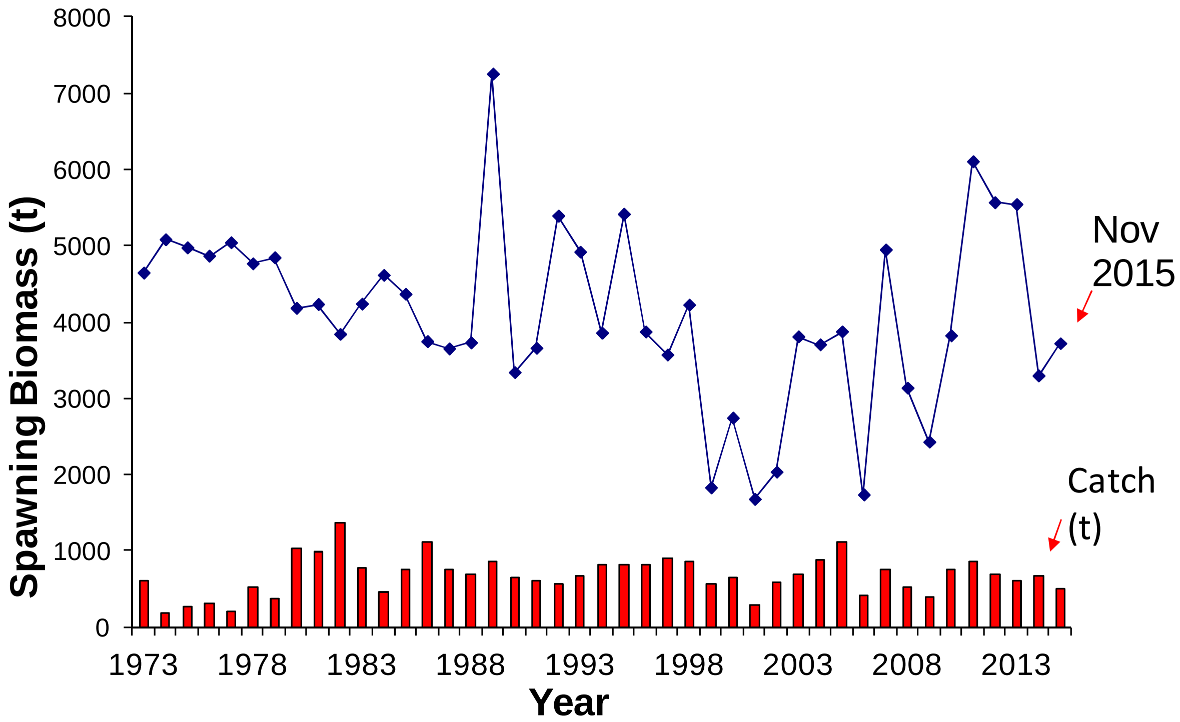
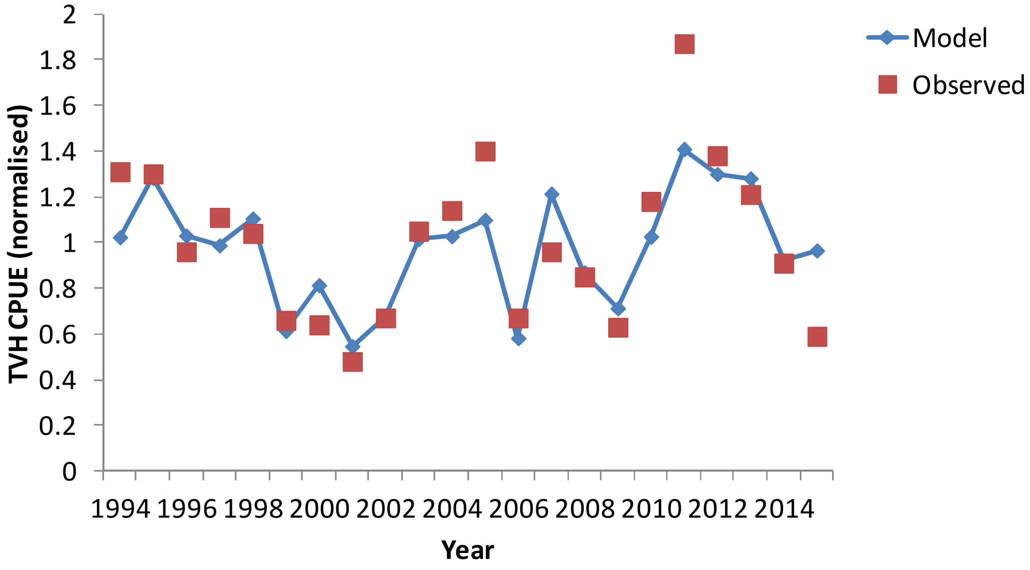


Fig. 4. Model trajectories of the lobster spawning biomass (t) over the model period shown together with annual catches by the trawling and other sectors combined.



b) REFERENCE CASE FIT TO TIB CPUE (nominal)

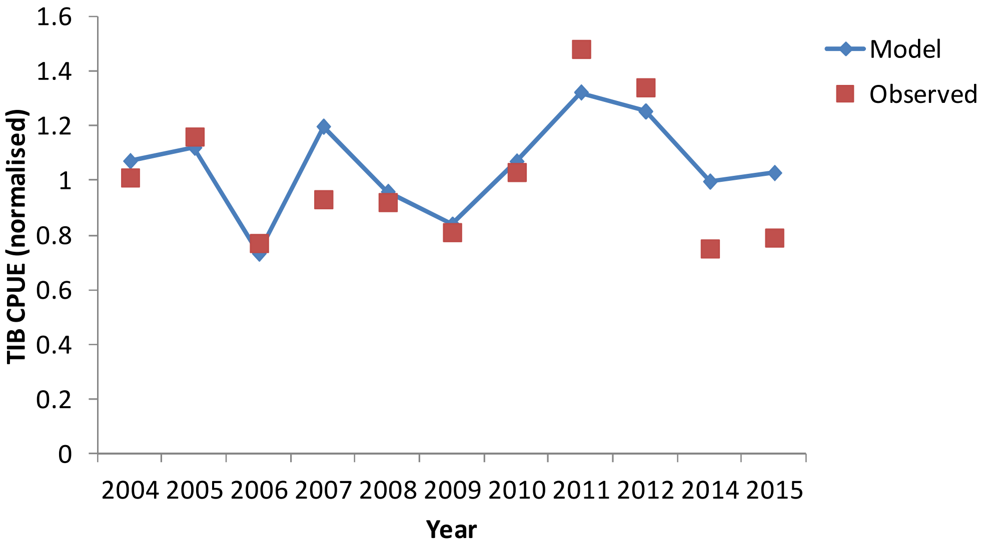
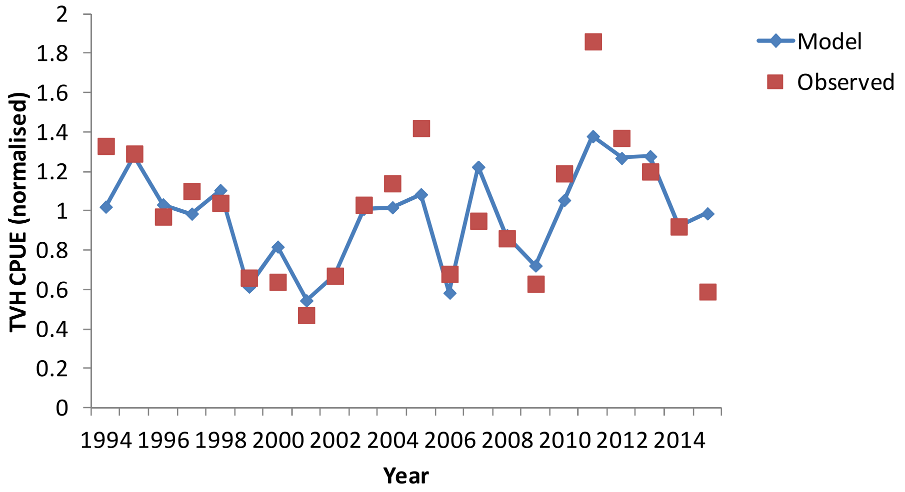


Figure 5. Comparison between CPUE data and corresponding model-predicted estimates. The plots are respectively a) Reference-Case fit of the model to CPUE standardised estimates from the TVH sector with lower bound for sigma set at 0.15, b) fit to TIB CPUE nominal estimates available from 2004-2015 (no data for 2013); assuming hyperstable relationship (with power shape parameter 0.75 and 0.5 respectively) between CPUE and exploitable biomass for the TVH and TIB sectors.



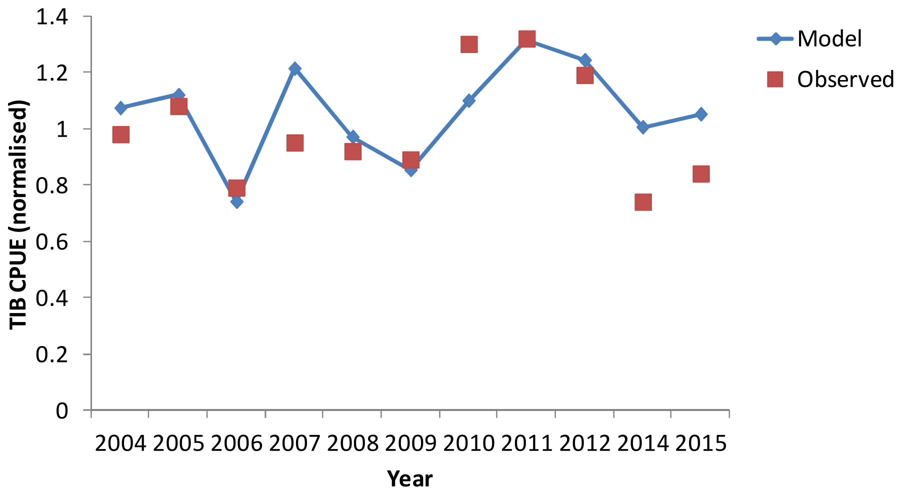
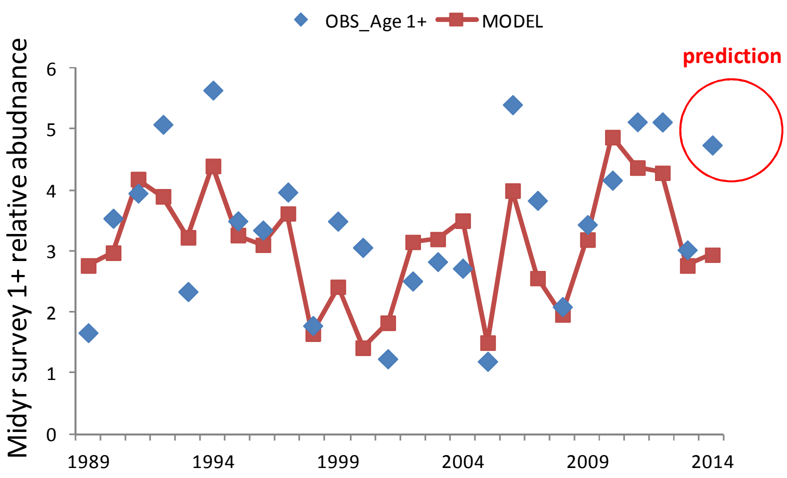
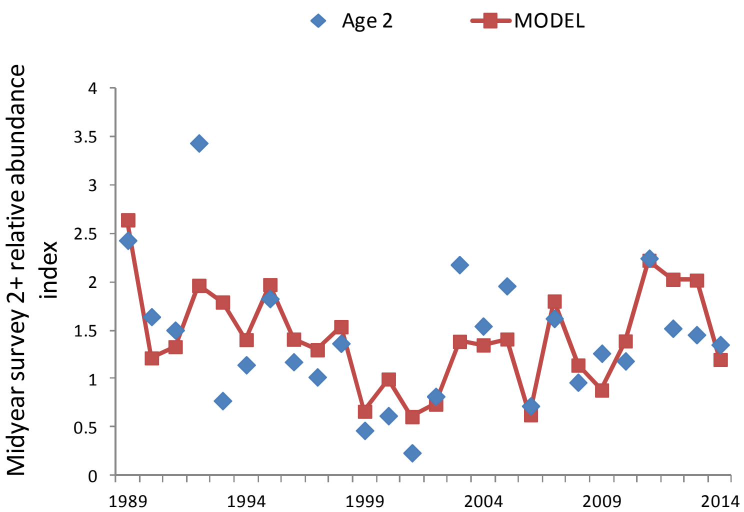


Fig. 6. Sensitivity test showing fit to alternative CPUE standardized series. TVH = Int-2A; TIB – Main effects.





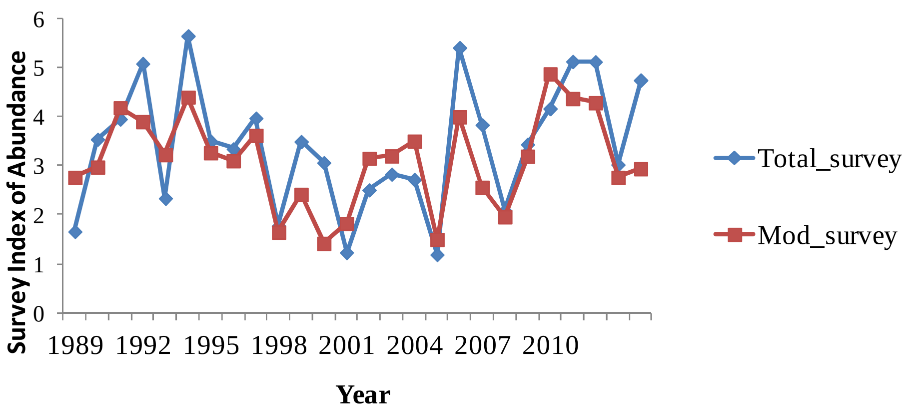


Figure 7. Comparison between survey midyear index of abundance (in terms of total numbers of 1+ and 2+ lobsters) compared with the corresponding model-estimated values for A) Reference Case with fitting to separate series and B) fit shown when combining total numbers

Table 1a. Revised Reference Case model results (repeated in following Table for comparison)

	(a) Revision with Preseason Survey		
Parameter	**Parameter**	**Value**	**90% CI**
B(1973)^{sp} *(tons)*	4688	3325	6052
M	0.70	0.57	0.82
h	fixed 0.7		
Sel (age 1+) 1973-1988	0.43	0.24	0.62
Sel (age 1+) 1989-2001	0.16	0.14	0.19
Sel (age 1+) post2002	0.02	0.00	0.03
Recruitment residuals (1985-2015)		31 parameters	
Model estimates and depletion statistics			
B(2015)^{sp} *(tons)*	3719	2349	5088
RBCprelim(2016) model	796	524	1067
RBCforecast(2017) mode	677	489	866
Current Depletion (Nov) *B(2015)*^{sp} */ B(1973)sp*	0.80	0.57	1.04
Bexp(2015) (tons)	4185	2851	5519
No. parameters estimated	36		
'-lnL:overall	**-166.416**		
AIC	**-260.832**		
Likelihood contributions		**Sigma**	**q**
'-lnL:CAA	-53.90	0.05	
'-lnL:CAAsurv	-19.25	input	
-lnL:CAA historic	-21.89	0.13	
-lnL:Survey Index 1+	-17.40	input	3.932E-07
-lnL:Survey Index 2+	-14.46	input	4.129E-07
-lnL:Survey benchmark	-3.11	input	
'-lnL:PRESEASON	-6.55	input	5.163E-07
-lnL:PRESEASON 0+	-4.88	input	8.920E-08
-lnL:CPUE (TVH)	**-19.59**	0.25	0.0019
-lnL:CPUE (TIB)	**-12.02**	0.21	0.0161
'-lnL:RecRes	6.63	0.50	(input sigma 0.5)

Table 1b. Summary of initial model sensitivity tests as shown (see text for details). Note these are compared with a preliminary revised model version and the August 2015 Reference Case

	(a) Revision with Preseason Survey			(B) Prelim August 2015			(C) Hyperstability = 1			(D) Alternative CPUE series			(E) Preseason survey index all si		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**		**Parameter**	**Value**	**90% CI**	**Paramete**	**Value**	**90% CI**	**Paramete**	**Value**	**90% CI**
B(1973) ^{sp} *(tons)*	4688	3325	6052	4590	3274	5905	4621	3292	5951	4727	3351	6103	4693	3332	6053
M	0.70	0.57	0.82	0.69	0.56	0.81	0.70	0.57	0.82	0.70	0.57	0.82	0.70	0.57	0.82
h	fixed 0.7			fixed 0.7			fixed 0.7			fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.43	0.24	0.62	0.43	0.24	0.63	0.43	0.24	0.62	0.43	0.24	0.63	0.43	0.24	0.62
Sel (age 1+) 1989-2001	0.16	0.14	0.19	0.17	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
Recruitment residuals (1985-2015)		31 parameters			**30 parameters**			31 parameters			31 parameters			31 parameters	
Model estimates and depletion statistics															
B(2015) ^{sp} *(tons)*	3719	2349	5088	4554	2960	6149	3428	2219	4636	3872	2472	5271	3906	2446	5367
RBCprelim(2016) model	796	524	1067	704	510	897	782	519	1046	811	535	1088	833	559	1107
RBCforecast(2017) mode	677	489	866	664	481	846	667	484	850	683	493	873	678	490	867
Current Depletion (Nov)															
B(2015) ^{sp} */ B(1973)sp*	0.80	0.57	1.04	1.01	0.73	1.28	0.75	0.54	0.96	0.83	0.59	1.06	0.84	0.59	1.09
Bexp(2015) (tons)	4185	2851	5519	5193	3653	6734	3907	2725	5089	4334	2972	5696	4372	2949	5794
No. parameters estimated	36			35			36			36			36		
'-lnL:overall	**-166.416**			-171.160			-161.995			-166.105			-168.508		
AIC	**-260.832**						-251.990			-260.210			-265.016		
Likelihood contributions		**Sigma**	**q**		Sigma	q		Sigma	q		Sigma	q		Sigma	q
'-lnL:CAA	-53.90	0.05		-53.57	0.05		-54.36	0.05		-53.89	0.05		-53.96	0.05	
'-lnL:CAAsurv	-19.25	input		-19.69	input		-19.32	input		-19.23	input		-19.66	input	
-lnL:CAA historic	-21.89	0.13		-21.75	0.13		-21.71	0.13		-21.91	0.13		-21.90	0.13	
-lnL:Survey Index 1+	-17.40	input	3.932E-07	-15.67	input	3.997E-07	-13.98	input	3.991E-07	-18.37	input	3.916E-07	-17.90	input	3.937E-07
-lnL:Survey Index 2+	-14.46	input	4.129E-07	-16.15	input	4.201E-07	-14.02	input	4.207E-07	-14.39	input	4.114E-07	-14.65	input	4.139E-07
-lnL:Survey benchmark	-3.11	input		-3.10	input		-3.09	input		-3.12	input		-3.11	input	
'-lnL:PRESEASON	-6.55	input	5.163E-07	-6.39	input	4.519E-07	-6.46	input	5.217E-07	-6.46	input	5.057E-07	-8.51	input	7.610E-07
-lnL:PRESEASON 0+	-4.88	input	8.920E-08	-3.53	input	1.010E-07	-4.34	input	9.137E-08	-4.91	input	8.761E-08	-4.71	input	8.912E-08
-lnL:CPUE (TVH)	**-19.59**	0.25	0.0019	-27.11	0.17	0.0019	-20.96	0.23	0.0002	-18.47	0.26	0.0019	-18.90	0.26	0.0019
-lnL:CPUE (TIB)	**-12.02**	0.21	0.0161	-11.09	0.20	0.0166	-9.21	0.27	0.0003	-11.81	0.22	0.0162	-11.83	0.22	0.0161
'-lnL:RecRes	6.63	0.50	(input sigma 0.5)	6.86	0.50	(input sigma 0.5)	5.44	0.50	(input sigma	6.44	0.50	(input sigma 0.5	6.61	0.50	out sigma 0

Table 2. Summary of Preliminary allocation for 2016 for Tropical Rock Lobster (*Panulirus ornatus*) Fishery in the Torres Straits

TAC/Catch (t)	2012	2013	2014	2015	2016
Forecast TAC (90% CI)	532 (282-782)	769 (485-1053)	767 (518-1016)	751 (556-945)	719 (515-923)
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?
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** Dec 2015 update?
Final TAC	964	871	616	Mar 2015 (revision with preseason survey = 769t)	Dec 2015
Catch	696	597	666.7	495t	-

APPENDIX 1 – REVISED MODEL STOCK RECRUITMENT RESIDUALS

	Value	90% Confidence Interval	
1985	0.06	-0.37	0.49
1986	-0.01	-0.69	0.68
1987	-0.04	-0.57	0.49
1988	0.64	0.39	0.88
1989	-0.11	-0.35	0.13
1990	-0.04	-0.27	0.19
1991	0.23	0.01	0.44
1992	0.25	0.02	0.48
1993	0.05	-0.18	0.27
1994	0.31	0.07	0.55
1995	0.02	-0.20	0.24
1996	0.00	-0.21	0.21
1997	0.11	-0.11	0.33
1998	-0.63	-0.88	-0.39
1999	-0.24	-0.49	0.01
2000	-0.80	-1.08	-0.51
2001	-0.39	-0.63	-0.15
2002	0.07	-0.14	0.28
2003	0.20	-0.02	0.42
2004	0.24	0.03	0.45
2005	-0.73	-0.94	-0.52
2006	0.26	0.04	0.47
2007	-0.19	-0.40	0.01
2008	-0.30	-0.49	-0.12
2009	-0.01	-0.21	0.20
2010	0.48	0.27	0.70
2011	0.42	0.21	0.64
2012	0.32	0.08	0.56
2013	-0.17	-0.40	0.06
2014	-0.10	-0.35	0.15
2015	0.22	-0.05	0.49

APPENDIX 2 - 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 8). A schematic summary timeline underlying the new Integrated model is presented in Figure 8. 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.

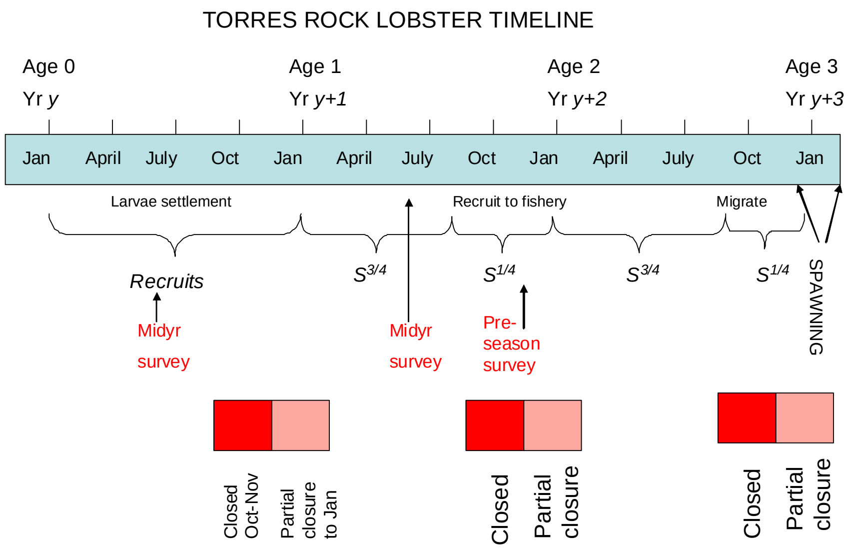


Figure 8. Summary timeline for Torres Strait Rock Lobster model.

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^{TM} (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

$$N_1^{virg} = 1 \qquad 9$$

$$N_a^{virg} = N_{a-1}^{virg} e^{-M_{a-1}} \qquad \text{for } 2 < a \leq m \qquad 10$$

Total catch and catches-at-age

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

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

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):

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

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

and hence:

$$B_y^{ex} = B_y^{ex,1+} + B_y^{ex,2+} \qquad 14$$

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:

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

i.e.

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

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

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

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

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

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

$$F^{1+}_y = C^{1+}_y \;/ B^{exp,1+}_y \quad 20$$

$$F^{2+}_y = C^{2+}_y \;/ B^{exp,2+}_y \quad 21$$

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

$$C^{1+}_y = p_{y,1+}C_y \quad 22$$

and

$$C^{2+}_y = \left(1 - p_{y,1+}\right)C_y \quad 23$$

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:

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

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

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

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

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:

$$B^{sp}_{y_0} = \theta \cdot K^{sp} \quad 27$$

with the starting age structure:

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

where

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

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

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 ($-\ell nL$) 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:

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

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:

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

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:

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

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

$(\sigma_y)^2 = \ln\left(1+(CV_y)^2\right)$ 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:

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

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.

Glossary

AFMA	Australian Fisheries Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Agency
TRL	Tropical Rock Lobster
TSSAC	Torres Strait Scientific Advisory Committee
CPUE	Catch Per Unit Effort
TAC	Total Allowable Catch
TVH	Transferrable Vessel Holder (Licence)
TRL RAG	Tropical Rock Lobster Research Advisory Group
PNG	Papua New Guinea

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Catch and Effort Statistics and Standardised CPUE Indices for the Torres Strait Tropical Rock Lobster Fishery

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Introduction

This report provides a short summary of the catch and effort data and analyses undertaken as part of the updated stock assessment for Torres Strait rock lobster fishery undertaken during November/December 2015. Data for the 2015 season was received from AFMA on Monday 9 November. All data was loaded into the ORACLE database managed by CSIRO and checked. A summary of the annual data for each fishery the data is provided in sections 2 and 3 below. Annual indices of resource abundance based on standardised CPUE were also developed for each component of the fishery and are reported in sections 4 and 5 below. More comprehensive reports will be provided to TRSL-RAG in 2016.

TVH Catch and Effort Data

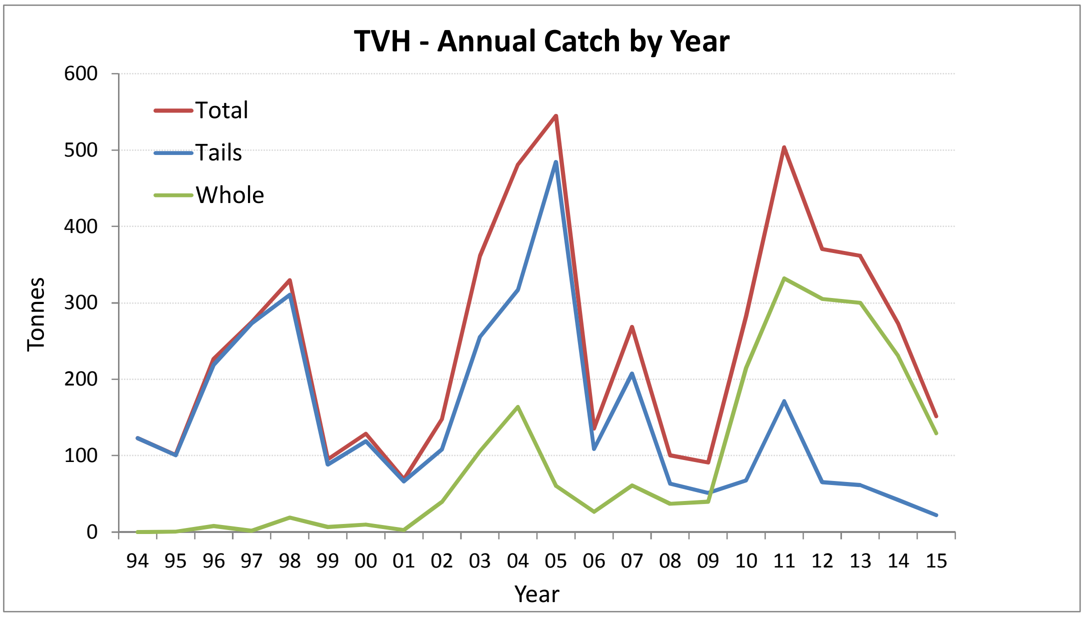
Catch and effort data for the TVH fishery are based on information recorded in the TR04 logbook and estimates of the annual catch taken within the TVH fishery are shown in Table 1 and Figure 1. The number of vessels in the fishery together with the number of logbook records reporting each fishery method are also shown.

Table 1. Annual catch and effort statistics for the TVH fishery.

	Number of Vessel by -			Diving Method			Total	Catch by Processed State (kg)			Total		
Year	Name	Symbol	Both#	Hookah	Free	Unknown	Records	Tails	Whole	Unknown	Catch	%Tails	%Whole
1994	11	11	11	1,505	136	804	2,445	123,006	0	0	123,006	100.0%	0.0%
1995	14	14	14	947	59	629	1,635	100,407	635	0	101,042	99.4%	0.6%
1996	20	20	20	1,609	87	1,851	3,547	219,045	7,810	0	226,855	96.6%	3.4%
1997	20	20	20	1,890	112	2,009	4,011	273,151	1,880	8	275,039	99.3%	0.7%
1998	23	22	23	2,681	169	2,331	5,181	310,635	18,922	0	329,557	94.3%	5.7%
1999	15	14	15	1,412	38	365	1,815	88,416	6,681	0	95,097	93.0%	7.0%
2000	20	19	20	2,330	114	267	2,711	118,824	10,038	0	128,862	92.2%	7.8%
2001	14	14	14	812	26	1,047	1,885	66,347	2,729	0	69,076	96.0%	4.0%
2002	17	17	17	1,721	10	1,380	3,111	108,216	39,471	0	147,687	73.3%	26.7%
2003	21	21	21	3,958	104	100	4,162	255,447	105,964	0	361,411	70.7%	29.3%
2004	25	24	25	5,045	154	1	5,200	317,467	163,651	0	481,118	66.0%	34.0%
2005	22	23	23	4,101	199	2	4,302	484,497	60,480	0	544,977	88.9%	11.1%
2006	22	20	22	2,307	119	2	2,428	108,909	26,539	0	135,448	80.4%	19.6%
2007	20	20	20	2,829	39	1	2,869	207,463	61,133	0	268,596	77.2%	22.8%
2008	13	12	14	1,205	6	0	1,211	63,378	37,060	0	100,438	63.1%	36.9%
2009	10	10	10	1,281	27	0	1,308	51,322	39,729	10	91,061	56.4%	43.6%
2010	13	12	13	2,356	12	0	2,368	67,817	214,797	0	282,614	24.0%	76.0%
2011	14	13	14	2,668	1	1	2,670	171,469	332,064	0	503,533	34.1%	65.9%
2012	14	13	14	2,311	0	0	2,311	65,282	305,198	2	370,482	17.6%	82.4%
2013	11	12	12	3,006	2	0	3,008	61,631	300,030	0	361,661	17.0%	83.0%
2014	13	13	13	2,901	0	0	2,901	42,054	230,511	120	272,685	15.4%	84.5%
2015	13	12	13	2,654	1	4	2,659	22,219	129,251	0	151,470	14.7%	85.3%
Total				51,529	1,415	10,794	63,738	3,327,002	2,094,573	140	5,421,715	61.4%	38.6%

The number of unique combinations of both vessel-name and vessel-symbol.

Figure 1. Time–series of total annual catches taken in the TVH fishery. The amounts of the total catch taken as tails and whole lobsters are also shown.



TIB Data

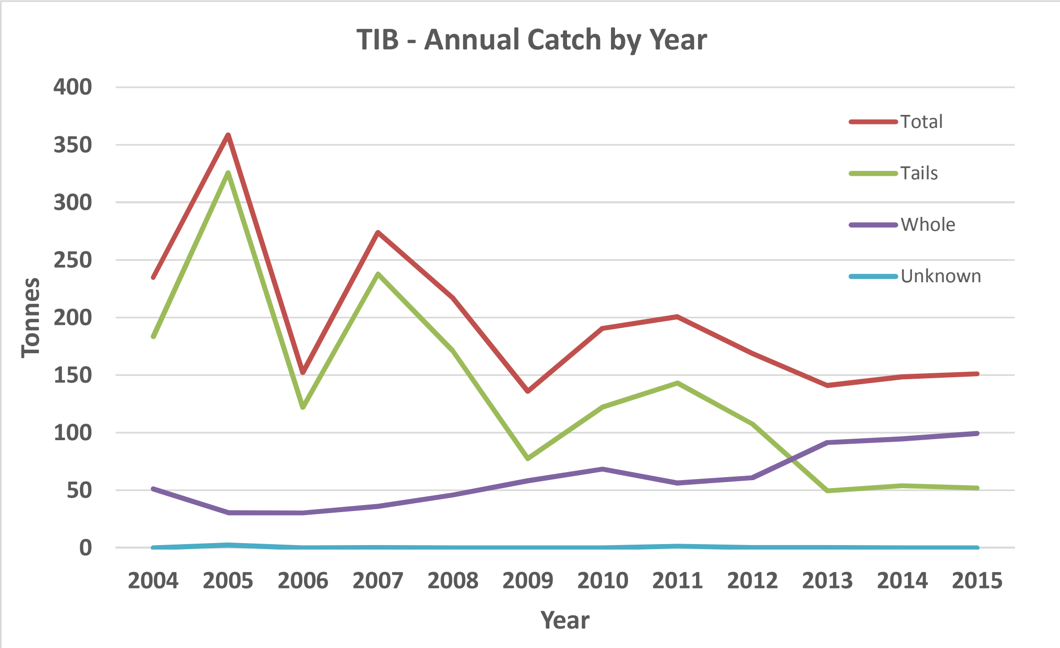
Estimates of the annual catch and effort statistics for the TIB fishery are shown in Table 2a and Figure 2.

Table 2a. Annual catch and effort statistics for the TIB fishery.

			Process Type			Fishing Method					
YEAR	Records	Catch (kg)	Tails	Whole	Unknown	Free D	Hookah	Unspec	Lamp	Other	Unknown
2004	4645	234,808	78.1%	21.8%	0.0%	28.2%	41.3%	1.6%	6.4%	5.3%	17.3%
2005	6671	358,474	90.8%	8.5%	0.7%	35.2%	53.3%	0.0%	3.3%	1.7%	6.5%
2006	4087	152,259	80.1%	19.9%	0.0%	52.7%	27.1%	0.3%	8.8%	3.9%	7.1%
2007	5957	273,902	86.8%	13.2%	0.1%	38.9%	33.8%	0.0%	5.6%	1.8%	19.9%
2008	4822	216,937	78.9%	21.1%	0.0%	36.8%	31.8%	0.0%	8.7%	1.4%	21.3%
2009	3540	135,898	57.0%	42.9%	0.1%	43.0%	40.8%	0.2%	10.0%	2.5%	3.6%
2010	3099	190,669	64.1%	35.9%	0.0%	15.5%	35.1%	0.2%	5.0%	2.3%	41.9%
2011	2954	200,691	71.3%	28.0%	0.7%	20.4%	54.1%	5.3%	4.7%	3.1%	12.4%
2012	1394	168,561	63.8%	36.1%	0.1%	22.8%	41.6%	0.0%	2.2%	2.1%	31.4%
2013	688	141,064	35.1%	64.8%	0.2%	1.7%	23.4%	0.0%	0.0%	0.3%	74.7%
2014	1855	148,538	36.3%	63.6%	0.0%	16.3%	21.7%	0.0%	2.2%	0.1%	59.7%
2015	1445	151,215	34.3%	65.7%	0.0%	8.1%	25.6%	0.0%	0.9%	3.7%	61.8%

As noted in previous reports relating to the TIB fishery (e.g. Campbell 2015a), the reporting to AFMA of the information in the Docket-books used to record catch and effort this fishery is voluntary. Currently there is no means of measuring the reporting rate of docket-books sent to AFMA but given an independent estimate of the 2015 TIB catch being around 160 t, the estimate of 151 t shown in Table 2a for this year suggests that the reporting may be reasonably good. However, in recent years around 50% of the catch has been reported directly from processor receipts for which there is no corresponding Docket-book information.

Figure 2. Time–series of total annual catches taken in the TIB fishery. The amounts of the total catch taken as tails and whole lobsters are also shown.



Some uncertainty also remains concerning the reporting of TIB primary vessels. In past years these vessels completed the TVH logbook but this appears to have not been the case since 2013. How much of the catch taken by these vessels may be covered by the Docket-book also remains uncertain. A number of other data issues also remain relating to possible double-reporting and interpretation of some of the fields in the TIB database and these are being worked through with AFMA. Moves to implement a catch receiver reporting system in the fishery would help outcome current problems with estimating the total catch taken in the fishery and also help in understanding some of these other data issues.

It has also been noted, that the reporting of the information in the Docket-books can be patchy with some of the data fields not being completed. The non-reporting of such information has increased in recent years. A summary of the missing data is provided in Table 2b.

Table 2b. Annual catch and effort statistics for the TIB fishery.

	Number distinct, and percentage of total catch for which related field is not null							
YEAR	Vessels	%Catch	Sellers	%Catch	Op-Date	%Catch	Days Fishe	%Catch
2004	123	25.4%	433	100.0%	295	100.0%	7249	78.1%
2005	206	18.3%	477	100.0%	301	100.0%	9584	92.0%
2006	223	51.3%	394	100.0%	286	100.0%	5889	88.2%
2007	246	30.2%	440	100.0%	297	100.0%	9031	78.2%
2008	187	37.4%	336	100.0%	293	100.0%	8905	78.5%
2009	124	34.9%	279	100.0%	278	100.0%	10712	94.1%
2010	149	29.2%	234	100.0%	290	100.0%	7674	94.0%
2011	199	60.2%	294	94.6%	281	100.0%	8538	86.3%
2012	80	32.6%	239	82.8%	247	100.0%	8677	66.7%
2013	23	31.9%	116	76.2%	184	60.7%	892	25.3%
2014	60	7.7%	182	100.0%	258	55.1%	4462	38.0%
2015	22	1.4%	190	100.0%	201	49.1%	7471	39.9%

TVH Standardised CPUE Indices

Indices of resource abundance based on CPUE for the TVH fishery were developed based on the protocols described in Campbell (2015b).

In order to explore the impact of each fitted effect, the first set of analyses were based on the following model where no interactions between main effects were included:

CPUE = Intercept + Year + Month +Area + Vessel-Identifier +Fishing-Method

+ Proportion of Catch Landed as Tails + Monthly-SOI

/ distribution = gamma, link = log

= *I + Y + M + A + V + F + P + SOI* / dist= gamma, link=log

The SAS GENMOD procedure was used to fit the model. All effects *Year, Month, Area, Vessel and Method* (Hookah, Free and Unknown) were fitted as class variables. The *Proportion-Tails* was also fitted as a class variable with each record classified as one of the following five levels: (<20%, 20% to <40%, 40% to <60%, 60% to <80%, >=80%). Following advice from TSRL-RAG the vessel-identifier used in the above model was based on a combination of vessel-symbol and vessel-name. The monthly Southern Oscillation Index (SOI) was fitted as a continuous variable. A log-gamma distribution was assumed for the distribution of CPUE values.

A second set of analyses was undertaken in order to explore whether the inclusion of 2-way interactions between the main spatial-temporal effects improved the model fit to the data. Specifically, the following four models were examined:

Int-1:

CPUE = Intercept + Year +Month + Month Area*

+ Vessel-Name +Fishing-Method + Proportion-Tails + SOI

/ distribution = gamma, link = log

Int-2A:

*CPUE = Intercept + Year*Month + Month* Area*

+ Vessel-Name +Fishing-Method + Proportion-Tails + SOI

/ distribution = gamma, link = log

Int-2B:

*CPUE = Intercept + Year*Area + Month* Area*

+ Vessel-Name +Fishing-Method + Proportion-Tails + SOI

/ distribution = gamma, link = log

Int-2C:

*CPUE = Intercept + Year*Month +Year*Area*

+ Vessel-Name +Fishing-Method + Proportion-Tails + SOI

/ distribution = gamma, link = log

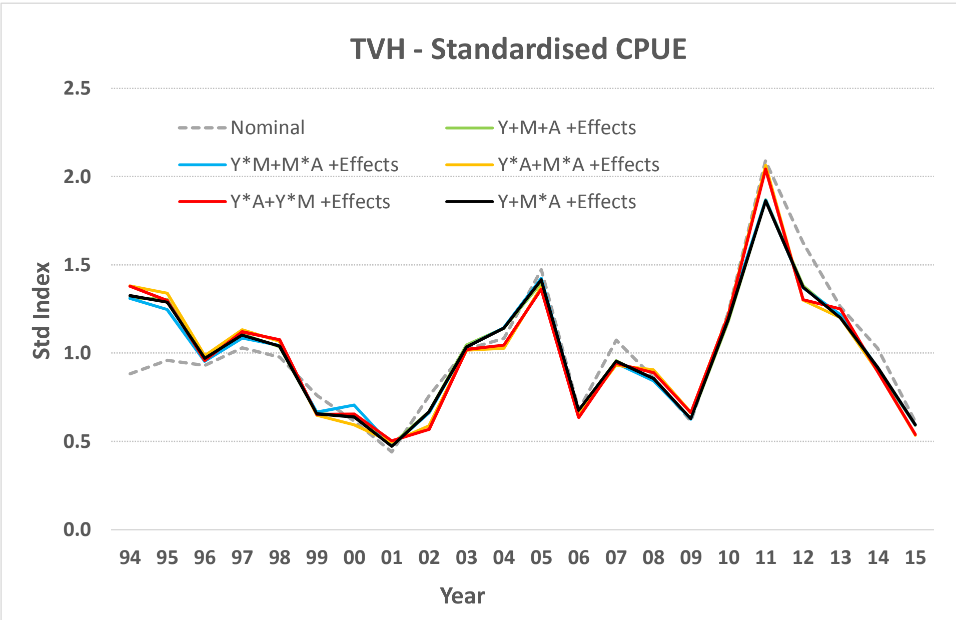
where * indicates an interaction between the related effects. The inclusion in these 2-way interactions allows for the relative distribution of the resource between the different areas and months to be different between years.

The calculated annual index of abundance based on the standardised CPUE calculated for each of the above five models is given in Table 3 and displayed in Figure 3.

Table 3. Annual index of abundance based on the standardised CPUE for the TVH fishery using the five GLMs described in the text. The nominal CPUE (total-catch/total-effort) is also provided for comparison.

Year	Nominal	Y+M+A +Effects	Y+M*A +Effects	Y*M+M*A +Effects	Y*A+M*A +Effects	Y*A+Y*M +Effects
94	0.88	1.31	1.33	1.31	1.38	1.38
95	0.96	1.30	1.29	1.25	1.34	1.30
96	0.93	0.96	0.97	0.95	0.98	0.96
97	1.03	1.11	1.10	1.09	1.13	1.12
98	0.98	1.04	1.04	1.04	1.07	1.08
99	0.76	0.66	0.66	0.66	0.65	0.65
00	0.61	0.64	0.64	0.71	0.59	0.65
01	0.44	0.48	0.47	0.47	0.50	0.50
02	0.76	0.67	0.67	0.66	0.59	0.57
03	1.02	1.05	1.03	1.03	1.02	1.02
04	1.08	1.14	1.14	1.14	1.03	1.05
05	1.47	1.40	1.42	1.42	1.37	1.36
06	0.68	0.67	0.68	0.67	0.65	0.64
07	1.07	0.96	0.95	0.94	0.93	0.94
08	0.86	0.85	0.86	0.84	0.90	0.89
09	0.61	0.63	0.63	0.62	0.66	0.66
10	1.23	1.18	1.19	1.21	1.21	1.21
11	2.09	1.87	1.86	1.87	2.06	2.04
12	1.63	1.38	1.37	1.37	1.30	1.30
13	1.26	1.21	1.20	1.22	1.20	1.25
14	1.03	0.91	0.92	0.91	0.90	0.89
15	0.61	0.59	0.59	0.59	0.53	0.54
Mean	1.00	1.00	1.00	1.00	1.00	1.00

Figure 3. Annual index of abundance based on the standardised CPUE for the TVH fishery using the five GLMs described in the text.



TIB Standardised CPUE Indices

Indices of resource abundance based on CPUE for the TVH fishery were developed based on the protocols described in Campbell (2015a).

In order to explore the impact of each fitted effect, the first set of analyses were based on the following model where no interactions between main effects were included:

CPUE = Intercept + Year + Quarter +Area +Fishing-Method + Seller

+ Proportion of Catch Landed as Tails + Monthly-SOI

/ distribution = gamma, link = log

= *I + Y + Q + A + F + S + P + SOI* / dist= gamma, link=log

The SAS GENMOD procedure was used to fit the model. All effects *Year, Quarter, Area*, *Seller and Method* (Hookah, Free and Other/Mixed) were fitted as class variables. The *Proportion-Tails* was also fitted as a class variable with each record classified as one of the following five levels: (<20%, 20% to <40%, 40% to <60%, 60% to <80%, >=80%). The monthly Southern Oscillation Index (SOI) was fitted as a continuous variable. A log-gamma distribution was assumed for the distribution of CPUE values.

Considerable work has gone into ‘cleaning-up’ the Seller-Names recorded in the Docket-book data, assisted by TIB-industry representatives who attended the recent TIB-workshop held in Brisbane in early November. This has reduced the number of unique Seller-Names in the TIB Docket-book database from 2606 to 983. Due to the large number of Sellers in the fishery, the above GLM analysis was limited to a sub-set of the data where Sellers had fished for four or more years and for which there were at least 30 data records. This resulted in 228 Sellers being included in the GLM analyses. The data was also filtered to exclude a few (possibly anomalous) records where catches were greater than 1000 kg or catch rates higher than 200 kg/hour.

A second set of analyses was undertaken in order to explore whether the inclusion of 2-way interactions between the main spatial-temporal effects improved the model fit to the data. Specifically, the following two models were examined:

Int-1:

*CPUE = Intercept + Year + Quarter + Quarter * Area*

+ Fishing-Method + Seller +Proportion-Tails + SOI

/ distribution = gamma, link = log

Int-2:

CPUE = Intercept + Year Quarter + Quarter * Area*

+ Fishing-Method + Seller +Proportion-Tails + SOI

/ distribution = gamma, link = log

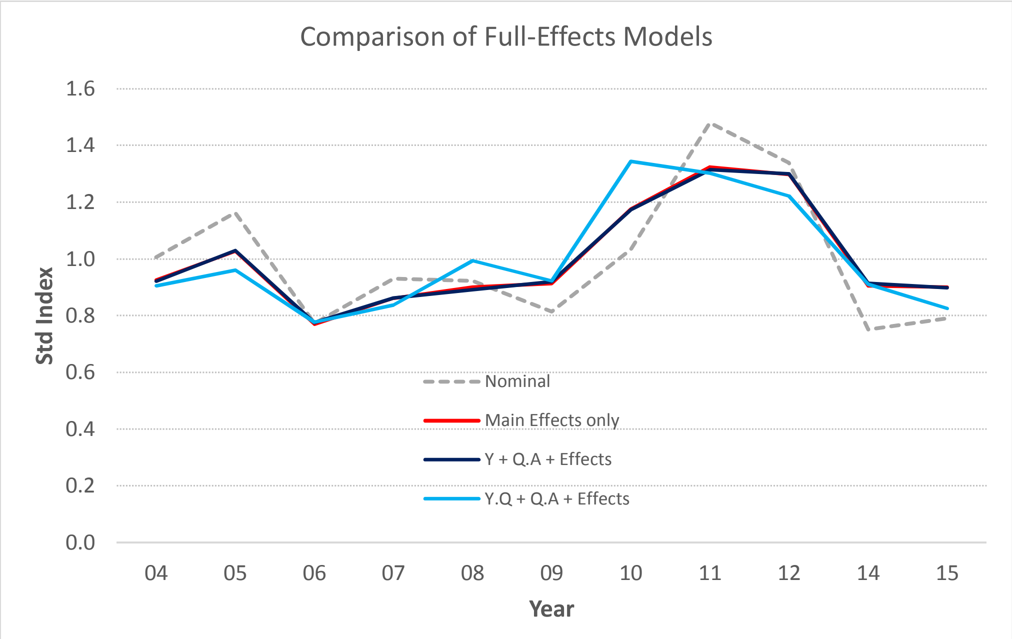
where * indicates an interaction between the related effects. The inclusion in these 2-way interactions allows for the relative distribution of the resource between the different areas and months to be different between years.

The calculated annual index of abundance based on the standardised CPUE calculated for each of the above five models is given in Table 4 and displayed in Figure 4.

Table 4. Annual index of abundance based on the standardised CPUE for the TIB fishery using the three GLMs described in the text. The nominal CPUE (total-catch/total-effort) is also provided for comparison.

Year	Nominal	Main Effects	Y + Q*A + Main Effects	Y*Q + Q*A + Main Effects
04	1.01	0.93	0.92	0.91
05	1.16	1.03	1.03	0.96
06	0.77	0.77	0.77	0.78
07	0.93	0.86	0.86	0.84
08	0.92	0.90	0.89	0.99
09	0.81	0.91	0.92	0.92
10	1.03	1.18	1.17	1.34
11	1.48	1.32	1.31	1.30
12	1.34	1.30	1.30	1.22
14	0.75	0.91	0.91	0.91
15	0.79	0.90	0.90	0.83
Mean	1.00	1.00	1.00	1.00

Figure 4. Annual index of abundance based on the standardised CPUE for the TIB fishery using the three GLMs described in the text.



References

Campbell, R.A., 2015a. Use of TIB Docket-Book Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2015 update. Information paper presented to the 14th meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 25-26 August 2015, Thursday Island.

Campbell, R.A., 2015b. Use of TVH Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2015 update. Information paper presented to the 14th meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 25-26 August 2015, Thursday Island.

Estimation of Total Annual Effort in the Torres Strait Tropical Rock Lobster Fishery

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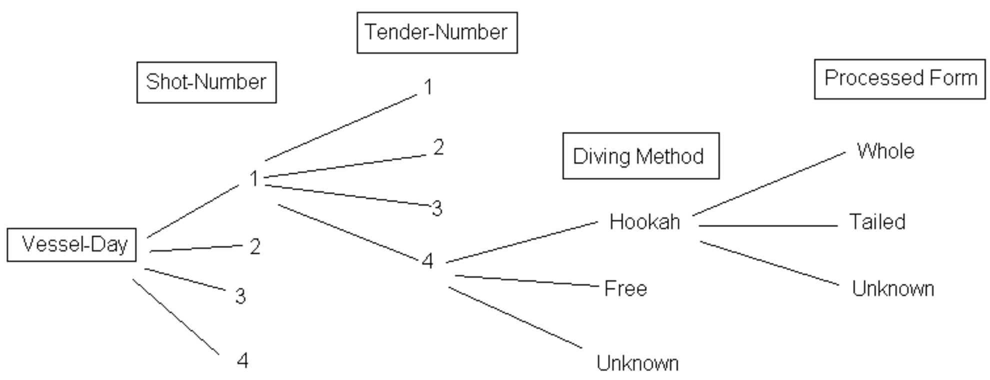
TVH Fishery

Data Summary

Catch and effort data for the TVH sector of the Torres Strait rock lobster fishery is recorded in the TRL04 logbook. The structure of the data is shown in Figure 1. For each vessel-day there can be multiple shots (up to 4) with each shot consisting of up to 8 tenders. Each tender has a catch recorded by diving method (hookah, free or unknown) and the catch is recorded by processed form (whole, tailed or unknown). The data was aggregated so that each record refers to the catch for a unique vessel-day, shot, tender and diving method (also known as a tender-set). Between 2004 and 2015 there are a total of 33,235 TVH records or tender-sets.

Figure 1. Structure of the TVH data



The distribution of these 33,235 records by year and month are given in Table 1. It is apparent that there has been little if any effort during October and November before 2006 and since 2006 there has been zero effort in the months October-to-January.

Effort is recorded as “Hours-Fished” which records the duration of the fishing trip for each tender-set. Unfortunately this field has not been completed for all tender-sets (c.f. Figure 2), with the number of hours fished recorded for only 31,171 (93.8%) of the 33,235 records. The distribution of hours fished for these records is shown in Figure 3. The number of recorded hours fished was between 0.15 hours and 96 hours, though was less than12 hours for 98.9% of all records. All records (20) where the recorded hours-fished was greater than 12 hours were considered suspect due to possible recording errors and as such only those records where the hours-fished was 12 hours or less were included in the analysis. A further two records where effort was less than 0.5 hours were also excluded. Note, the number of hours fished was recorded as 24 hours for 315 records and was assumed to represent a “day’s” fishing. This left a total of 30,831 records (92.8% of all tender-sets) having a recorded effort between 0.5 and 12 hours for further analysis.

Table 1. Number of TVH catch records by year and month.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2004	24	607	712	571	662	761	729	633	395			106	5200
2005	13	662	615	543	519	538	552	533	323			4	4302
2006		409	436	361	286	206	349	289	92				2428
2007		288	427	446	542	489	402	184	91				2869
2008		133	222	113	161	96	159	175	152				1211
2009		148	227	174	201	200	125	163	70				1308
2010		255	333	302	324	292	309	294	253		6		2368
2011		286	384	371	322	380	356	310	261				2670
2012		166	344	371	311	336	318	264	201				2311
2013		461	383	414	424	324	374	385	243				3008
2014		357	395	297	433	408	445	274	291		1		2901
2015		419	408	441	355	313	250	346	127				2659
Total	37	4,191	4,886	4,404	4,540	4,343	4,368	3,850	2,499	0	7	110	33,235

Figure 2. The total number of TVH catch records each year and the number of records for which the corresponding effort data is available. The percentage of records for which no effort is recorded is also shown (right hand axis).

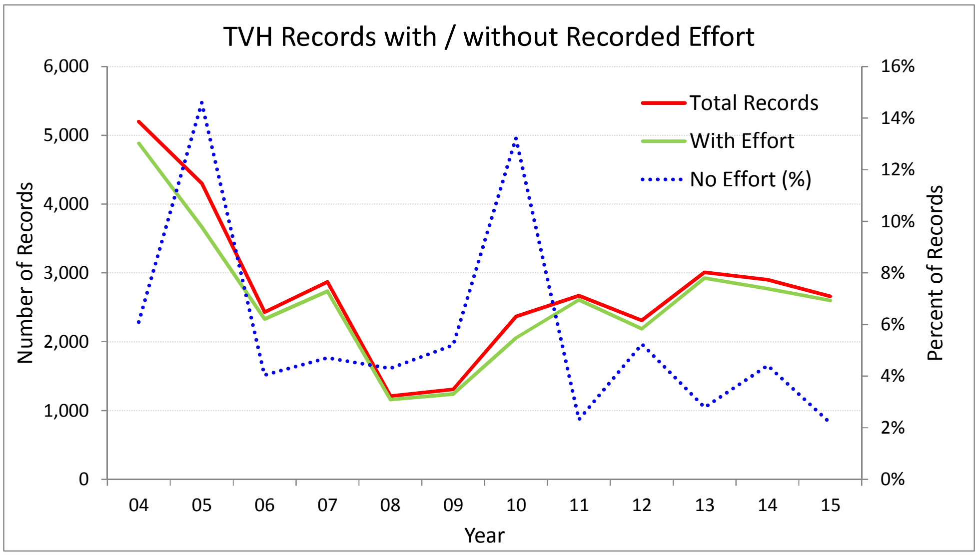


Figure 3. Distribution of effort for the 31,170 records for which effort was recorded on TVH logbooks between 2004 and 2015.

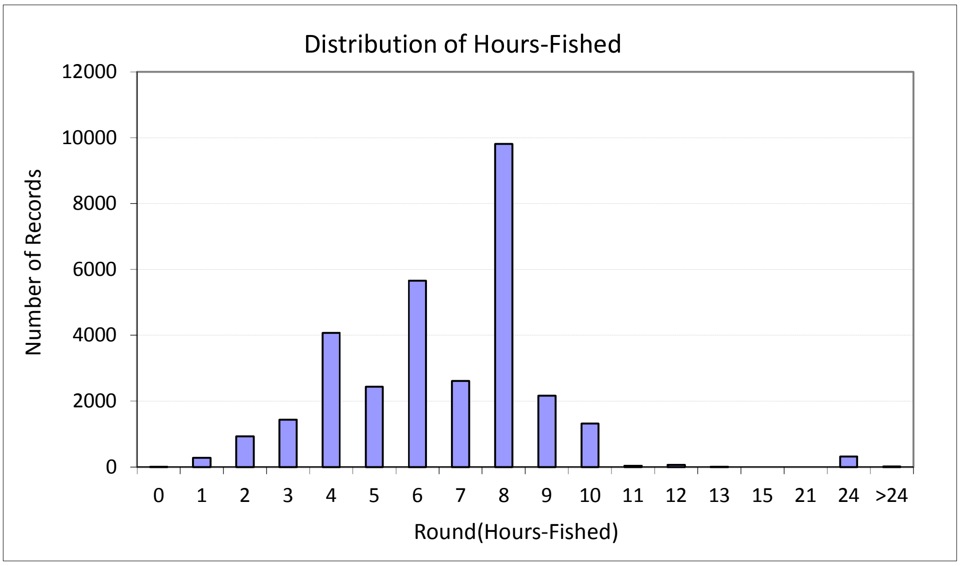
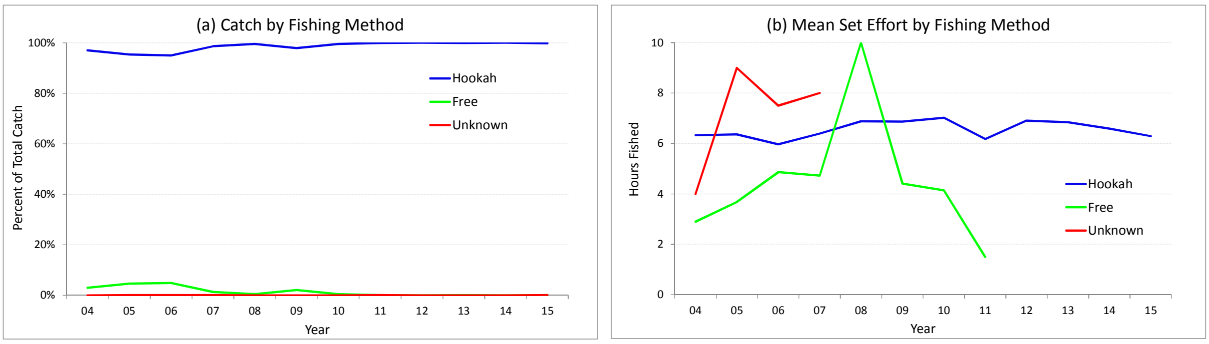


Figure 4. (a) The percent of total TVH catch each year caught by each fishing method, and (b) the mean number of hours fished per tender-set for each fishing method.



Finally, the percent of total TVH catch each year caught by each fishing method, and the mean number of hours fished per tender-set for each fishing method are shown in Figure 4.

Estimate of Annual Effort

Given the above data preparation and filtering the following process was adopted for estimating the total annual effort:

1. First, an annual listing of the number of TVH records against the number of hours fished was prepared (c.f. Table 2a). Records listed against zero hours fished pertain to those where the effort was either not recorded or was outside the 0.5 to 12 hour band used. The total number of tender-sets for each year is also shown in this table.
2. For those records where the hours-fished was recorded the total number of hours fished for these tender-sets was totalled. This result is shown as the Total Hours in Table 2b.
3. To account for those records where the hours-fished was not recorded, the total calculated in the previous section was adjusted as follows:

$$Total\ Hours\ (Adj) = Total\ Hours * \frac{\sum_{i=0}^{12} NumberRecords_i}{\sum_{i=1}^{12} NumberRecords_i}$$

This assumes that the distribution of hours -fished for those records where effort was not recorded is similar to the distribution of hours -fished for those records where effort was recorded. Again, for each year this result is shown as the Total Hours -Adj in Table 2b.

Table 2. Annual listing of (a) the number of TVH records against the number of hours fished. – rounded to the nearest integer, and (b) unadjusted and adjusted total number of hours fished.

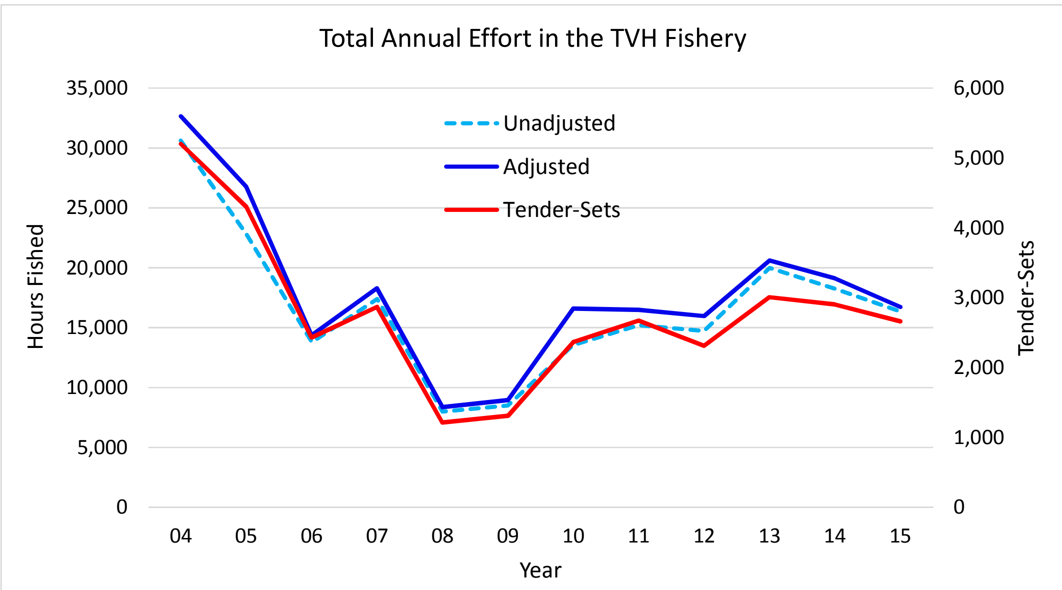
(a)

Hours-Fished	04	05	06	07	08	09	10	11	12	13	14	15	Total
0	320	631	99	138	52	68	435	205	180	88	129	59	2,404
1	61	48	37	14	15	10	10	21	5	15	21	22	279
2	188	135	102	76	24	22	36	88	40	54	74	94	933
3	396	286	198	100	34	66	34	58	44	87	63	73	1,439
4	607	598	354	424	129	92	215	610	263	341	199	245	4,077
5	399	231	255	282	86	120	94	145	73	170	124	457	2,436
6	727	482	445	587	128	180	389	464	326	420	965	549	5,662
7	422	266	182	199	129	132	126	118	187	324	329	195	2,609
8	1622	1293	596	638	375	378	677	728	951	1080	744	733	9,815
9	337	251	37	267	143	127	91	70	207	318	129	186	2,163
10	69	81	123	144	94	113	261	156	30	111	95	44	1,321
11	7	0	0	0	2	0	0	1	4	0	24	1	39
12	45	0	0	0	0	0	0	6	1	0	5	1	58
Total Tender-Sets	5,200	4,302	2,428	2,869	1,211	1,308	2,368	2,670	2,311	3,008	2,901	2,659	33,235

(b)

Total Hours	30,627	22,829	13,775	17,403	7,996	8,484	13,547	15,216	14,721	19,994	18,253	16,351	199,196
Total Hours - Adj	32,635	26,753	14,361	18,282	8,355	8,949	16,596	16,481	15,964	20,597	19,102	16,722	214,798

Figure 5. Estimates of unadjusted and adjusted total number of hours fished and number of tender-sets for the TVH sector each year.



The results of the above process are shown in Figure 5. Note that the final adjusted effort shown for each year (Total Hours-Adj) is only an estimate as it is difficult to know how accurate the recording of this effort is in the logbook (which is understood to relate to the time away from the primary vessel). Nevertheless, the trends in both the annual effort measured in hours fished or number of tender-sets are similar.

TIB Fishery

Docket-book Coverage

The Buyers and Processors Docket-Book (TDB01), used in the TIB sector of the Torres Strait rock lobster fishery, records the catch sold by fishers (known as sellers on the docket-book) at the end of a fishing trip. However, unlike the logbook for the TVH sector of fishery, which requires catch and effort data to be recorded for individual fishing operations related to each vessel tender, the docket-book requires only aggregate catch and effort data to be recorded at the end of each trip. In particular, the docket-book records the transaction date, the name of the seller together with details of the catch (in weight) and the price obtained. Additional information is also provided regarding the vessel, the number of crew, the number of days fished and the fishing methods used. This information therefore provides a measure of both the catch and effort for a given seller (or fisher) during a fishing trip.

However, there are a number of issues with the docket-book system which create problems with using this data for estimating the total catch and effort in the TIB fishery. These issues include:

i. The requirement that completion of the docket-book is only voluntary,
ii. The fact that catches recorded in the docket-book can also be reported elsewhere, including the TVH logbook,
iii. The fact that processors can also record catches in the docket-book, essentially creating duplicates.

Given the duplication of catch information from both the TVH sector and processors which occurs in the docket-book data, several filters are applied to this data to remove these duplicates. In particular, records are removed from the docket-book where the Seller-Type is recorded as ‘TVH’, the vessel-symbol begins with an ‘F’ (as this indicates the vessel is a TVH vessel), and where the Seller-Name has been recorded as a processor. Further to these issues, several TIB boats only record their catch in the TVH-related logbook (TRL04) and these catch records need to be transferred to the TIB database.

Docket-book Data Summary

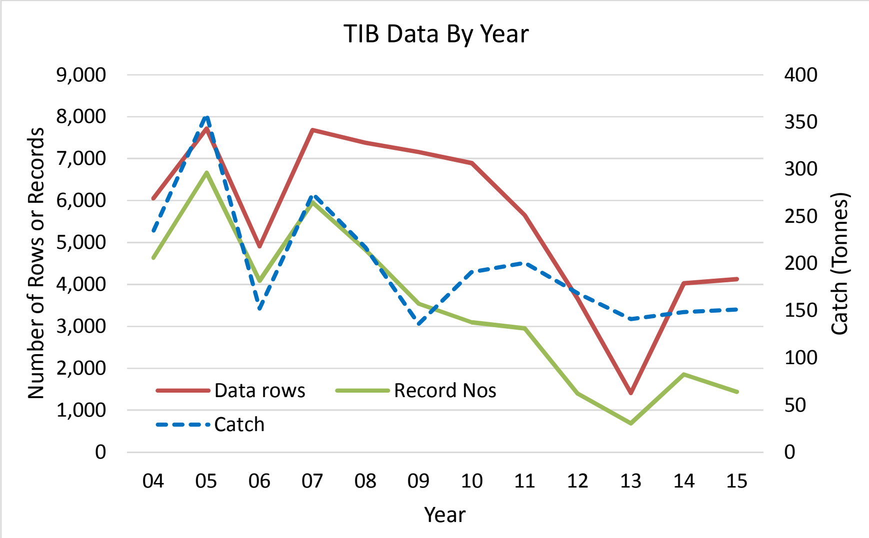
Considerable effort has gone into understanding the nature of both the docket-book and logbook data so as to identify the catch records that should be assigned to the TIB fishery and a total of 66,644 catch records of Torres Strait rock lobsters have now been attributed to the TIB fishery covering the years 2004 to 2015. The few docket-book records having a zero catch of lobsters are not included in this total as it is assumed that other species may have been targeted on these trips.

The number of catch records and the associated estimate of the total catch of rock lobsters in the TIB sector each year is shown in Table 3 and Figure 6. The number of records has decreased significantly after 2012. This is due to the fact that a significant portion (43%) of the catch in 2013 was not recorded in the docket-book but instead was solely attributed to two aggregate catch records added to the TIB database to account for an additional 40,029 kilograms of whole lobsters and 5,746 kilograms of tails received by processors. A similar situation also occurred in both 2014 and 2015 when again two aggregate catch records (representing around 50% of the total catch for both years) were added to the TIB database to account for catch received by processors but not recorded in the docket-book. These amounts were an additional 45,312 kilograms of whole lobsters and 7,975 kilograms of tails for 2014 and an additional 56,133 kilograms of whole lobsters and 7,759 kilograms of tails for 2015. Whether or not other caches have also not been recorded in the docket-book during 2013-2015 or in other years remains unknown.

Table 3. Number of TIB database rows, distinct TIB Record Nos, and associated catch per year.

	Rows in	Unique	Catch	
Year	Database	Record-Nos	(kg)	Tonnes
2004	6,053	4,636	234,808	235
2005	7,715	6,664	358,474	358
2006	4,907	4,084	152,259	152
2007	7,682	5,956	273,902	274
2008	7,374	4,821	216,937	217
2009	7,159	3,540	135,898	136
2010	6,891	3,097	190,669	191
2011	5,648	2,950	200,691	201
2012	3,652	1,394	168,561	169
2013	1,409	688	141,064	141
2014	4,029	1,852	148,538	149
2015	4,125	1,438	151,215	151
Total	66,644	41,120	2,373,017	2,373

Figure 6. Number of TIB data rows, distinct TIB Record Nos, and associated catch (in tonnes) per year.



Data Preparation and Filtering

Each catch record in the TIB data is associated with a Record-No. While there are usually multiple catch records associated with a given Record-No (often due the need to record separately the different grades of fish sold pertaining to a single catch), the structure of the docket-book would seem to indicate that there should be a unique Record-No for each vessel, date and seller-name. However, investigation of the data indicates that there are often multiple Record-Nos associated for a given vessel, date and seller-name. The reason for these multiple records remains unknown. In order to identity the appropriate data for analysis, the following procedure was adopted:

1. The TIB data was aggregated over vessel-symbol, date and seller-name and where the vessel-symbol or seller-name was null these fields were set to 'Unknown'. This resulted in a total of 39,688 aggregate records (known henceforth as Seller records).
2. Only those Seller records having a unique Record-No were selected for further analysis – accounting for 38,349 (96.93%) of all records identified in the previous step. It was assumed that where the vessel or seller were unknown, that selection of only those records having a unique Record-No limited the records chosen to those associated with a single vessel and a single seller.
3. Finally, those Seller records where the number of days-fished, method or the number of crew were not unique were filtered out leaving a total of 37,866 Seller records (95.4% of the total above). This was done to help eliminate data errors. The area-fished was found to be unique for each Record-No.

Unlike the TVH data where the measure of effort is hours-fished, the measure of effort for the TIB data is coarser, being days-fished. Furthermore, and as noted above, it has been assumed that each selected Seller record pertains to the catch and effort of a single fisher (or seller) during a given trip, i.e. it is assumed that the measure of effort (days fished) associated with each Seller record also pertains to the actual effort expended by that seller in obtaining the recorded catch. While the number of days fished for each Record-No in the data is unique, there are instances nevertheless where for the same vessel, date and seller there are multiple Record-Nos where the number of days fished is different. An example is shown in Table 4, where all of the TIB data records associated with a single vessel and a single date are shown.

Table 4. An example of the TIB data showing all records associated with a single vessel and a single date. For each seller there are multiple Record-Nos and for each Record-No there are multiple catch record, several for the same method, process-type and grade.

RECORD_NO	OP_DATE	CREW	METHOD	PROCES	GRADE	KGS_KEPT	SELLERNAME	DAYS-FISHED	AREA
1075486	25-May-08	2	MDH	Whole	M	7.58	Seller 1	2	9
1075486	25-May-08	2	MDH	Whole	M	26.77	Seller 1	2	9
1075486	25-May-08	2	MDH	Tailed	M	11.95	Seller 1	2	9
1075486	25-May-08	2	MDH	Whole	M	42.02	Seller 1	2	9
1075487	25-May-08	2	MDH	Whole	M	4.54	Seller 2	2	9
1075487	25-May-08	2	MDH	Whole	M	7.17	Seller 2	2	9
1075487	25-May-08	2	MDH	Whole	M	16.06	Seller 2	2	9
1075487	25-May-08	2	MDH	Whole	M	25.21	Seller 2	2	9
1075488	25-May-08	2	MDH	Whole	M	16.81	Seller 3	2	9
1075488	25-May-08	2	MDH	Whole	M	10.7	Seller 3	2	9
1075488	25-May-08	2	MDH	Whole	M	3.03	Seller 3	2	9
1075488	25-May-08	2	MDH	Whole	M	4.78	Seller 3	2	9
1075500	25-May-08	2	MDH	Whole	M	1.28	Seller 1	1	9
1075500	25-May-08	2	MDH	Tailed	M	2.79	Seller 1	1	9
1075500	25-May-08	2	MDH	Whole	M	9.55	Seller 1	1	9
1075500	25-May-08	2	MDH	Whole	M	17.16	Seller 1	1	9
1075502	25-May-08	2	MDH	Whole	M	5.73	Seller 2	1	9
1075502	25-May-08	2	MDH	Whole	M	0.77	Seller 2	1	9
1075502	25-May-08	2	MDH	Tailed	M	1.67	Seller 2	1	9
1075502	25-May-08	2	MDH	Whole	M	10.29	Seller 2	1	9
1075505	25-May-08	2	MDH	Tailed	M	1.11	Seller 3	1	9
1075505	25-May-08	2	MDH	Whole	M	3.82	Seller 3	1	9
1075505	25-May-08	2	MDH	Whole	M	0.51	Seller 3	1	9
1075505	25-May-08	2	MDH	Whole	M	6.86	Seller 3	1	9
1075508	25-May-08	2	MDH	Whole	M	19.69	Seller 1	1	9
1075508	25-May-08	2	MDH	Whole	M	10.62	Seller 1	1	9
1075508	25-May-08	2	MDH	Tailed	M	3.83	Seller 1	1	9
1075511	25-May-08	2	MDH	Whole	M	6.37	Seller 2	1	9
1075511	25-May-08	2	MDH	Whole	M	11.81	Seller 2	1	9
1075511	25-May-08	2	MDH	Tailed	M	2.29	Seller 2	1	9
1075512	25-May-08	2	MDH	Whole	M	7.87	Seller 3	1	9
1075512	25-May-08	2	MDH	Whole	M	4.24	Seller 3	1	9
1075512	25-May-08	2	MDH	Tailed	M	1.53	Seller 3	1	9

There are multiple records for three sellers and a number of questions arise. For example, why there are multiple catch records pertaining to the same process-type and grade of lobsters for a single Record-No? Why are there multiple Record-Nos for the same seller for the same vessel-date? Finally, why are the days-fished different for several of the Record-Nos for the same seller? If, as has been assumed above, these records relate to a single trip then perhaps some of the dates are incorrect.

Estimate of Annual Effort

Given the above data preparation and filtering, and in order to account for the under-reporting of all trips in the docket-book database, the following process was adopted for estimating the total annual effort:

1. First, an annual listing of the number of Seller records against the number of days fished was prepared (c.f. Table 5). Note: trips of duration greater than 2-3 days have been recorded and whether these are correct remains uncertain.
2. For those Seller records where the days-fished has been recorded the total number of days fished was calculated as follows:

$$Total\ Days = \sum_{i=1}^{16} NumberSellerRecords_i * DaysFished_i$$

For each year this result is shown as the Total Days in Table 5b.

Table 5. (a) Annual listing of the number of Seller records against the number of days fished. (b). Unadjusted and adjusted total number of days fished each year.

(a)

Days-Fished	04	05	06	07	08	09	10	11	12	13	14	15	Total
0	688	407	336	345	165	89	110	217	240	411	223	118	3,349
1	3000	4752	2926	4652	3859	2716	2184	2303	650	39	1170	868	29,119
2	354	398	257	376	311	260	67	82	195	99	124	142	2,665
3	129	183	138	123	116	131	77	60	110	77	56	88	1,288
4	87	89	60	45	35	64	19	44	41	2	17	43	546
5	55	97	50	61	37	52	3	32	25	1	6	34	453
6	12	38	3	5	8	13	2	22	36	0	1	8	148
7	12	24	15	5	9	17	2	11	16	0	4	4	119
8	10	10	6	8	4	5	4	5	10	0	2	7	71
9	11	5	1	2	0	0	0	3	5	0	1	5	33
10	2	5	2	2	1	7	0	8	2	0	0	0	29
11	3	0	0	0	3	5	0	1	7	0	0	0	19
12	0	5	0	1	0	2	0	0	0	0	0	0	8
13	4	1	1	2	0	0	0	0	0	0	0	0	8
14	2	1	1	1	0	0	0	1	0	0	0	0	6
15	0	0	0	1	0	1	0	0	0	0	0	0	2
16	0	0	3	0	0	0	0	0	0	0	0	0	3
Total Records	4,369	6,015	3,799	5,629	4,548	3,362	2,468	2,789	1,337	629	1,604	1,317	37,866

(b)

Total Days	5,186	7,596	4,619	6,492	5,340	4,546	2,698	3,364	2,209	481	1,743	1,935	46,209
Total Days - Adj1	6,155	8,147	5,067	6,916	5,541	4,670	2,824	3,648	2,692	1,388	2,024	2,125	51,198
Associated Catch	222,383	323,821	141,831	257,763	206,942	130,102	153,349	191,052	166,062	76,493	68,315	68,721	2,006,834
Total Catch	234,808	358,474	152,259	273,902	216,937	135,898	190,669	200,691	168,561	141,064	148,538	151,215	2,373,017
Total Days -Adj2	6,499	9,019	5,440	7,349	5,809	4,878	3,511	3,832	2,733	2,559	4,402	4,677	60,707

3. To account for those Seller-Records where the days-fished was not recorded, the total calculated in the previous section was adjusted as follows:

$$Total\ Days\ (Adj1) = Total\ Days * \frac{\sum_{i=0}^{16} NumberSellerRecords_i}{\sum_{i=1}^{16} NumberSellerRecords_i}$$

   This assumes that the distribution of days-fished for those Seller records where effort was not recorded is similar to the distribution of days-fished for those Seller records where effort was recorded. Again, for each year this result is shown as the Total Days-Adj1 in Table 5b.

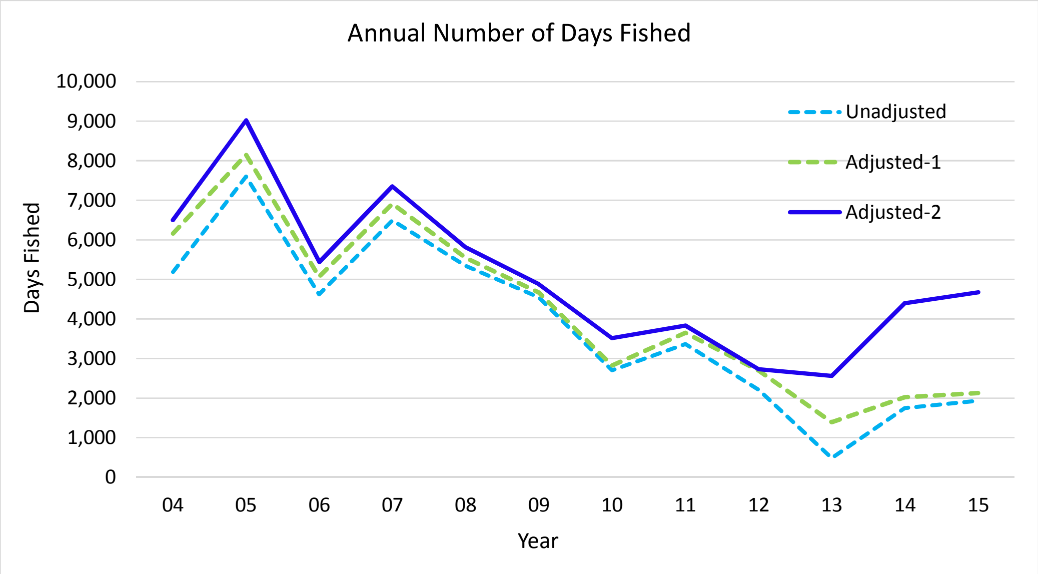
4. Finally, to account to the trips which were not recorded in the docket-book database, a final estimate of the total number of days fished each year was calculated as follows:

$$Total\ Days\ (Adj2) = Total\ Days(Adj1) * \frac{Total\ TIB\ Catch}{Associated\ Seller\ Catch}$$

where the associated Seller catch relates to the total catch pertaining to the 37,866 Seller records identified previously. This assumes that the relationship between catch and effort for those TIB records not recorded in the docket-books is similar to the relationship for those records recorded in the docket-books. Again this result is shown as the Total Days-Adj2 in Table 5b.

The results of the above process are shown in Figure 7. Note that the final adjusted effort shown for each year (Total Days-Adj2) is only an estimate and it is difficult to know how accurate this estimate is for each year. For example, the low effort estimate for 2012 is no doubt influenced by the small amount of data available for that year – only 211 Seller records had effort recorded. Finally, the time-series of annual effort is premised on the total TIB catch data captured by AFMA by various means (docket-books, logbooks, processors) and if this data is not complete given the caveats on the data mentioned previously then this this will impact on the annual estimate of total effort.

Figure 7. Estimates of unadjusted and adjusted total number of days fished each year in the TIB sector.



Appendix A. Annual Catch-Per-Unit-Effort

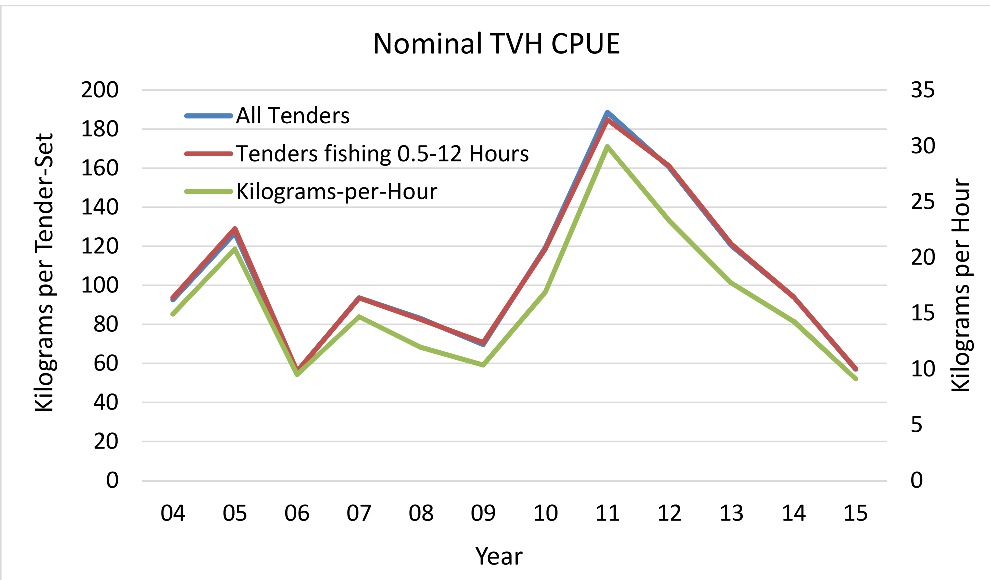
TVH Sector

Effort in the TVH-sector is recorded as hours fished by a tender during each set. As indicated in Table 2 the hours fished for the majority of tender sets (92.8%) are between 0.5 and 12 hours, while the hours fished is not recorded for 6.2% of tender sets. The effort recorded for the remainder of tender sets (<0.5 or >12 hours) is considered not reliable. The annual total number of tender sets, associated catch and corresponding catch-per-unit-effort (CPUE) for (a) all tender-sets and (b) those where effort is between 0.5 and 12 hours is listed in Table A1 while the CPUE for each of the data sets is displayed in Figure A1.

Table A1. (a) Annual total number of tender-sets, associated catch (kilograms) and corresponding CPUE (kilograms per tender-set) for all TVH tender sets, and (b) annual total number of tender-sets, associated hours fished and catch (kilograms) and corresponding CPUE (kilograms per tender-set) and kilograms per hour fished for TVH tender sets where effort is between 0.5 and 12 hours.

	(a) All Sets			(b) Sets fishing 0.5-12 Hours				
Year	N-sets	Catch	CPUE	N-sets	Hours	Catch	CPUE	Kg/hour
04	5,200	481,118	92.5	4,880	30,627	456,700	93.6	14.9
05	4,302	544,977	126.7	3,671	22,829	473,774	129.1	20.8
06	2,428	135,448	55.8	2,329	13,775	130,533	56.0	9.5
07	2,869	268,596	93.6	2,731	17,403	255,468	93.5	14.7
08	1,211	100,438	82.9	1,159	7,996	95,452	82.4	11.9
09	1,308	91,061	69.6	1,240	8,484	87,696	70.7	10.3
10	2,368	282,614	119.3	1,933	13,547	229,162	118.6	16.9
11	2,670	503,533	188.6	2,465	15,216	455,579	184.8	29.9
12	2,311	370,482	160.3	2,131	14,721	342,986	161.0	23.3
13	3,008	361,661	120.2	2,920	19,994	353,786	121.2	17.7
14	2,901	272,685	94.0	2,772	18,253	260,590	94.0	14.3
15	2,659	151,469	57.0	2,600	16,351	149,059	57.3	9.1

Figure A1. Annual CPUE (kilograms per tender-set and kilograms per hour) for (a) all TVH tender sets and (b) tender sets where effort is between 0.5 and 12 hours.



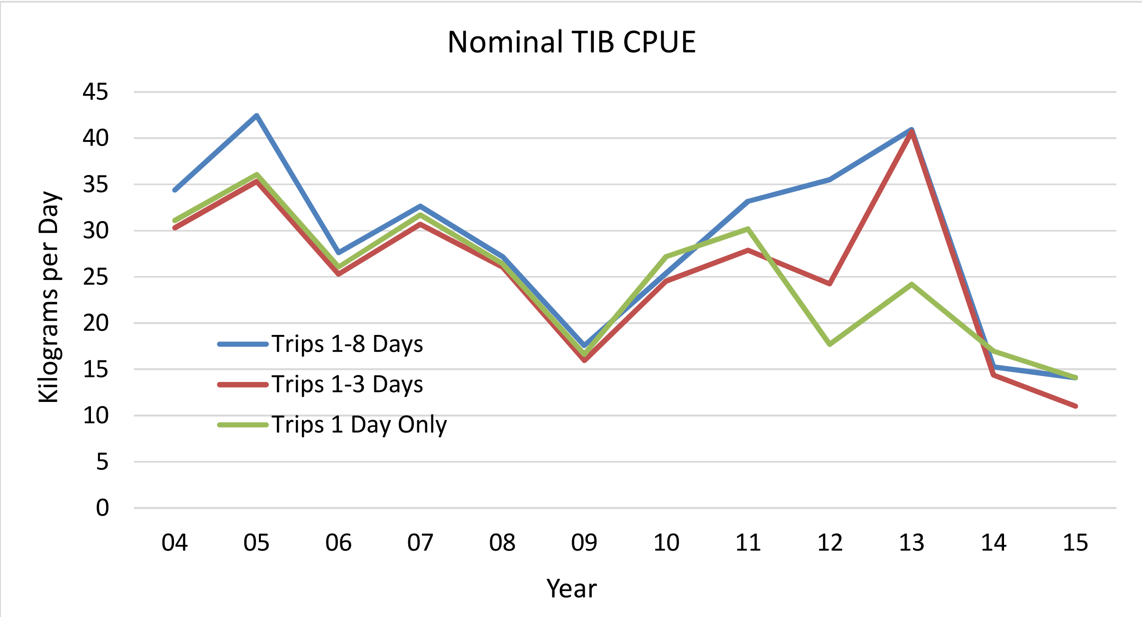
TIB Sector

Effort in the TIB-sector is recorded as the length of each fishing trip in days fished. As indicated in Table 5 fishing trips of up to 16 days have been recorded in the TIB docket-book, though the majority of trips (76.9%) are recorded as having a length of only one day. Whether or not the effort for trips having a long duration is recorded correctly remains unknown. The annual total number of days fished, associated catch and corresponding catch-per-unit-effort (CPUE) for trips having a duration of (a) 1-8 days, (b) 1-3 days and (c) 1 day only is listed in Table A2 while the CPUE (kilograms per day) for each of the data sets is displayed in Figure A2.

Table A2. Annual total number of days fished, associated catch (kilograms) and corresponding catch-per-unit-effort (kilograms per day) for TIB trips having a duration of (a) 1-8 days, (b) 1-3 days and (c) 1 day only.

	Trips 1 to 8 Days			Trips 1-3 Days			Trips 1 Day Only		
Year	Days	Catch	CPUE	Days	Catch	CPUE	Days	Catch	CPUE
04	6,601	227,048	34.4	6,601	200,027	30.3	5,105	158,711	31.1
05	8,374	355,355	42.4	8,374	295,808	35.3	6,669	240,578	36.1
06	5,454	150,592	27.6	5,454	137,956	25.3	4,215	109,928	26.1
07	8,356	272,666	32.6	8,356	256,258	30.7	6,811	215,718	31.7
08	7,949	216,304	27.2	7,949	207,320	26.1	6,591	174,250	26.4
09	7,581	133,288	17.6	7,581	120,949	16.0	5,828	96,828	16.6
10	7,511	190,537	25.4	7,511	184,153	24.5	6,280	170,630	27.2
11	5,080	168,420	33.2	5,080	141,547	27.9	4,190	126,488	30.2
12	3,020	107,174	35.5	3,020	73,205	24.2	1,459	25,828	17.7
13	872	35,680	40.9	872	35,504	40.7	75	1,814	24.2
14	3,684	56,235	15.3	3,684	52,940	14.4	2,770	46,983	17.0
15	4,096	57,719	14.1	4,096	45,136	11.0	2,384	33,628	14.1

Figure A2. Annual CPUE (kilograms per day) for TIB trips having a duration of (a) 1-8 days, (b) 1-3 days and (c) 1 day only.



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