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## Refined stock assessment and TAC estimation for the Torres Strait rock lobster (TRL) fishery



Australian Fisheries Management Authority

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# Refined Stock Assessment \& TAC estimation for TS lobster fishery 

AFMA Project Number: 2009/837

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Australian Fisheries Management Authority Torres Strait Research Program Final Report

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## NON-TECHNICAL SUMMARY

## PROJECT:

AFMA Project Number: 2008/837. Refined Stock Assessment \& TAC estimation for TS lobster fishery

## PRINCIPAL INVESTIGATOR:

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## OBJECTIVES:

1. Conduct a mid-year survey of the relative abundance of recruiting (1+) and fished (2+) lobsters, size-frequency of the TRL population and record seabed habitat.
2. Update the age-structured fishery model using recruit and fished lobster abundance data from the survey to allow assessment of the current stock status.
3. Collate commercial fishery catch data for use in the stock status assessment.

## NON-TECHNICAL SUMMARY:

A fishery-independent survey of the Torres Strait lobster population was carried out in May 2009. Indices of recruiting ( $1+$ ) and fished (2+) lobster abundance were estimated for comparison with historical levels and input to the integrated fishery model. A brief update on results of the recently completed 2010 mid-year survey is provided. Outcomes of catch at age estimation, refined commercial CPUE estimation and lobster growth parameter estimation tasks are presented. Stock assessment of the Torres Strait rock lobster fishery based on a new integrated fishery model and including the current mid-year survey abundance indices as well as the latest commercial catch data will be reported at the October 2010 TRL RAG meeting

## Lobster population surveys

A fishery-independent population survey was carried out in 2009 to estimate the relative abundance of the Torres Strait rock lobster population. The main purpose of the annual mid-year surveys is to provide estimates of the sizes of the recruiting (1+) and fished (2+) lobster populations that are basic input data for stock assessment. The $2+$ lobster abundance estimates inform estimates of the sizes of the subsequent breeding populations. These survey data are thus input to a stock assessment model and essentially used to inform estimation of a stock recruitment relationship and to forecast future stock levels.

The mid-year survey of the Torres Strait lobster population was conducted in May 2009 by four CSIRO staff, using the vessel M.V. James Kirby. A total of 74 sites were surveyed by divers and each site was re-located accurately using portable GPS.

As in the 1989 survey, measured belt transects ( 500 m by 4 m ) were employed as the primary sampling unit, as they were found to give the greatest precision ( $\mathrm{p}=\mathrm{SE} / \mathrm{Mean}$ ) of lobster abundance. Transect distance was measured, to the nearest metre using a Chainman ${ }^{\circledR}$ device.
The $20091+$ year-class was well above the 2008 level and the long-term average, continuing the generally strong levels recorded since 2005. The steady recovery in both recruitment and stock recorded during 2001 to 2004 suggested that the new management measures had aided stock recovery
and contributed to more reliable recruitment levels. However, whilst this may have been the case, recruitment levels since that time have been variable with below average levels in 2005 and 2008. Given recruitment levels are very difficult to forecast there is a need for annual monitoring of stock and recruitment levels to ensure appropriate management recommendations such that the fishery remains sustainable.

The 2009 2+ year-class was just greater than the 2008 level and the long-term average. Although not as high as the 2003-2005 levels, recent consistent stock abundances suggest subsequent breeding populations will also be consistent. The small stock increase was not forecast given the lower recruitment observed in 2008. As the fishery targets almost exclusively 2+ lobsters, the 2009 commercial catch was forecast to be slightly greater than the 2008 catch. This did not eventuate with a slightly smaller commercial catch in 2009. However, as discussed above the smaller catch may have been due to the change in lobster distribution. In particular the low stock abundance in the Kircaldie_rubble stratum would have impacted heavily on the TVH catch, with dual endorsed fishers likely opting to work on the Queensland east coast.

The 2010 1+ year-class was just greater than the 2009 level, continuing the increase recorded since 2008. The recent increased recruitment is a positive sign for the fishery, although the historical data highlights the high variability in recruitment likely influenced by several environmental variables that are difficult if not impossible to predict. Although the increased recruitment in 2009 did not translate into an increased stock in 2010, the higher recruitment in 2010 suggests the 2011 stock should be above average.
The 2010 2+ year-class was just smaller than the 2009 year-class. As the fishery targets almost exclusively $2+$ lobsters, the 2010 commercial catch should be similar to the 2009 catch. However, as discussed above the commercial catches are heavily influenced by spatial and temporal changes in lobster distribution.

In 2010 a large proportion of both hard and soft coral was bleached, likely due to a warming event that occurred in March 2010. If these corals do not recover this event has the potential to affect lobster abundance either directly or indirectly.

## Data Analysis and Stock assessment

An Oracle database was developed by CSIRO to manage all lobster data and provide analysts with a centralised repository of both fishery-dependent and fishery-independent data. Data series have been updated for input to the 2010 stock assessment update and are summarized in this Report. The new Integrated stock assessment model developed in 2009 is fitted to all available data sources, including:
a) the benchmark survey observed total lobster abundances in 1989 and 2002;
b) the survey midyear index of abundance (in terms of total numbers of $1+$ and $2+$ lobsters) and the observed and model-predicted proportions in each age;
c) all available data from the Pre-season surveys; and
d) CPUE data from the TVH sector.

Three detailed investigations and analyses of model input data were conducted as follows. Firstly, an alternative method for splitting commercial landing information into the two age-categories ( $1+$ and ${ }^{2+}$ ) was proposed. The method relies on somatic growth (Phillips et al., 1992) and morphometric relationships to determine size at age, and uses the survey data to determine the age structure of the population and variability of length at age. Intermediate results were compared to available independent data to check the validity of the method. This error checking evidenced a systematic under-estimation, of around $20 \%$ of mean weight at age in the catch compared to data provided by the MG Kailis group, and consequently this aspect merits further investigation.

A Generalized Linear Model (GLM) of a subset of the Transferable Vessel Holder (TVH) license catch and effort data currently provides an index of lobster abundance in Torres Strait which was shown to be proportional to abundance estimates from the fishery-independent survey data (Ye and Dennis, 2009, Ye et al., 2007). In 2009, the size of this subset decreased to 7 licenses following a voluntary surrender of licenses owned by Australian fishers to meet Australia's obligation under the Torres Strait Treaty (Wilson et al., 2009). The TRL RAG raised some concerns that further subsetsize reductions might be small enough to bias results. The GLM methodology was thus revisited and the effects of subsetting investigated. Preliminary analyses suggest that simpler approaches using the whole TVH dataset may be preferable to the previously applied more complex approach. Two alternative abundance index series, derived from catch and effort data, are developed for use as inputs to the stock assessment model. Future work may explore further improved alternatives for standardisation of the TVH CPUE data. In particular it may be important to incorporate a spatial factor given the comments noted above as to changes in lobster spatial distribution.

Although there is generally very good agreement between the fishery-independent midyear survey data and the fishery-dependent CPUE data, future analyses will benefit from an improved understanding of factors contributing to differences. This is particularly important if CPUE data are ever to be used in place of midyear survey data in providing management advice. Future work (including planned research in the related MSE project) will be exploring the consequences of using alternative combinations of information to inform assessments, such as the use of a CPUE series in combination with a Pre-Season survey. The latter series can potentially play an important role in reducing the uncertainty associated with model-derived TAC estimates.

Given the importance of accurately quantifying lobster growth, an in-depth analysis of length measurements collected during scientific surveys was conducted to refine estimation of parameters of the Von Bertalanffy growth function. Lobster growth estimated from 129 individuals tagged between 1980 and 1983 (Phillips et al, 1992) was found to be similar to that observed between 1989 and 2009 based on length frequency information. This recent research builds on the work of Phillips et al. (1992) through estimation of the parameter $\mathrm{t}_{0}$ as well as providing estimates of the uncertainty associated with the von Bertalanffy growth function parameters.

The Integrated stock assessment model is currently being updated based on the inputs presented in this Report. An updated assessment will accordingly be presented at the next RAG meeting, and updated model-derived TAC estimates provided.

## Recommendations for management

The mid-year surveys, conducted since 1989, are a valuable time series and provide essential inputs for stock assessment of the Torres Strait lobster fishery. While potentially useful as an additional series, the CPUE data don't give an estimate of the number of $1+$ lobsters for the following year, and hence are inadequate on their own. The recent inclusion of the pre-season survey data substantially improves predictive ability, and these data will be critical once the quota management system is implemented.

The new integrated model is the preferred method for setting TACs under the future quota management system. It deviates from the previous three stage approach to the setting of the TAC because it integrates all available information in a single self-consistent framework. This facilitates an understanding of the way in which data inputs ultimately translate into an assessment of resource status and productivity, sustainable catch levels and hence TAC estimates. It is recommended that the model TAC estimate is used as the final TAC for the forthcoming year, subject to pre-specified harvest control rules that pertain to the status of the stock relative to the target level. There was support for the preliminary TAC for the following year to be set more conservatively by selecting the
lower end of the $75 \%$ confidence interval so that there is a low probability that it will be higher than the Final TAC.

The TAC setting process should be adaptively revised and modified each year, taking new data into account. The effectiveness of the harvest control rules in achieving management objectives should be examined using a Management Strategy Evaluation (MSE) approach. Linked research that is planned to be undertaken as part of the MSE project will serve to better evaluate and test the robustness of a range of plausible harvest strategies for use in combination with the model TAC estimate.

Initial groundwork has been laid to better communicate the details of the stock assessment process, and this aspect will be developed further.

## Outcomes Achieved

A fishery-independent survey of the Torres Strait rock lobster population was completed during this project. These survey data together with the commercial catch at age and standardised CPUE statistics are the primary data sources for the new approach to lobster population dynamics and assessment of the long-term sustainable productivity of the lobster fishery. The updated survey data series now covers twenty years (mid-1989 to mid-2009). This extended data-set provides the essential information for stock assessment and management of the lobster fishery. The new results provide estimates of current stock status and fishing capacity of the fleet, and therefore, necessary management actions can be taken to ensure the sustainability and desirable production level of the fishery.

The results of this project have been presented at a number of key meetings including the TRL Working Group meeting and the TRL Resource Assessment Group meeting and these results have influenced the industry, managers and stakeholders to adopt more effective and precautionary measures in managing the lobster fishery; for example, setting a TAC based on pre-defined decision rules.

KEYWORDS: Torres Strait, Tropical Rock Lobster Fishery, Stock Assessment, Total Allowable Catch

## 1. INTRODUCTION

### 1.1. BACKGROUND

The Torres Strait rock lobster (TRL) fishery is the most important commercial fishery to Torres Strait Islanders and provides significant financial independence for island communities in the region. In addition, the fishery provides significant income for non-indigenous fishers living in and outside of Torres Strait. The fishery is managed by the Protected Zone Joint Authority (PZJA), comprising representatives from the Australian and Queensland governments, under Article 22 of the Torres Strait Treaty (February 1985) between Australia and Papua New Guinea. The treaty established the Torres Strait Protected Zone (TSPZ, Figure 1-1), maritime boundaries between the two countries and protection of the way of life and livelihood of traditional inhabitants and conservation of the marine environment. Members of the PZJA also participate in bilateral (Australia/PNG) meetings on issues of fisheries management common to both countries.

Commercial catches of lobsters increased steadily during the 1970s, with most of the catch taken by prawn trawlers in PNG waters (Figure 1-2). The total catch peaked in 1982 and this catch has not been exceeded. The diver catch increased during the 1980s, peaking at $\sim 900 \mathrm{t}$ in 1986 and remained steady at $\sim 550$ t during the 1990s. Trawling for lobsters was banned in 1984. A rapid decline in Australian diver catch during 1999-2001 raised concerns that the fishery had become unsustainable and new management measures (increased minimum size limit from 100 mm tail length to 115 mm tail length, closed season October-November, hookah ban December-January) were introduced to enable the stock to recover. The subsequent recovery of the stock was dramatic with commercial catches increasing to the record 2005 level ( 930 t). However, more recent catches were below the long-term average; 230 t were taken by Australian divers in 2009.

CSIRO and PNG NFA initiated fishery-independent diver surveys of the lobster population in Torres Strait in 1989, to estimate stock abundance and establish a baseline with which to compare future fishery-independent surveys. This fishery-independent data was subsequently input to fishery models to allow assessment of the long-term status of the fishery which provided important information for sustainable fisheries management.

The TRL fishery in Torres Strait is currently managed through input controls including limited licence numbers. Fishery regulations include: limiting the method of taking of lobster to either hand or with the use of a hand held implement, such as a spear or scoop net; an October-November (inclusive) ban on all commercial fishing; a December-January (inclusive) ban on the use of hookah gear; a minimum tail size of 115 mm or minimum carapace length of 90 mm for all commercially caught lobsters; a bag limit of 3 lobsters per person or 6 lobsters per dinghy for traditional fishing (Islander or visiting PNG Traditional Inhabitants); a prohibition on the processing or carrying of tropical rock lobster meat; and interim controls including a moon-phase closure and tender reductions. Assessments of the status of the fishery have relied on relative abundance indices derived from the annual mid-year population surveys (1989-2010) and commercial catch statistics. The mid-year population surveys provided abundance indices for the recruiting (1+) and fished ( $2+$ ) year-classes, which are input to the new fishery model developed for the TRL fishery.

In July 2005 the Torres Strait Protected Zone Joint Authority (PZJA) made the decision to change management of the Tropical Rock Lobster (TRL) fishery from effort restricted to a quota management system through modification of the input controls. The new management system included moving to a 50/50 share of Australian commercial entitlements between Torres Strait islanders and non-islanders. The decision brought about an urgent need to develop a method to set a sustainable total allowable catch (TAC) and to prioritise research needed to obtain the necessary lobster stock and fishery data to estimate the TAC. The new quota management system has been delayed until after 2011.

A pre-season population survey of recruiting (1+) lobster abundance is critical to support the new TAC estimation, and the first pre-season survey was conducted in November 2005 to provide
managers with information on the abundance and biomass of fishery recruits and the likely stock biomass available to be fished in the 2006 fishing season. This information was subsequently used by the TRL research assessment group (RAG), to help formulate a method to set sustainable TACs for each fishing season.

Several methods to estimate a sustainable TAC for the Torres Strait lobster fishery have been developed and assessed and the merits of these methods were discussed at TRL RAG meetings. The RAG stressed the importance of pre-season surveys to determine the current size of the recruiting (1+) year-classes to be fished in the following seasons.


Figure 1-1. Map of northern Queensland and southern Papua New Guinea showing the EEZ boundary, boundaries of the lobster fisheries in both countries, the Torres Strait Protected Zone and the 200 m and 1000 m isobaths.

The mid-year population surveys have been carried out since 1989 to support long-term stock assessment for the TRL fishery; whilst the pre-season population surveys provide critical information to ensure the annual TACs are set at sustainable levels. The TRL RAG recommended that both midyear and pre-season surveys should be continued while the quota management system is being developed. However, given the mid-year survey data extends well beyond the pre-season data it was recently decided that under budgetary constraints mid-year surveys would be accorded higher priority than pre-season surveys.

This report summarizes the results of the 2009 research tasks and the key outcomes of these tasks. Results of the 2009 population survey are compared with results of all previous fishery-independent surveys co-funded by AFMA since 1989, and an update from the recent 2010 survey is provided. Results of key tasks aimed at refining fishery model input data, including catch at age, commercial catch per unit effort and growth parameter estimates are provided. Stock status assessment and TAC estimation are not included here as both tasks are ongoing with results to be presented at the October TRL RAG meeting.


Figure 1-2. Commercial lobster catches taken by the Australian and PNG diver and trawl fisheries in Torres Strait and the Queensland diver fishery between 1973 and 2009.

### 1.2. NEED

Following the decision by the PZJA in July 2005 to move to a quota management system for the Torres Strait Tropical Rock Lobster Fishery, AFMA and CSIRO identified the need to develop research methods to estimate sustainable TACs for each fishing season. Under the input controlled management system, stock assessment was based on results of mid-year (May/June) fisheryindependent population surveys and annual catch statistics. Given that the implementation of the quota management system is not likely in the short-term, and under budgetary constraints, the TRL RAG identified the mid-year survey data as highest priority. Mid-year survey data will be used in the integrated fishery model, with updated commercial catch data, to recommend a TAC.

### 1.3. OBJECTIVES

1. Conduct a mid-year survey of the relative abundance of recruiting (1+) and fished (2+) lobsters, size-frequency of the TRL population and record seabed habitat.
2. Update the age-structured fishery model using recruit and fished lobster abundance data from the surveys to allow assessment of the current stock status.
3. Collate commercial fishery catch data for use in the stock status assessment.

## 2. MID-YEAR POPULATION SURVEYS

### 2.1. INTRODUCTION

Annual fishery-independent monitoring of the Torres Strait ornate rock lobster Panulirus ornatus population has been carried out during 1990 to 2010. These surveys, conducted mid-year, provided the only long-term information on the relative abundance of recruiting ( $1+$ ) and fished ( $2+$ ) lobsters, since there has been no comprehensive monitoring of commercial catch and effort prior to 2003. The relative abundance indices and age composition data are used in the TRL fishery model for assessments of the status of the stock, and to set and evaluate new management regulations.

During 1990-1995 the annual population surveys involved a sub-set of 100 paired sites from the original 542 paired sites sampled in 1989. Since then there have been several modifications to the sample design used for the annual population surveys to address funding constraints, imposition of conservative new dive regulations under the Australian Standard for Scientific Diving AS2299.2 and spatial distribution of sampling sites. A sub-set of 42 sites from the original survey in 1989 were retained in all years providing a reference for inter-annual comparisons.

As for sample design, there have been several modifications of the sampling method used during the annual population surveys. Although the original absolute stock survey in 1989 involved surveys of measured ( $500 \times 4 \mathrm{~m}$ ) transects along a line laid on the seabed, this method was considered overly time consuming and subsequent annual surveys involved divers counting and collecting lobsters during timed ( 20 minute) swims. The introduction of reliable GPS coverage in 1992 allowed the first recording of distance swum to compare with the timed swim data. Subsequent availability of the Chainman ${ }^{\circledR}$ device in 1996, which allows recording of distance swum underwater, allowed a precise record of the transect length for the latter years. These distance records in combination with duration, current and visibility data have allowed standardisation of the abundance data from timed swim (20 minute) counts to measured transect ( 500 m by 4 m ) counts for all years (Ye et al. 2005). The interannual trends were similar for both data-sets (Figure 2-1), but the measured transect counts provided more precise relative abundance information for use in the integrated fishery model developed for the TRL fishery.

During 1989 to 2001 the relative abundance indices from the annual population surveys were corroborated by CPUE data recorded during concurrent monitoring of the island-based catch and effort. The subsequent introduction of compulsory logbooks for the TVH sector of the fishery provided CPUE data that could be compared with the fishery-independent survey data. The validated abundance indices provided information on the relative strength of the recruiting $(1+)$ and fished $(2+)$ year-classes and forewarning of trends in future stock size. This data was also used to calculate the stock-recruitment relationship which is a critical component of the integrated fishery model.
The $20^{\text {th }}$ annual population survey was conducted in May 2009 and the $21^{\text {st }}$ survey was recently completed in June 2010. Brief results of the 2010 survey are provided here as an update.

### 2.2. METHODS

### 2.2.1. Survey Design

As in all previous years the study area included all seabed habitats bounded by $142^{\circ} \mathrm{E}$ in the west, Warrior Reef and $142.9^{\circ} \mathrm{E}$ in the east, the southern PNG coastline in the north and $10.8^{\circ} \mathrm{S}$ in the south (Figure 1-1). This area encompasses the main fishing grounds in both Australia and PNG, and nearly all of the commercial catch is taken within this area. The study area covers about $19000 \mathrm{~km}^{2}$ and depth is generally less than 25 m throughout. The seabed habitat in the study area is heterogeneous, ranging from bare mud and sand to complex coral reefs and seagrass meadows. The distribution of seabed habitats was determined during several historical research surveys conducted by CMAR, including the 1989 lobster population survey. This information, with seabed bottom stress, was collated in 2002 to allow optimisation of the Benchmark Lobster Survey and allocation of sampling strata, containing more homogenous seabed habitats. The sampling strata were further refined in 2005 to exclude locations in the west of the study area that were shown to be unsuitable lobster habitat (sand/mud) and to split the Mabuiag stratum into a northern stratum (Buru stratum) and a southern stratum (Figure 2-2).


Figure 2-1. Relative abundance of recruiting (1+) and fished (2+) ornate rock lobsters Panulirus ornatus recorded between 1989 and 2009. Red lines show data scaled to 20 minute swim counts and blue lines show data scaled to 500 m by 4 m transect counts. Error bars represent standard errors.

The study area is characterized by predominantly turbid waters, due to terrestrial inputs from southern PNG and high tidal current flow which re-suspends sediments. Unlike eastern Torres Strait, live coral cover is low in the area of the fishery and reefs are characteristically mud or sand banks with a small fringing reef. The Warrior Reef complex, which delineates the eastern margin of the lobster fishery has a large reef flat containing dense seagrass meadows and the perimeter of the reef is colonized by macro-algae (Sargassum spp., Turbinaria ornata, Padina spp.).
The climate in Torres Strait is monsoonal, with strong persistent south-east trade winds dominating in winter (May-September) and sporadic north-west winds in the summer months. Current flow is strong (up to 8 knots) during spring tides, particularly in the networks of inter-reefal channels throughout the fishery. For this reason and as water clarity is generally higher then, most lobster fishing is restricted to periods of neap tides.


Figure 2-2. Map of western Torres Strait showing distribution of the sampling strata used in the 2009 mid-year population survey, and ornate rock lobster Panulirus ornatus abundance recorded during the 2002 Benchmark Lobster Survey.

The sample design employed during the annual (mid-year) population survey in 2009 was the same as that employed during 2004-2008 (Plaganyi et al, 2009). Of the thirteen sampling strata (Table 2-1), seven were sampled in 2009. No sampling has been done in PNG waters since 2007.

Table 2-1. List of sampling strata employed during the annual (mid-year) lobster population surveys, and number of sites sampled each year between 2002 and 2009. A total of 24 sites were sampled using underwater video in 2002 and 29 of the 69 sites sampled in PNG waters in 2003 were sampled using video.

| SAMPLING STRATUM | Sampled |  |  |  |  |  |  |  | Area_km ${ }^{2}$ <br> Area |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |  |
| BURU |  |  | 6 | 5 | 4 | 6 | 7 | 3 | 1689 |
| KIRCALDIE_RUBBLE | 22 | 5 | 8 | 8 | 8 | 8 | 10 | 8 | 961 |
| MABUIAG | 121 | 19 | 13 | 13 | 13 | 12 | 14 | 11 | 1394 |
| NO_SAMPLE |  |  |  |  |  |  |  |  | 2086 |
| PNG_SAMPLE | 16 | 69 | 29 |  |  | 18 |  |  | 529 |
| SE_OMIT |  |  |  |  |  |  |  |  | 514 |
| SAND_OMIT | 11 |  |  |  |  |  |  |  | 6301 |
| SAND_SAMPLE | 2 |  |  |  |  |  |  |  | 561 |
| SOUTH-EAST | 48 | 26 | 14 | 15 | 14 | 15 | 17 | 14 | 893 |
| TI_BRIDGE | 119 | 31 | 31 | 30 | 27 | 32 | 39 | 24 | 2924 |
| WARRABER_BRIDGE | 16 | 5 | 8 | 8 | 8 | 8 | 8 | 8 | 744 |
| WARRIOR_BACK | 2 |  |  |  |  |  |  |  | 231 |
| REEF-EDGE | 18 | 3 | 8 | 7 | 6 | 7 | 8 | 6 | 93 |
| TOTAL | 375 | 158 | 117 | 86 | 80 | 106 | 103 | 74 | 18920 |

### 2.2.2. Field Surveys

The 20th annual (mid-year) survey of the Torres Strait lobster population was conducted during May 2009 by four CSIRO staff, using the vessel M.V. James Kirby. A total of 74 sites were surveyed by divers and each site was re-located accurately using portable GPS.
As in the 1989 survey, measured belt transects ( 500 m by 4 m ) were employed as the primary sampling unit, as they were found to give the greatest precision ( $\mathrm{p}=\mathrm{SE} / \mathrm{Mean}$ ) of lobster abundance. Transect distance was measured, to the nearest metre using a Chainman® device.

At the completion of each transect a diver recorded; the number of lobsters caught, the number and age-class of those missed, 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.

### 2.2.3. Lobster Size and Age Distribution

The sampled lobsters were measured (tail width in mm ), sexed and moult staged to provide sizefrequency data. The year-class components in the size frequency distribution of sampled lobsters were determined using modal analysis (Mix; Macdonald and Pitcher, 1979). The resulting proportions of recruiting (1+) and fished (2+) year-classes were combined with the counts of missed 1+ and 2+ lobsters to estimate the age composition of the lobster population.

### 2.3. RESULTS

### 2.3.1. Lobster Distribution

As in 2008, the distribution of recruiting ( $1+$ ) lobsters recorded in May 2009 ( Figure 2-3) was divergent to the relatively consistent distributions recorded during 2005 -2007. In particular, the relatively low densities of recruiting lobsters in the Warraber_bridge and Kircaldie_rubble strata contrasted with distributions recorded in recent years. The density of recruiting lobsters was, in comparison, relatively high. In 2009, 1+ lobsters were recorded at $77 \%$ of sites surveyed cf. $49 \%, 73 \%, 70 \%$ and $61 \%$ in 2005, 2006, 2007 and 2008 respectively (Table 2-2). As in 2005-2008 the distribution of fished (2+) lobsters recorded in May 2009 was patchy Figure 2-3. However, in contrast to 2008 when nearly all fished lobsters occurred along the eastern margin of the fishery, in 2009 most fished lobsters occurred in the north-western area of the fishery. Zero 2+ lobsters were observed at most of the sites surveyed in the south-eastern area of the fishery. In 2009, 2+ lobsters were recorded at $39 \%$ of sites surveyed cf. $51 \%, 30 \%, 36 \%$ and $29 \%$ in 2005, 2006, 2007 and 2008 respectively (Table 2-2).
The temporal consistency of lobster distribution is important as the annual mid-year and pre-season population surveys are conducted at repeated sites, and the lobster populations at these sites are presumed to be representative of the whole area. Apart from some minor shifts the spatial distribution of lobsters throughout western Torres Strait has not changed significantly since the initial population survey in 1989, as shown by the Benchmark Lobster Survey in 2002 and subsequent annual population surveys. The distribution of lobsters is largely determined by the distribution of seabed habitats which have also remained consistent through time. However, anomalous distributions of recruiting and fished lobsters were recorded in 2008 and 2009, particularly the latter. Nevertheless, the wide spatial extent of the survey sites should largely account for changes in lobster distribution and provide a representative index of abundance. In contrast, the TVH CPUE data will be significantly affected by changes in lobster distribution as fishers target specific fishing grounds and must maintain a certain catch rate to remain viable. For example, the Kircaldie rubble stratum is important for the TVH sector and no 2+ lobsters were recorded there during the 2009 survey, although roughly average abundance was recorded in the remaining strata. Hence, whilst the TVH CPUE will reflect a poor catch rate the survey index will reflect abundance throughout the entire fishery.

Table 2-2. Number of sites sampled in Australian waters during the 2005-2008 lobster population surveys and percentage of sites with non-zero counts of newly-settled ( $0+$ ), recruit ( $1+$ ) and fished ( $2+$ ) lobsters.

| Year | Survey | Sites | \% sites with non-zero lobster counts |  |  |  |
| :--- | :--- | :---: | :---: | :---: | :---: | :---: |
|  |  | All <br> lobsters |  |  |  | $\mathbf{0 +}$ |
| 2005 | Mid-year | 86 | 70 |  | $\mathbf{1 +}$ | $\mathbf{2 +}$ |
|  | Pre-season | 154 | 67 | 41 | 49 | 51 |
| 2006 | Mid-year | 80 | 76 |  | 78 | 13 |
|  | Pre-season | 144 | 71 | 28 | 59 | 30 |
| 2007 | Mid-year | 88 | 80 |  | 70 | 4 |
|  | Pre-season | 152 | 68 | 24 | 59 | 10 |
| 2008 | Mid-year | 103 | 69 |  | 61 | 29 |
|  | Pre-season | 148 | 60 | 28 | 51 | 5 |

### 2.3.2. Lobster Density Estimates

The pattern of densities of recruiting (1+) lobsters amongst the sampling strata in 2009 was divergent to previous years, with average density highest in the Mabuiag stratum and relatively low in the Warraber_bridge stratum (Figure 2-4). The relative average density in the Warraber_bridge stratum fell significantly from the strong levels recorded since 2006. Overall, the precision of the 2009 recruiting ( $1+$ ) lobster abundance estimate was comparable to all years except the low precision recorded in 2007. Further, precisions of the stratum means recorded in 2009 were consistent suggesting the site allocation to each stratum was effective. The anomalous pattern of densities recorded in 2008 indicated that there had been a change in distribution. The 2009 pattern of densities was again anomalous but divergent from the 2008 pattern. This result highlights the need to ensure sampling adequately throughout the fishery to capture regional changes in abundance.

The patterns of densities of fished (2+) lobsters amongst sampling strata were variable amongst all years (Figure 2-4), although the highest densities were recorded in the Warraber-bridge stratum since 2005. However, in 2009 the precision of the Warraber_bridge stratum estimate was low indicating lobsters were patchily distributed. Commercial TVH fishers reported low catch rates in the southeastern area of the fishery and many vessels relocated to the QLD east coast due to these conditions.

### 2.3.3. Mid-year Survey Abundance Indices

Standardised estimates of abundance indices for recruiting (1+) and fished (2+) lobsters are presented in Figure 2-5. Overall, the abundance of age $1+$ lobsters was extremely variable with a decreasing trend 1995-2005. Since 2005 recruiting lobster abundance has been generally strong, although the 2008 year-class was well below the long-term average.
The trends in abundance of age $2+$ lobsters were different from those of age $1+$ lobsters, with much less variation. Overall, the abundance of age $2+$ lobsters was consistent in most years, but with anomalously high catch rates in 1989, 1992, 2003-2005 and very low catch rates during 1999-2001. The above average stock in 2007 suggested an above average recruitment in 2009 and a more promising season in 2010.
The 2009 1+ year-class was well above the 2008 level and the long-term average, continuing the generally strong levels recorded since 2005 (Figure 2-5). The steady recovery in both recruitment and stock recorded during 2001 to 2004 suggested that the new management measures had aided stock recovery and contributed to more reliable recruitment levels. However, whilst this may have been so recruitment levels since that time have been variable with below average levels in 2005 and 2008. The long-term variability in recruitment of $1+$ lobsters to the fishery highlights how both stock levels and environmental conditions impact on the stock-recruitment relationship. Given recruitment levels are very difficult to forecast there is a need for annual monitoring of stock and recruitment levels to ensure the fishery remains sustainable. Once the quota management system is in place it will be even more critical to determine recruitment levels so that TACs are set at appropriate levels.
The 2009 2+ year-class was just greater than the 2008 level and the long-term average (Figure 2-5). Although not as high as the 2003-2005 levels, recent consistent stock abundances suggest subsequent breeding populations will also be consistent. The small stock increase was not forecast given the lower recruitment observed in 2008. As the fishery targets almost exclusively $2+$ lobsters, the 2009 commercial catch was forecast to be slightly greater than the 2008 catch. This did not eventuate with a slightly smaller commercial catch in 2009. However, as discussed above the smaller catch may have been due to the change in lobster distribution. In particular the low stock abundance in the Kircaldie_rubble stratum would have impacted heavily on the TVH catch, with dual endorsed fishers likely opting to work on the Queensland east coast.


Figure 2-3. Densities of recruiting (1+) and fished (2+) ornate rock lobsters (Panulirus ornatus) recorded during the 2009 mid-year survey of the Torres Strait population. The pink line shows the boundary of the Torres Strait Protected Zone.


Age 1 in 2006


Age 1 in 2007


Age 1 in 2008


Age 1 in 2009



Age 2 in 2006




Age 2 in 2009


Figure 2-4. Densities of recruiting (1+) and fished (2+) ornate rock lobsters (Panulirus ornatus) in the sampling strata recorded during annual (mid-year) population surveys conducted in western Torres Strait between 2004 and 2008.


Figure 2-5. Relative abundance of recruiting (1+, blue) and fished (2+, red) ornate rock lobsters (Panulirus ornatus) recorded during annual (mid-year) population surveys conducted between 1989 and 2010. Error bars represent standard errors. Catch rates have been standardized to measured $500 \times 4 \mathrm{~m}$ belt transect counts.

### 2.3.4. Lobster Size and Age Distribution

The size-frequency distributions of ornate rock lobsters Panulirus ornatus sampled during the annual (mid-year) population surveys between 1989 and 2009 were comprised of two modes, representing the recruiting ( $1+$ ) and fished ( $2+$ ) year-classes (Figure 2-6). The mean size of the recruiting year-class in 2009 was slightly smaller than in 2008, but the mean size of $2+$ lobsters in 2009 was greater than in 2008.

The size-frequency distributions of lobsters sampled from the island-based commercial catches prior to 2002 (Figure 2-6) were comprised mainly of 2+ lobsters and the vast majority of the recruiting ( $1+$ ) lobsters in the historical commercial catches were smaller than the current minimum size limit (115 mm tail length $\approx 60 \mathrm{~mm}$ tail width). The size distributions of lobsters sampled mid-year and preseason between 2005 and 2009 (Figure 2-7) show that virtually all recruiting lobsters are below legal size until after the seasonal closure ends in November. This protection is why commercial catches are comprised almost entirely of 2+ lobsters (Figure 2-8).

### 2.4. DISCUSSION

The annual (mid-year) surveys of the Torres Strait lobster population provide key data for assessment of the status of the Torres Strait lobster stock including; relative abundance of recruiting (1+) and fished ( $2+$ ) lobsters and age composition. Commercial CPUE data have been shown to be a useful alternative proxy for $2+$ lobster abundance but there are no alternative sources of mid-year recruit ( $1+$ ) abundance. The TRL RAG recommended continuing the mid-year surveys only whilst the fishery continues to be managed using input controls.
Both the recruiting ( $1+$ ) and fished (2+) year-classes were above the long-term average in 2009. The increased 2009 recruiting year-class suggests that the 2010 stock and TAC estimate from the fishery model would also be above the long-term average.

The mid-year relative abundance data continues to be used to inform the stock-recruitment relationship which is a critical component of the new integrated fishery model used to assess the status of the lobster stock and provide TAC recommendations for management. Given the delay to the introduction
of the quota managed system the TRL RAG decided to continue the mid-year surveys into 2010. However, once the QMS is introduced it is likely a single population survey will be undertaken each year to allow an estimate of TAC due to the prohibitive cost of two annual surveys. The strong linear relationship between commercial CPUE and the fishery-independent survey data suggests that CPUE can be used at least to estimate the relative abundance of the fished (2+) year-class.

### 2.5. 2010 MID-YEAR SURVEY UPDATE

The $21^{\text {st }}$ annual (mid-year) survey of the Torres Strait lobster population was conducted during June 2010 by four CSIRO staff, again using the vessel M.V. James Kirby. As in 2009, a total of 74 sites (see Figure 2-9) were surveyed by divers and each site was re-located accurately using portable GPS. As in the 1989 survey, measured belt transects ( 500 m by 4 m ) were employed as the primary sampling unit, as they were found to give the greatest precision ( $\mathrm{p}=\mathrm{SE} / \mathrm{Mean}$ ) of lobster abundance. Transect distance was measured, to the nearest metre using a Chainman ${ }^{\circledR}$ device.
A total of 41 lobsters collected during the 2010 lobster population survey were tagged with anchor tags and released at the site of capture. Each tag provides contact information coordinated through the Infofish program.

The 2010 1+ year-class was just greater than the 2009 level, continuing the increase recorded since 2008 (Figure 2-5). The recent increased recruitment is a positive sign for the fishery, although the historical data highlights the high variability in recruitment likely influenced by several environmental variables that are difficult if not impossible to predict. Although the increased recruitment in 2009 did not translate into an increased stock in 2010, the higher recruitment in 2010 suggests the 2011 stock should be above average. Recruitment levels recorded during the mid-year surveys are not as effective as those from pre-season surveys given the long delay between the survey and the fishery opening. Once the quota management system is in place it will be critical to determine recruitment levels so that TACs are set at appropriate levels.

The 2010 2+ year-class was just smaller than the 2009 year-class (Figure 2 5). As the fishery targets almost exclusively $2+$ lobsters, the 2010 commercial catch should be similar to the 2009 catch. However, as discussed above the commercial catches are heavily influenced by spatial and temporal changes in lobster distribution.

The seabed habitat at each survey site has been recorded since 1989, and is used to assess environmental changes that may influence lobster abundance. In 2010 a large proportion of both hard and soft coral was bleached, likely due to a warming event that occurred in March 2010. If these corals do not recover this event has the potential to affect lobster abundance either directly or indirectly.


Figure 2-6. Size frequency distributions of the ornate rock lobster (Panulirus ornatus) catch landed at Mabuiag/Badu Islands in June/July 1989-2001 contrasted with the size-frequency distributions of the Torres Strait lobster population sampled by research divers mid-year between 1989 and 2009. The graphs are scaled by CPUE of the fishery and survey respectively to indicate inter-annual differences in relative abundance.






Figure 2-7. Size frequency distributions of ornate rock lobsters (Panulirus ornatus) sampled during the annual (mid-year) and pre-season population surveys in western Torres Strait between 2005 and 2009. The dashed lines indicate the minimum legal size limits.

2005
2006




Figure 2-8. Size frequency distributions of ornate rock lobsters Panulirus ornatus measured from commercial catches taken in Torres Strait between 2005 and 2009. Box plots of the same data are displayed at the top of each pane.


Figure 2-9. Map of western Torres Strait showing locations of the 74 sites surveyed during the 2010 lobster population survey. The blue line shows the track of the survey vessel.

## 3. DATA ANALYSIS AND STOCK ASSESSMENT

### 3.1. INTRODUCTION

A new stock assessment model (termed the "Integrated Model") 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);
- 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 can 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). The full details of the model and its application in 2009 are given in Plagányi et al. (2009). Further developments of both the input data and model itself are currently underway, and updated model results will be presented at the 2010 RAG meeting. This chapter summarises progress to date pertaining to both data analyses and model development.

### 3.2. METHODS AND RESULTS

An Oracle database has been setup by CSIRO as part of this project. Its purpose is to manage all lobster data and provide analysts with a centralised repository. It holds both fishery-dependent and fishery-independent data (Table 3.1). It readily provides formatted output as required by different agencies (CSIRO, AFMA and BRS).

Table 3.1 Time series and resolution of the different Torres Strait lobster datasets available in the Oracle database (Resolution/time series).

| Fishery dependent <br> data |  |  | Fishery independent data |
| :---: | :---: | :---: | :---: |
| TVH | TIB | PNG | Visual census |
| Vessel-day / 1994—2009 | Vessel-day / 2004—2009 <br> Year/ 2000—2003 | Year / 1973-2009 |  |
| Australia |  |  |  |
| Year / 1973—2009 |  |  |  |

The new Integrated Model is fitted to all available data sources. These include:
a) the benchmark survey observed total lobster abundances in 1989 and 2002;
b) the survey mid-year index of abundance (in terms of total numbers of 1+ and 2+ lobsters) and the observed and model-predicted proportions in each age;
c) all available data from the Pre-season survey (there are currently four years worth of data), including use of the recently-settled ( $0+$ ) information. Continuation of this data series will be particularly valuable once TAC recommendations are implemented;
d) CPUE data from the TVH sector. A standardised CPUE series was available for the period 1994 to 2007 from Ye et al. (2007) and the model was fitted to these data as a sensitivity test. Previous analyses suggested that there is a strong correlation between these indices and the survey indices of abundance, and hence including CPUE in the model fitting process did not significantly alter model results. It was noted that this series needed to be updated and the RAG requested that the effect of basing the analysis on a subset of the data (rather than the full dataset) be investigated.

The new Integrated Model is age-based to ensure continuity with the previous approach applied. Although cohort slicing is widely in use and has been adequate for current purposes, an improved method would be to fit the population model directly to length data assuming a fixed (time independent) growth curve with time-independent but length-dependent variance in length-at-age. This is unlikely to make much qualitative difference and hasn't been attempted yet given other priorities, but in the longer term the stock assessment model should ideally be fitted directly to length information. Plagányi et al (2009) highlighted that the major differences (particularly in fishing mortality estimates) between the new and old model could all be attributed to the use of different growth relationships in the models, and recommended that this aspect be explored further.
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:

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

where $C L$ 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 $=0.00258 *(\mathrm{CL} \wedge 2.76014)$
the Trendall et al (1988) relationship translated into average individual masses that were less than the observed average mass of lobsters caught in the fishery (Plagányi et al. 2009). The 2009 Integrated model thus used the Phillips et al. (1992) male growth relationship:

$$
\begin{aligned}
& \qquad L=L_{\infty}\left(1-e^{-k t}\right) \\
& \text { where } \quad L_{\infty}=165.957 \quad m m \\
& \\
& \kappa=-0.0012 ; \text { and } \\
& t \text { is age in DAYS. }
\end{aligned}
$$

Three separate analyses have been attempted to further advance the analysis of input data and parameters for the stock assessment model. The methodology and preliminary results are summarised in the following three Appendices:

## Appendix 3.1 Catch at age estimation

Updated commercial catches for the period 1989-2009 are presented in Table 3.1.3. This Appendix summarises an alternative method for splitting commercial landing information into the two agecategories (1+ and 2+). The method relies on somatic growth (Phillips et al., 1992) and morphometric relationships to determine size at age, and uses the survey data to determine the age structure of the population and variability of length at age. Intermediate results were compared to available independent data to check the validity of the method. This error checking evidenced a systematic under-estimation, of around $20 \%$ of mean weight at age in the catch compared to data provided by the MG Kailis group. As a consequence, numbers at age in the catch are over-estimated by this method. This aspect merits further investigation.

As a further check, output from the stock assessment model in the form of the average mass (g) of the modelled commercial catch was compared with the MG Kailis group data for a range of months over the period 2006-2009 (Fig. 3.1). The model matches the data fairly well in some years but slightly under-estimates the average mass of fished lobsters in other years, which may partly be a consequence of assuming that the catch is taken as a pulse rather than continuously through the fishing season. These comparisons serve as a useful additional diagnostic test of model performance, and will be explored further in future work.


Figure 3-1. Comparison between stock assessment model output average mass of the commercial catch (g) (solid line) with observed median mass measured between January 2006 and September 2009 (data provided by MG Kailis Group).

## Appendix 3.2 Commercial CPUE estimation

A Generalized Linear Model (GLM) of a subset of the Transferable Vessel Holder (TVH) licence catch and effort data currently provides an index of lobster abundance in Torres Strait which was shown to be proportional to abundance estimates from the fishery-independent survey data (Ye and Dennis, 2009; Ye et al., 2007). In 2009, the size of this subset decreased to 7 licences following a voluntary surrender of licences owned by Australian fishers to meet Australia's obligation under the Torres Strait Treaty (Wilson et al., 2009). The TRL RAG raised some concerns that further subsetsize reductions might create a subset too small to draw any valid conclusion and in the most extreme case, preclude the analysis. The GLM methodology was thus revisited and the effects of subsetting
investigated. Preliminary analyses suggest that simpler approaches that use the whole TVH dataset may be preferable to the previously applied more complex approach. Two alternative abundance index series, derived from catch and effort data, have been developed for use as inputs to the stock assessment model.

## Appendix 3.3 Updated lobster growth parameter estimation

An analysis of approximately 10000 length measurements collected during scientific surveys was performed to estimate the parameters of the von Bertalanffy growth function. Several models describing growth variation in the past 21 years were compared to determine which hypotheses were best supported by the data. Lobster growth estimated from 129 individuals tagged between 1980 and 1983 (Phillips et al, 1992) was found to be similar to that observed between 1989 and 2009. This new analysis builds on the work of Phillips et al. (1992) through estimation of the parameter $t_{0}$ as well as providing estimates of the uncertainty associated with the von Bertalanffy growth function parameters.

### 3.3. DISCUSSION

Field sampling this year has been completed and the results analysed. An Oracle database has been established to manage all lobster data. Data series have been updated and alternative analysis methods explored with the aim of gradually improving the inputs to the stock assessment. Updated data inputs to be used in the 2010 stock assessment update are summarized in the Appendix Tables. The alternative methodologies described in Appendices 3.1 - 3.2 are still under development and will be discussed at forthcoming RAG meetings. Broadly these methods relate to a more detailed analysis of lobster growth information and assumptions, and to splitting commercial landing information into the two age-categories ( $1+$ and $2+$ ) to inform our estimates of the relative sizes of lobster cohorts.

Future work may explore further improved alternatives for standardisation of the TVH CPUE data, including the use of random effect models (Venables and Dichmont 2004). Moreover, it may be important to incorporate a spatial factor. This was illustrated by the data presented in Chapter 2 which showed, for example, zero $2+$ lobsters having been recorded in the Kilcaldie rubble stratum, an important fishing ground, in contrast to average abundance elsewhere. Although there is generally very good agreement between the fishery-independent mid-year survey data and the fishery-dependent CPUE data, future analyses will benefit from an improved understanding of factors contributing to differences. This is particularly important if CPUE data are ever to be used in place of mid-year survey data in providing management advice. Future work (including planned research in the related MSE project) will be exploring the consequences of using alternative combinations of information to inform assessments, such as the use of a CPUE series in combination with a Pre-Season survey. The latter series can potentially play an important role in reducing the uncertainty associated with model-derived TAC estimates.

The Integrated stock assessment model is currently being updated with the recent input series described in this chapter. An updated assessment will accordingly be presented at the next RAG meeting, and updated model-derived TAC estimates provided. Linked research that is planned to be undertaken as part of the MSE project will serve to better evaluate and test the robustness of a range of plausible harvest strategies for use in combination with the model TAC estimate.

## Appendix 3.1: commercial data and catch at age estimation

### 3.1.1 Introduction

The method used to assess the status of the rock lobster stock in Torres Strait uses catch at age data as an input. Prior to the assessment, commercial landings (in kg ) are converted into an estimated number of individuals caught, grouped into two age-categories $\left(1^{+}\right.$and $\left.2^{+}\right)$. These estimates are derived from (1) the population age-structure derived from scientific survey samples collected annually since 1989 and (2) minimum landing carapace length (MLCL) regulations imposed on this fishery.

At least four factors influence the age composition of the catch. First, the variability of length at age plays an important role as it determines the fraction of individuals of a certain age over the MLCL. Second, the relative strength of cohorts determines the relative abundance of each age-group over the MLCL. Third, mortality (which will be confounded with cohort strength in a length frequency histogram) decreases the proportion of the older age-group as it increases. And last, size selectivity (if present) will favour the presence of one age-group over the other in the catch.

This section describes a method implemented to calculate total number of lobster caught from 1989 to 2009 in the Torres Straits using commercial and scientific survey data. The results are compared to independent sources to assess how accurate this method is.

### 3.1.2 Method

The method developed to convert landings (in weight) to number of lobsters at age assumes that landings were composed only of two age-groups, $1^{+}$and $2^{+}$. Given numbers at age ( $N_{1^{+}}$and $N_{2^{+}}$) and mean weight at age ( $W_{1^{+}}$and $W_{2^{+}}$), the catch in a given period of time, such as month, can be expressed as follows

$$
\begin{equation*}
C=N_{1^{+}} \times W_{1^{+}}+N_{2^{+}} \times W_{2^{+}} \tag{1}
\end{equation*}
$$

Further, replacing $N_{1^{+}}$and $N_{2^{+}}$by a proportion of age-group $1^{+}(p)$ of the total number of individuals caught ( $N$ ), yields

$$
\begin{equation*}
C=N \times p \times W_{1^{+}}+N \times(1-p) \times W_{2^{+}} \tag{2}
\end{equation*}
$$

where $N=N_{1^{+}}+N_{2^{+}}=p \times N+(1-p) \times N$.
Calculations of number at age $\left(N_{1^{+}}\right.$and $\left.N_{2^{+}}\right)$depend on three parameters ( $p, W_{1^{+}}$and $W_{2^{+}}$) which are estimated using the methods described in the following paragraphs.

Somatic growth and morphometric relationships Somatic growth was assumed to follow a Von Bertalanffy growth function (Von Bertalanffy, 1957) with parameters estimated, for males, from tag-recapture data analysed by Phillips et al (1992), i.e. $L_{\infty}=166 \mathrm{~mm}, k=0.0012$ days $^{-1}$. The adjustment parameter $\left(t_{0}\right)$ was not provided by these authors and was estimated using a maximum likelihood fit of the mid-year survey carapace length frequency distribution (see section 3.1.2).

Using the Phillips et al (1992) parametrisation, with $t_{0}=0$, implies that lobster would reach a MLCL of 90 mm carapace length at age 1.8 years ( 651 days). Since lobster emigrate from the Torres Strait at around 2.75 years old, landings are most certainly composed of a mixture of age-groups $1^{+}$and $2^{+}$. The proportion of age-group $1^{+}(p)$ is expected to increase during the year as (a) age-group $1^{+}$becomes larger than the minimum landing size, and (b) age-group $2^{+}$moves out of the Torres Straits.

Each year since 1989, a sample of lobster was collected during the scientific survey to measure tail width ( T ), in mm . These measurements were converted into carapace length ( L ), to be consistent with Phillips et al (1992), using the following equation (not published)

$$
\begin{equation*}
\mathrm{L}=1.433 \times \mathrm{T}+1.089 \tag{3}
\end{equation*}
$$

Moreover the following length-weight relationship was used to convert carapace length, in mm, into whole individual weight, in grams:

$$
\begin{equation*}
W=0.00258 \times \mathrm{L}^{2.76014} \tag{4}
\end{equation*}
$$

Estimating the lobster population age-structure Carapace length frequency distribution (CLFD) collected each year displayed a clear bi-modal distribution that was assumed to represent two groups of individuals whose age differed by 1 year. Each CLFD was fitted, using maximum likelihood, with a mixture of two Gaussian distributions (Venables and Ripley, 2003) to estimate a mean carapace length for each age-group ( $\mu_{1+}$ and $\mu_{2^{+}}$, in mm ) and standard deviation common to both age-groups ( $\sigma$, in mm ); as well as the proportion $(\theta)$ of measurements belonging to the first age-group. Mean carapace lengths ( $\mu_{1^{+}}$and $\mu_{2^{+}}$, in mm) were constrained by Phillips et al (1992)'s parameterisation of the Von Bertalanffy growth function (VBGF) for males using age, in days, as the sum of the survey date (since the beginning of the year and a multiple of 365 days appropriate to each age-group $(1 \times 365$ or $2 \times 365))$ :

$$
\begin{equation*}
\mu_{j}=166\left[1-\exp \left(-0.0012 \times\left(t-t_{0}\right)\right)\right] \tag{5}
\end{equation*}
$$

The adjustment parameter $\left(t_{0}\right)$ was estimated for each survey, allowing translation of the VBGF along the age axis.

Estimates of $\mu_{1^{+}}, \mu_{2^{+}}, \sigma, \theta$ and the VBGF adjustment parameter $\left(t_{0}\right)$, for each survey, were obtained by maximising the log-likelihood function given by Venables and Ripley (2003) :

$$
\begin{equation*}
\ell=\sum_{i=1}^{n} \log \left(\frac{\theta}{\sigma} \phi\left(\frac{\mathrm{~L}_{\mathrm{i}}-\mu_{1^{+}}}{\sigma}\right)+\frac{1-\theta}{\sigma} \phi\left(\frac{\mathrm{L}_{\mathrm{i}}-\mu_{2^{+}}}{\sigma}\right)\right) \tag{6}
\end{equation*}
$$

where $\phi$ represents the density of a normal distribution and $i$ a particular length measurement collected in a mid-year survey. Each CLFD was fitted separately.

Estimating the proportion of age-group $1^{+}(p)$ in the catch The fraction of the monthly landing comprising age-group $1^{+}(p)$ was calculated assuming that (1) mean length at age can be derived from a VBGF for the middle date of each month; (2) parameter $t_{0}$ was estimated from length frequency decomposition; (3) length was normally distributed with SD estimated from length frequency decomposition; (4) MLCL was set to 78 mm before $2001^{1}$ and 90 mm in and after 2001 and (5) cohort strength was estimated by length frequency decomposition $(\theta)$. Using these assumptions, the proportion of age-group $1^{+}(p)$ was calculated using the areas (A1 and A2) under the 2 Gaussian curves, using MLCL as the lower limit (Fig. 3.1.1).

The proportion of age-group $1^{+}(p)$ was set to $100 \%$ in October and November to account for the spawning immigration of age-group $2^{+}$. Fishery size-selectivity was set to $0 \%$ for December to account for fishermen targeting larger lobster in response to consumer demand over Christmas.

Estimating mean weight at age in the catch ( $W_{1^{+}}$and $W_{2^{+}}$) by month Mean weight of age-group $1^{+}$and $2^{+}$in the catch $\left(W_{1^{+}}\right.$and $\left.W_{2^{+}}\right)$were estimated for each month in the years 1989 to 2009 using the expected length over MLCL converted into weight. Carapace length at age was assumed to be normally distributed with mean given by VBGF evaluated at the middle of each month and SD estimated from length frequency decomposition. Mean weights of lobster landed were calculated using (1) the probability of having a specific carapace length over MLCL times and (2) the associated weight converted from carapace length using the length-weight relationship (Eq. 4)

$$
\begin{equation*}
\overline{W_{a}}=\frac{\int_{M L C L}^{+\infty} W(L) f(L \mid \text { age }- \text { group }=a) d L}{\int_{M L C L}^{+\infty} f(L \mid \text { age }- \text { group }=a) d L} \tag{7}
\end{equation*}
$$

where $f(L \mid$ age - group $=a)$ is the probability density function of carapace length at age $a$.

Treatment of highly aggregated landing data The conversion of catch data into number at age utilised landing statistics reported on a monthly basis. Landings were available at a monthly resolution since 1994 for TVH (Tab. 3.1.1), since 2004 for TIB (Tab. 3.1.2) and were always aggregated by year for PNG data (Tab. 3.1.3). Therefore the following additional assumptions were required:

- To estimate the number at age caught by TVH-licence holders between 1989 and 1993, it was assumed that the catch proportion caught each month was the same as the median monthly proportion observed between 1994 and 2009.
- To estimate the number at age from yearly aggregated catch (TIB between 1989 and 2003 and PNG from 1989 to 2009), it was assumed that the monthly pattern of catch was the same as TVH.


### 3.1.3 Results

Estimation of the population age-structure CLFD were fitted by maximum likelihood with a mixture of Gaussian distributions to estimate $\mu_{1^{+}}, \mu_{2^{+}}, \sigma, \theta$ and the VBGF adjustment parameter $\left(t_{0}\right)$. Six examples are shown in Fig. 3.1.2. Estimates of mean carapace length for age-group $1^{+}\left(\mu_{1^{+}}\right)$ranged from 52 to 66 mm and $\mu_{2+}$ ranged between 93 and 101 mm (Tab. 3.1.4). Estimates of the VBGF adjustment parameter ( $t_{0}$ ) ranged between 117 and 201 days. Variability in length at age is related to variation in sampling date: mean carapace

[^0]length being larger when samples were collected later in the year. Estimated standard deviations ( $\sigma$ ) of length at age were found to vary between 9 and 12 mm . Fractions of age-group $1^{+}(\theta)$ in the survey samples were found to vary substantially between years, from $37 \%$ to $91 \%$. These estimates were compared to cohort strength estimates calculated using the ratio of age-group abundance given by survey data (Fig. 3.1.3) which showed that these 2 estimates were well correlated ( $\rho=0.95$ ).

Estimation of the proportion of age-group $1^{+}(p)$ in the catch by month Proportions of age-group $1^{+}$ lobster landed between 1989 and 2009 were found to be very low in the first quarter of the year (Fig. 3.1.4 and Tab. 3.1.5). Before 2001, this increased steadily throughout the year, at a rate that depended on the strength of the age-group $1^{+}$cohort. Particularly large proportions of age-group $1^{+}$were estimated to be landed in 1994 and 1997. The effect of a fishery management decision to increase the MLCL to 90 mm , can be seen after 2001: the proportion of age-group $1^{+}$caught was estimated to have become almost null until September when age-group $2^{+}$start their spawning migration. The proportion of age-group $1^{+}$were set to $100 \%$ for October and November and to $0 \%$ in December (see section 3.1.2).

Estimation of mean weight at age in the catch ( $W_{1^{+}}$and $W_{2^{+}}$) by month Estimated mean weight at age in the catch ranged from 395 to 792 grams for age-group $1^{+}$and from 610 to 1493 grams for age-group $2^{+}$(Tab. 3.1.6 and 3.1.7). A comparison of estimated weight for age-group $2^{+}$lobster in the catch with commercial data provided by MG Kailis Group, Cairns, Australia (Tab. 3.1.8) showed that the correlation between the estimated and observed mean lobster weight in the catch is weak ( $\rho=0.35$, Fig. 3.1.5). Moreover it appeared that estimates were systematically lower than the observed mean weight in the catch.

Estimation of number at age landed ( $N_{1^{+}}$and $N_{2^{+}}$) The number at age were estimated for TVH since 1994 (Tab. 3.1.9) and TIB since 2004 (Tab. 3.1.10) using landings reported by month. An additional assumption about the monthly pattern of catch was made to estimate the number of lobsters caught by TVH between 1989 and 1993 (Tab. 3.1.11). Applying the seasonal fishing pattern observed and inferred for TVH to all catch data aggregated by year (TIB from 1989 to 2003 and PNG from 1989 to 2009), provided an estimated total number of lobster caught in the Torres Strait fishery by both Australia and PNG (Tab. 3.1.12).

### 3.1.4 Conclusion and discussion

The method described to estimate the number of lobster at age caught in Torres Strait provided point estimates for the whole fishery since 1989. These point estimates of number at age should be complemented with a measure of uncertainty using, for example, error propagation (Bevington and Robinson, 2003). It is impossible to verify these estimates of number at age but care was taken to compare, to independent data sources, two components of the calculations that lead to these results: (1) the proportion of age-group $1^{+}$in the survey ( $\theta$ ) and (2) mean weight at age $\left(W_{1^{+}}\right.$and $\left.W_{2^{+}}\right)$by month. The first comparison evidenced that the mixture distribution model provided consistent results with the age-category assigned by the scientific divers during the surveys. The second comparison showed that estimated mean weight in the catch ( $W_{1^{+}}$and $W_{2^{+}}$) were systematically lower than mean lobster weight by month provided by the industry. This discrepancy between model output and reality might result from the absence of characterisation ${ }^{2}$ of the size selectivity process that might take place in this fishery. As a consequence, the estimated number of lobster landed in the Torres Strait fishery are possibly overestimated given the official landing figures. Weight measurements from landed lobster would certainly

[^1]provide more realistic information than this model and improve estimates of the number of lobster at age landed.
This analysis is still preliminary as a number of sensitivity tests still need to be performed. For example, future analyses will investigate the effect of using VBGF parameters for males/females only as well as in combination. The pre-processing of lobster data for input to a stock assessment is not ideal, but the method presented here is nonetheless an improvement on previous approaches. In the long run, an improved method would be to perform all estimations internally within the stock assessment model, and to move to a length-based approach.

## References

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## 1995



Figure 3.1.1: Illustration of the calculation of the proportion of age-group $1^{+}$in the catch, using 1995 mid-year survey.


Figure 3.1.2: Six examples of the fit of a mixture of 2 Gaussians distribution to carapace length frequency distributions collected during mid-year surveys.

Prop. of age-group 1+ in mid-year surveys


Figure 3.1.3: Comparison of the proportion of age-group $1^{+}$in each mid-year survey obtained by different methods. The solid line represents $y=x$.


Figure 3.1.4: Estimated monthly proportion of age-group $1^{+}$in Torres Strait lobster catch between 1989 and 2009.


Figure 3.1.5: Comparison between estimated monthly mean weight (in g.) of age-group $2^{+}$and mean lobster weight caught between Jan. 2006 and Sept. 2009 (data provided by MG Kailis Group). Vertical and horizontal lines represent 1 standard deviation from the mean values. The solid line represent $y=x$.
40

|  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1994 | 6769 | 8096 | 10754 | 22075 | 20767 | 16815 | 12170 | 17838 | 12829 | 2462 | 0 | 2945 |
| 1995 | 1284 | 7175 | 4401 | 9095 | 11363 | 10355 | 8154 | 13896 | 18274 | 81 | 0 | 16965 |
| 1996 | 18104 | 17331 | 24965 | 15628 | 25444 | 16310 | 23966 | 28395 | 23763 | 0 | 0 | 32948 |
| 1997 | 33059 | 20529 | 25319 | 15876 | 39289 | 16159 | 34470 | 36754 | 17011 | 2954 | 2957 | 40615 |
| 1998 | 27370 | 45716 | 35622 | 36002 | 44215 | 32756 | 42430 | 45834 | 23437 | 1073 | 3513 | 18236 |
| 1999 | 6356 | 9162 | 23250 | 16155 | 13350 | 16255 | 11953 | 5549 | 8051 | 0 | 0 | 16232 |
| 2000 | 10836 | 13296 | 17736 | 9830 | 16622 | 17147 | 17249 | 9190 | 3339 | 0 | 2103 | 12799 |
| 2001 | 18942 | 4948 | 9274 | 1880 | 8885 | 8569 | 6801 | 5592 | 3596 | 95 | 27 | 1828 |
| 2002 | 373 | 13728 | 13816 | 12283 | 21454 | 17559 | 20364 | 27148 | 18623 | 0 | 0 | 2337 |
| 2003 | 3475 | 41304 | 34444 | 37112 | 43108 | 53102 | 58258 | 56148 | 29660 | 0 | 0 | 4948 |
| 2004 | 452 | 58965 | 73030 | 57142 | 70551 | 79438 | 65765 | 48014 | 22625 | 0 | 0 | 4984 |
| 2005 | 398 | 108962 | 106276 | 73510 | 59328 | 53765 | 60102 | 51794 | 30814 | 0 | 0 | 25 |
| 2006 | 0 | 22512 | 24860 | 17491 | 14798 | 11490 | 21952 | 16756 | 5589 | 0 | 0 | 0 |
| 2007 | 0 | 20996 | 42465 | 48169 | 63351 | 49295 | 26910 | 13633 | 6368 | 0 | 0 | 232 |
| 2008 | 0 | 14625 | 18087 | 11798 | 11912 | 9485 | 17380 | 18182 | 9545 | 0 | 0 | 0 |
| 2009 | 0 | 15576 | 19925 | 13766 | 10929 | 14610 | 9746 | 10993 | 3470 | 0 | 0 | 0 |

Table 3.1.1: Lobster landings, in kg, by Transferable Vessel Holder (TVH) licensees.

| Date | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 2004 | 16172 | 25488 | 38883 | 18753 | 31210 | 28842 | 28234 | 19989 | 13133 | 24 | 25 | 21648 |
| 2005 | 15165 | 52567 | 61348 | 51926 | 56830 | 46715 | 34934 | 24635 | 17409 | 346 | 71 | 12604 |
| 2006 | 9490 | 24455 | 32351 | 19451 | 18562 | 9857 | 10102 | 7672 | 2747 | 0 | 51 | 19002 |
| 2007 | 24941 | 24985 | 63246 | 36030 | 37055 | 29301 | 25939 | 16097 | 10104 | 916 | 0 | 10435 |
| 2008 | 14273 | 36541 | 45155 | 30914 | 19952 | 17266 | 27531 | 8524 | 8410 | 18 | 0 | 12872 |
| 2009 | 13091 | 18404 | 22351 | 22321 | 15010 | 11915 | 13278 | 7129 | 4714 | 529 | 0 | 386 |

Table 3.1.2: Lobster landings, in kg, by Traditional Inhabitant (TIB) licensee.

\left.| Year | Australia |  |
| :---: | :---: | :---: |
|  | TIB | TVH |$\right]$

Table 3.1.3: Landings, in tons, by year and country, subdivided by fleet where possible.

| Survey date | Nb obs | $\mu_{1+}$ | $\mu_{2+}$ | $\sigma$ | $\theta$ | $t_{0}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $30 / 06 / 1989$ | 816 | 59 | 97 | 12 | 43 | 177 |
| $20 / 06 / 1990$ | 521 | 57 | 95 | 12 | 66 | 188 |
| $09 / 06 / 1991$ | 655 | 59 | 97 | 12 | 79 | 162 |
| $12 / 06 / 1992$ | 851 | 62 | 99 | 12 | 72 | 136 |
| $05 / 07 / 1993$ | 334 | 62 | 99 | 12 | 73 | 158 |
| $06 / 07 / 1994$ | 599 | 62 | 99 | 10 | 84 | 164 |
| $22 / 06 / 1995$ | 458 | 59 | 97 | 11 | 73 | 172 |
| $23 / 05 / 1996$ | 367 | 54 | 93 | 12 | 84 | 183 |
| $14 / 06 / 1997$ | 457 | 62 | 99 | 11 | 81 | 142 |
| $23 / 06 / 1998$ | 386 | 66 | 101 | 11 | 55 | 117 |
| $04 / 06 / 1999$ | 375 | 58 | 97 | 12 | 87 | 158 |
| $29 / 05 / 2000$ | 231 | 53 | 93 | 10 | 77 | 192 |
| $15 / 06 / 2001$ | 148 | 54 | 94 | 10 | 82 | 201 |
| $29 / 05 / 2002$ | 272 | 55 | 94 | 10 | 75 | 180 |
| $28 / 05 / 2003$ | 499 | 60 | 97 | 10 | 60 | 140 |
| $29 / 04 / 2004$ | 340 | 55 | 94 | 10 | 69 | 151 |
| $03 / 05 / 2005$ | 232 | 55 | 94 | 12 | 37 | 155 |
| $30 / 07 / 2006$ | 306 | 61 | 98 | 12 | 91 | 195 |
| $31 / 05 / 2007$ | 339 | 56 | 95 | 11 | 66 | 170 |
| $27 / 05 / 2008$ | 207 | 58 | 97 | 12 | 69 | 151 |
| $12 / 05 / 2009$ | 238 | 52 | 93 | 9 | 72 | 180 |

Table 3.1.4: Maximum likelihood estimates of mean and standard deviation of carapace length (in mm) of agegroups $1^{+}$and $2^{+}\left(\mu_{1^{+}}, \mu_{2^{+}}\right.$and $\left.\sigma\right)$, proportion of age-group $1^{+}(\theta)$ and Von Bertalanffy adjustment parameter ( $t_{0}$ in days) from mid-year surveys data collected since 1989.

| Date | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| :---: | :---: | :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: |
| 1989 | 0 | 0 | 1 | 2 | 4 | 7 | 11 | 16 | 21 | 100 | 100 | 0 |
| 1990 | 0 | 0 | 1 | 3 | 7 | 13 | 21 | 30 | 38 | 100 | 100 | 0 |
| 1991 | 1 | 2 | 6 | 12 | 21 | 33 | 44 | 53 | 61 | 100 | 100 | 0 |
| 1992 | 1 | 4 | 8 | 15 | 23 | 33 | 42 | 50 | 56 | 100 | 100 | 0 |
| 1993 | 1 | 2 | 5 | 10 | 18 | 27 | 37 | 46 | 53 | 100 | 100 | 0 |
| 1994 | 0 | 1 | 2 | 7 | 16 | 30 | 45 | 57 | 67 | 100 | 100 | 0 |
| 1995 | 0 | 1 | 2 | 5 | 10 | 19 | 30 | 40 | 49 | 100 | 100 | 0 |
| 1996 | 0 | 1 | 4 | 10 | 19 | 32 | 44 | 55 | 64 | 100 | 100 | 0 |
| 1997 | 1 | 3 | 7 | 15 | 27 | 40 | 51 | 60 | 67 | 100 | 100 | 0 |
| 1998 | 1 | 2 | 4 | 9 | 15 | 22 | 29 | 36 | 41 | 100 | 100 | 0 |
| 1999 | 1 | 4 | 10 | 21 | 34 | 48 | 59 | 68 | 74 | 100 | 100 | 0 |
| 2000 | 0 | 0 | 0 | 2 | 5 | 12 | 22 | 35 | 47 | 100 | 100 | 0 |
| 2001 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 5 | 12 | 100 | 100 | 0 |
| 2002 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 13 | 100 | 100 | 0 |
| 2003 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 8 | 14 | 100 | 100 | 0 |
| 2004 | 0 | 0 | 0 | 0 | 1 | 2 | 5 | 9 | 17 | 100 | 100 | 0 |
| 2005 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 5 | 7 | 100 | 100 | 0 |
| 2006 | 0 | 0 | 0 | 1 | 3 | 8 | 16 | 28 | 41 | 100 | 100 | 0 |
| 2007 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 8 | 14 | 100 | 100 | 0 |
| 2008 | 0 | 0 | 0 | 1 | 3 | 5 | 10 | 16 | 24 | 100 | 100 | 0 |
| 2009 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 8 | 100 | 100 | 0 |

Table 3.1.5: Estimated proportion of age-group 1 lobster by year and month.

|  | Date | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 198 | 0 (0) | 456(13) | 474(35) | 499(51) | 502(67) | 518(81) | 531(94) | 557(106) | 571(121) | 595(135) | 634(149) | 694(157) |
|  | 1990 | 0 (0) | 438(8) | 470(26) | 485(46) | 504(61) | 521(75) | 534(88) | 547(102) | 561(117) | 585(130) | 612(145) | 672(154) |
|  | 1991 | $437(0)$ | 462(26) | 486(43) | $494(60)$ | $510(74)$ | 525(87) | 550(99) | 563(114) | 577(129) | 602(144) | 664(153) | 724(161) |
|  | 1992 | 463(22) | 479(42) | 496(57) | $514(71)$ | $527(84)$ | 541(98) | 553(112) | 579(126) | 606(141) | 654(151) | 716(160) | 776(168) |
|  | 1993 | 438(8) | 472(26) | 483(46) | 504(61) | 519(75) | $534(88)$ | 545(102) | 559(116) | 585(130) | $610(145)$ | 672(154) | 732(162) |
|  | 1994 | 0 (0) | 0 (0) | 453(17) | 478(34) | 494(48) | 508(61) | 518(74) | 530(87) | 554(99) | 566(115) | 626(122) | 684(129) |
|  | 1995 | 0 (0) | 440 (0) | 460(26) | 485(42) | 502(56) | 517(70) | 528(83) | 540(96) | 553(111) | 578(124) | 627(135) | 686(143) |
|  | 1996 | O(0) | 451(8) | 471(30) | $484(50)$ | $502(64)$ | 519(78) | 531(91) | 545(105) | 571(118) | 583(134) | 622(147) | 682(155) |
|  | 1997 | 440(0) | 462(26) | 483(42) | 502(56) | $515(69)$ | 528(83) | 538(96) | 564(109) | 578(124) | 625 (135) | 686(143) | 745(150) |
|  | 1998 | 462(22) | $486(38)$ | 501(53) | 504(69) | $528(80)$ | $541(93)$ | 552(107) | 577(121) | $615(133)$ | 674(141) | 735(149) | 795 (156) |
|  | 1999 | 438(8) | 472(26) | 483(46) | 504(61) | 519(75) | 534(88) | 545(102) | 559(116) | 585(130) | 610(145) | 672(154) | 732(162) |
|  | 2000 | 0 (0) | 0 (0) | 0 (0) | 460(17) | 470(37) | 488(51) | 499(63) | 511(76) | 536(88) | 546(102) | 572(115) | $629(122)$ |
|  | 20 | 0(0) | 0 (0) | 0 (0) | $0(0)$ | $0(0)$ | $0(0)$ | 663(22) | 700(38) | $712(57)$ | 717(72) | 737(85) | 754(97) |
|  | 20 | 0(0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | $665(10)$ | 689(33) | 704(52) | $712(68)$ | 731(81) | 751(93) | 766(105) |
|  | 2003 | 0(0) | 0 (0) | 0 (0) | 0 (0) | 663(22) | 700(38) | 710(57) | 717(72) | $737(85)$ | 754(97) | 771(110) | 787(123) |
|  | 2004 | 0(0) | 0 (0) | 0 (0) | 0 (0) | 660(10) | 687(33) | 699(52) | 725(65) | 729(80) | 746(93) | 764(105) | 780(119) |
|  | 20 | 0(0) | 0 (0) | 0 (0) | $663(22)$ | 690(44) | 709(63) | 737(77) | 746(93) | 769(107) | 771(122) | 791(136) | 809(151) |
|  | 20 | 0(0) | 0 (0) | 0 (0) | 0 (0) | 660(10) | $695(34)$ | 715(55) | 731(73) | 741(89) | 762(102) | 767(118) | 785(131) |
|  | 200 | 0(0) | 0 (0) | 0 (0) | 0(0) | 657(16) | 685(38) | 716(54) | 727(71) | $734(87)$ | 753(99) | 773(112) | 789(126) |
|  | 2008 | 0(0) | 0 (0) | 0 (0) | $675(22)$ | 701(44) | 720(64) | 730(81) | 756(94) | 761(110) | 780(123) | 800(137) | 817(152) |
|  | 2009 | 0(0) | 0 (0) | 0 (0) | $0(0)$ | $0(0)$ | $0(0)$ | 669(16) | 688(37) | 697(54) | 716(67) | 734(78) | 749(90) |

Table 3.1.6: Estimated mean weight (in grams) and standard deviation (between parentheses) of age-group $1^{+}$lobster ( $W_{1^{+}}$) caught by year and month.

|  | Date | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1989 | 756(166) | 816(174) | 875(181) | 937(189) | 997(197) | 1058(204) | 1117(211) | 1176(218) | 1235(225) | 1291(231) | 1347(237) | 1400(243) |
|  | 1990 | 734(163) | 794(171) | 853(178) | 915(186) | 975(194) | 1037(201) | 1095(208) | 1155(215) | 1214(222) | 1270(229) | 1327(235) | 1381(241) |
|  | 1991 | 786(170) | 847(178) | 905(185) | 967(193) | 1027(200) | 1088(208) | 1146(214) | 1205(221) | 1263(228) | 1318(234) | 1374(240) | 1426(246) |
|  | 1992 | 839(177) | 899(184) | 957(192) | 1019(199) | 1078(206) | 1138(213) | 1195(220) | 1254(227) | 1311(233) | 1365(239) | 1419(245) | 1471(250) |
|  | 1993 | 794(171) | 855(179) | 913(186) | 975(194) | 1035(201) | 1095(208) | 1153(215) | 1212(222) | 1270(229) | 1325(235) | 1381(241) | 1433(246) |
|  | 1994 | 744(136) | 803(142) | 860(149) | 920(155) | 978(161) | 1038(167) | 1094(173) | 1152(178) | 1209(184) | 1262(189) | 1317(194) | 1368(199) |
|  | 1995 | 747(150) | 807(158) | 864(165) | 926(172) | 985(178) | 1045(185) | 1103(191) | 1161(198) | 1219(204) | 1274(209) | 1329(215) | 1381(220) |
|  | 1996 | 744(164) | 804(172) | 863(180) | 925(188) | 985(195) | 1046(203) | 1105(210) | 1165(217) | 1224(223) | 1280(230) | 1336(236) | 1389(242) |
|  | 1997 | 807(158) | 866(165) | 924(171) | 985(178) | 1043(185) | 1103(191) | 1159(197) | 1217(203) | 1274(209) | 1327(215) | 1381(220) | 1432(225) |
|  | 1998 | 856(164) | 916(171) | 973(177) | 1033(184) | 1091(190) | 1150(196) | 1206(202) | 1263(208) | 1318(214) | 1371(219) | 1424(224) | 1474(229) |
|  | 1999 | 794(171) | 855(179) | 913(186) | 975(194) | 1035(201) | 1095(208) | 1153(215) | 1212(222) | 1270(229) | 1325(235) | 1381(241) | 1433(246) |
|  | 2000 | 690(130) | 748(136) | 805(143) | 866(149) | 924(155) | 984(162) | 1041(167) | 1100(173) | 1157(179) | 1212(184) | 1268(189) | 1320(194) |
|  | 2001 | 771(110) | 787(123) | 801(138) | 848(147) | 907(154) | 967(160) | 1024(166) | 1083(172) | 1141(177) | 1196(183) | 1252(188) | 1304(193) |
|  | 2002 | 784(119) | 800(133) | 829(145) | 889(152) | 947(158) | 1007(164) | 1064(170) | 1122(175) | 1179(181) | 1234(186) | 1289(191) | 1341(196) |
|  | 2003 | 805(138) | 850(148) | 907(154) | 967(160) | 1024(166) | 1083(172) | 1139(177) | 1196(183) | 1252(188) | 1304(193) | 1358(198) | 1408(202) |
|  | 2004 | 798(133) | 829(145) | 885(151) | 945(158) | 1003(164) | 1062(170) | 1119(175) | 1176(181) | 1232(186) | 1285(191) | 1339(196) | 1390(201) |
|  | 2005 | 843(164) | 861(180) | 919(187) | 981(195) | 1041(202) | 1101(209) | 1159(216) | 1218(223) | 1276(229) | 1331(235) | 1386(241) | 1438(247) |
|  | 2006 | 805(146) | 823(161) | 853(174) | 901(185) | 961(192) | 1023(200) | 1082(207) | 1142(214) | 1201(221) | 1257(227) | 1314(233) | 1368(239) |
|  | 2007 | 808(140) | 825(155) | 868(165) | 930(172) | 989(179) | 1049(186) | 1106(192) | 1165(198) | 1223(204) | 1277(210) | 1333(215) | 1385 (221) |
|  | 2008 | 837(167) | 869(181) | 927(188) | 989(196) | 1048(203) | 1109(210) | 1167(217) | 1226(223) | 1283(230) | 1338(236) | 1393(242) | 1445(248) |
|  | 2009 | 766(103) | 781(117) | 809(129) | 869(134) | 926(140) | 985(145) | 1041(150) | 1099(156) | 1155(160) | 1209(165) | 1263(170) | 1315(174) |

Table 3.1.7: Estimated mean weight (in grams) and standard deviation (between parentheses) of age-group $2^{+}$lobster ( $W_{2^{+}}$)
caught by year and month.

|  | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 2006 | $1175(429)$ | $999(326)$ | $1135(479)$ | NA(NA) | $1168(428)$ | $1320(531)$ | $1235(509)$ | NA(NA) |
| 2007 | $895(324)$ | $876(246)$ | NA(NA) | NA(NA) | NA(NA) | NA(NA) | NA(NA) | NA(NA) |
| 2008 | NA(NA) | NA(NA) | $968(334)$ | $1014(342)$ | $1031(383)$ | $994(263)$ | NA(NA) | $1018(295)$ |
| 2009 | NA(NA) | $974(285)$ | $1036(466)$ | $1010(343)$ | $958(236)$ | $1260(467)$ | $1272(418)$ | $1138(375)$ |

Table 3.1.8: Mean weight, in grams, and standard deviation (between parentheses) of lobsters caught by year and month. Data from MG Kailis Group.

| Date | Nb $1+$ | Nb 2+ | Percentage of $2+$ |
| :---: | ---: | ---: | :---: |
| 1994 | 46341 | 112691 | 71 |
| 1995 | 22882 | 82949 | 78 |
| 1996 | 64720 | 191318 | 75 |
| 1997 | 95654 | 221351 | 70 |
| 1998 | 63841 | 297060 | 82 |
| 1999 | 43391 | 100095 | 70 |
| 2000 | 16584 | 133605 | 89 |
| 2001 | 1051 | 79162 | 99 |
| 2002 | 4405 | 146354 | 97 |
| 2003 | 10887 | 339088 | 97 |
| 2004 | 12368 | 473730 | 97 |
| 2005 | 6542 | 537902 | 99 |
| 2006 | 11849 | 134619 | 92 |
| 2007 | 4314 | 275874 | 98 |
| 2008 | 6953 | 101057 | 94 |
| 2009 | 646 | 109018 | 99 |

Table 3.1.9: Estimated lobster number at age caught each year by Transferable Vessel Holders (TVH) licensee.

| Date | Nb 1+ | Nb 2+ | Percentage of 2+ |
| :---: | :---: | :---: | :---: |
| 2004 | 5743 | 238037 | 98 |
| 2005 | 4439 | 366085 | 99 |
| 2006 | 6445 | 158193 | 96 |
| 2007 | 5471 | 288543 | 98 |
| 2008 | 7085 | 215273 | 97 |
| 2009 | 1401 | 145480 | 99 |

Table 3.1.10: Estimated lobster number at age caught each year by Traditional Inhabitant (TIB) licensee.

| Date | Nb 1+ | Nb 2+ | Percentage of 2+ |
| :---: | :---: | :---: | :---: |
| 1989 | 5909 | 94708 | 94 |
| 1990 | 11777 | 94024 | 89 |
| 1991 | 27039 | 81812 | 75 |
| 1992 | 25486 | 78228 | 75 |
| 1993 | 21987 | 83550 | 79 |

Table 3.1.11: Estimated lobster number at age caught each year by Transferable Vessel Holders (TVH) licensee.

| Year | Nb 1+ | Nb 2+ | Percentage of 2+ |
| ---: | ---: | ---: | ---: |
| 1989 | 52354 | 839113 | 94 |
| 1990 | 76327 | 609370 | 89 |
| 1991 | 165506 | 500771 | 75 |
| 1992 | 142008 | 435886 | 75 |
| 1993 | 147687 | 561205 | 79 |
| 1994 | 285239 | 693638 | 71 |
| 1995 | 184393 | 668438 | 78 |
| 1996 | 231538 | 684446 | 75 |
| 1997 | 300085 | 694421 | 70 |
| 1998 | 154653 | 719620 | 82 |
| 1999 | 197188 | 454876 | 70 |
| 2000 | 83303 | 671108 | 89 |
| 2001 | 4513 | 339944 | 99 |
| 2002 | 17432 | 579186 | 97 |
| 2003 | 21103 | 657287 | 97 |
| 2004 | 22791 | 891016 | 98 |
| 2005 | 13718 | 1129018 | 99 |
| 2006 | 30757 | 434411 | 93 |
| 2007 | 13414 | 796518 | 98 |
| 2008 | 36087 | 636799 | 95 |
| 2009 | 2791 | 380034 | 99 |

Table 3.1.12: Estimated lobster number at age caught each year in Torres Strait by Australia and Papua New Guinea.

# Appendix 3.2: analysis of catch per unit of effort 

### 3.2.1 Introduction

A Generalised Linear Model (GLM) of a subset of the Transferable Vessel Holder (TVH) licence catch and effort data currently provides an index of lobster abundance in Torres Strait which was shown to be proportional to abundance estimates from the fishery-independent survey data (Ye and Dennis, 2009; Ye et al, 2007). This was shown to be proportional to abundance estimates from the fishery-independent survey data, thereby increasing confidence in the utility of these data as an index of stock abundance. The data subset included 15 licences out of a total of 39 that were selected based on duration of use (they had been used in the fishery for at least 6 years) and median catch level (in excess of 4 tons of lobsters per year).

In 2009, the size of this subset decreased to 7 licences following a voluntary surrender of licences owned by Australian fishermen to meet Australia's obligation under the Torres Strait Treaty (Wilson et al, 2009). In light of this, the RAG raised concern that further subset size reduction might provide a dataset too small to draw any valid conclusions and recommended a review of the current method.

This chapter summarises results of investigating the effect of subsetting the dataset for CPUE analysis. This involved comparison of characteristics of this subset with those of the entire dataset and a sensitivity analysis of the relationship between commercial and survey abundance indices to variation of subsetting criteria was performed. Finally, an analysis of catch per unit of effort data, that relies on the entire dataset, was described to provide an alternative to the current GLM analysis.

### 3.2.2 Method

Data A small fleet of non-traditional freezer vessels can exploit lobster in Torres Strait using a Transferable Vessel Holder licence. This licence can be bought and sold with or without a boat (Queensland Government, 2010). Each licence is valid for a specific size category of vessel. A licence can be used on several vessels each year providing it is done one at a time. Moreover, when a licence owner replaces his/her vessel, he keeps the same fishing licence. The licence identification, also known as the distinguishing symbol, thus do not identify a specific vessel or person.

Vessels travel to the fishing ground on trips lasting from a few days to several weeks (Wilson et al, 2009). The divers usually work in pairs from dinghies (tenders or service vessels) that are about 5 m long. Each vessel carries between 1 and 14 tenders. Divers either free-dive or use hookah gear to spear rock lobster (Panulirus ornatus). The hookah gear supplies compressed air via a hose from the dinghy to the diver. This system allows the diver to reach greater depths and spend a longer duration on the seabed while fishing. Hookah diving dominates the TVH sector, especially in recent years (Table 3.2.1). We restricted the focus of this study to data reported as hookah diving catch. The total number of TVH licences granted in this fishery was 39. The median number of years each licence was used in this fishery was 9 years. Since 1994, between 11 and 25 TVH licence holders reported catch by day for each tender they used. Total landings from the TVH sector varied between 70 and 545 tons per year (Figure 3.2.1 and Table 3.2.2). Effort varied between 1700 and 6700 tender-days per year. The median catch per licence per year was 7.4 tons.

In previous studies, the current abundance index from commercial data was obtained using a subset of 15 licences that were chosen according to the following criteria (1) they were used in the fishery for at least 6 years and (2) median catches equaled or exceeded 4 tons of lobsters each year. Sub-samples represented between 50 and $67 \%$ of the total number of licences used each year (Table 3.2.3).

Analysis of catch per unit of effort The GLM approach with subsetting was reviewed and alternative approaches, that used the whole dataset, investigated. The latter approaches included (1) a (statistical) modelfree approach that used the ratio of catch (in kg ) to effort (in tender-days) as an index of abundance and (2) a linear model of the catch as a function of effort, on the log-scale, fitted to all the data grouped by vessel and year where the intercept, also referred as the "year effect", was used as an annual index of abundance.

Effect of subsetting The rational for excluding approximately $17 \%$ of the catch and effort records from the GLM analysis was that they would lead to an unnecessarily over-parameterized model and those licences used for one or two years contribute more noise than signal to the analysis (Ye and Dennis, 2009; Ye et al, 2007). Catch, in kg, and effort, in tender-days, data from this subset were compared to the entire dataset. The influence of subsetting on the coefficients of a linear regression between catch and effort (on the log-scale) was assessed.

Furthermore, the influence of various subsetting criteria on the relationship between the commercial index of abundance and survey estimates of age-group $2+$ densities was assessed using a coefficient of correlation ( $\rho$ ). It was equal to 0.83 for the GLM based index. A sensitivity analysis of this coefficient to the criteria of inclusion of licences in the GLM subset was performed by varying, in both directions, (1) the number of years that licences were used in the lobster fishery and (2) the median landing (in tons) reported in the logbook.

### 3.2.3 Results

Effect of subsetting A plot of the total catch (in kg) against the total effort (in number of tender-days), on the log-scale, per licence per year (Fig. 3.2.2) showed that the range of log-catch and log-effort by year were often much narrower for the subset than for the whole dataset. A linear regression fitted to the data showed that they provided a good fit to the data. Estimates of intercepts and slopes of the regressions tended to be similar when the subset provided a good coverage of the entire dataset. On the other-hand, they tended to diverge when the subset included licences displaying larger catch and effort values. Model parameter estimates were sensitive to the choice of data subset they were fitted to: the smaller their size and the narrower their coverage, the larger the deviation from the regression to the whole dataset. Comparison of log-CPUE between subset and all the data showed that they were very similar. The only difference was that, in some cases, the range of logCPUE in the subset was smaller: subsetting had, in some years, reduced the variability of log-CPUE (Fig. 3.2.3).

To assess the influence of various subsetting criteria, we computed the correlation coefficient between commercial index of abundance and survey estimates of age-group 2+ densities (Ye et al, 2007) (Table 3.2.5 and Fig. 3.2.5). The analysis of the sensitivity of this coefficient to the choice of subsetting criteria showed (Table 3.2.4) that

- the correlation was high for all cases $(0.70 \leq \rho \leq 0.85)$.
- larger threshold values produced larger correlations.
- the correlation coefficient was more sensitive to variation in median landing per year than number of years in the fishery: for 5 tons or more, it became in-sensitive to the number of year each licence was used in the fishery.
- substituting a threshold value for years in the fishery $\geq 6$ produced similar results.

The sensitivity analysis showed that increasing threshold values tended to increase, up to a certain point, the correlation between the GLM-based index of abundance and the survey estimates of density.

Alternative abundance indices As an alternative method to calculate an index of abundance from catch and effort data, using the whole dataset, we calculated the ratio of catch (in kg ) to effort (in tender-days). This model-free index of abundance correlated marginally better $(\rho=0.84)$ than the GLM analysis to the survey estimates (Table 3.2.5 and Figure 3.2.5).

As a second alternative to derive an index of abundance, linear regressions were applied to the entire dataset as they were shown to fit the data well (Figure 3.2.2). An analysis of co-variance (p. 62) showed that slopes could be assumed to be equal between years: in other words, the relation between catch and effort hasn't changed between years but the relative apparent abundance (Marr, 1951) has. The linear model explained $88 \%$ of the variability of log-catch between vessels (p. 62). Model fit diagnostics suggested that residuals tended to increase with decreasing level of effort (Fig 3.2.4): CPUE variability was larger between vessels with lower level of effort. Intercepts estimated for each year were used as an indices of abundance: its correlation to age-group $2+$ density estimates from survey was as good as for the GLM ( $\rho=0.83$ ) using the time series 1994-2007 (Table 3.2.5 and Figure 3.2.5) and was equal to 0.76 using the time series $1994-2009$ (Table 3.2.6).

### 3.2.4 Discussion

Survey density estimates were compared to a relative apparent abundance index provided by (1) Ye et al (2007)'s GLM to a subset of the data; (2) a ratio of total catch over total effort from all data grouped by year; and (3) a linear model of all the data in the interests of evaluating the more complex statistical method combined with data subsetting as applied by Ye and Dennis (2009). The performance of these methods, in terms of correlation with the survey, were found to be very similar. Both the model-free and LM are more general because they were applied to the whole dataset.

The size of the licence sub-sample has always been at least $50 \%$ of the total number of licences used annually. The fraction of licences included in the sub-sample has not declined since the voluntary surrender of licences that took place in 2007. However, given uncertainties around future changes, the reduction in the total number of licences and the comparisons presented in this document, we propose that the full data set be used to compute an index of abundance based on CPUE information.

## References

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Wilson D, Curtotti R, Begg G, Phillips K (eds) (2009) Fishery status report 2008: status of fish stocks and fisheries managed by the Australian Government. Bureau of Rural Sciences \& Australian Bureau of Agricultural and Resource Economics, Canberra

Ye Y, Dennis D (2009) How reliable are the abundance indices derived from commercial catch-effort standardization? Can J Fish Aquat Sci 66:1169-1178

Ye Y, Dennis D, Skewes T, Brewer D, Haywood M, McLeod I, Wassenberg T, Pillans R, Chetwynd D, Dell Q, Coman G (2007) 2007 relative abundance survey and assessment of the Torres Strait lobster fishery. Tech. Rep. AFMA Project Number: 2007/802, CSIRO


Figure 3.2.1: Tons of lobster landed by TVH licencee (vertical bars, left-hand scale) and number of tender-days fished by year (filled circles, right-hand scale).


Figure 3.2.2: Relationship between log of lobster catch and log of effort, measured in number of tender-day, by year for all TVH vessels fishing with hookah. The black dots represent the subset of vessel used to estimate an index of abundance (Ye et al, 2007). The grey line represent a fitted regression to the whole dataset and the black line to the subset of vessels.


Figure 3.2.3: Comparison of CPUE between subset and whole dataset grouped by year.


Figure 3.2.4: Diagnostic plot of a log-log CPUE model assuming a year effect.


Figure 3.2.5: Comparison between three abundance indices and the survey-based density estimates of age-group $2^{+}$. Each time-serie was scaled (centered around its mean and expressed in units of its standard deviation) to allow for the comparison.

|  | DI | DIF | DIH | DIU |
| ---: | ---: | ---: | ---: | ---: |
| 1994 | 1 | 6 | 95 | 31 |
| 1995 | 1 | 2 | 63 | 34 |
| 1996 | 1 | 2 | 119 | 105 |
| 1997 | 0 | 13 | 161 | 111 |
| 1998 | 4 | 19 | 217 | 116 |
| 1999 | 1 | 2 | 107 | 16 |
| 2000 | 0 | 5 | 115 | 11 |
| 2001 | 3 | 1 | 31 | 35 |
| 2002 | 0 | 0 | 98 | 50 |
| 2003 |  | 2 | 356 | 3 |
| 2004 | 0 | 6 | 475 |  |
| 2005 | 0 | 18 | 526 |  |
| 2006 | 0 | 5 | 130 |  |
| 2007 |  | 3 | 269 |  |
| 2008 |  | 1 | 111 |  |
| 2009 |  | 1 | 98 |  |

Table 3.2.1: Annual lobster landings (tons) obtained when using each of the different methods as shown (DI: diving, DIU: unknown diving, DIH: hookah diving and DIF: free diving).

| Year | Nb of vessels | Nb of licences | Landings tons | Nb of tender day | Catch tender day kg |
| ---: | ---: | ---: | ---: | ---: | ---: |
| 1994 | 13 | 13 | 134 | 2685 | 50 |
| 1995 | 14 | 14 | 101 | 1699 | 59 |
| 1996 | 20 | 20 | 227 | 4004 | 57 |
| 1997 | 23 | 23 | 285 | 4567 | 62 |
| 1998 | 26 | 25 | 356 | 6568 | 54 |
| 1999 | 21 | 17 | 126 | 2877 | 44 |
| 2000 | 15 | 21 | 130 | 3043 | 43 |
| 2001 | 17 | 17 | 70 | 2024 | 35 |
| 2002 | 22 | 21 | 148 | 4142 | 36 |
| 2003 | 22 | 24 | 362 | 5329 | 68 |
| 2004 | 22 | 23 | 545 | 6668 | 72 |
| 2005 | 21 | 21 | 135 | 5027 | 108 |
| 2006 | 15 | 14 | 111 | 3169 | 43 |
| 2007 | 11 | 11 | 99 | 1960 | 70 |
| 2008 |  |  | 2255 | 57 |  |
| 2009 |  |  |  | 44 |  |

Table 3.2.2: Summary of the transferable vessel holder licence logbooks

| Year | Number of licence | Fraction of total nb of licence |
| :--- | ---: | ---: |
| 1994 | 8 | 62 |
| 1995 | 9 | 64 |
| 1996 | 12 | 60 |
| 1997 | 14 | 61 |
| 1998 | 14 | 56 |
| 1999 | 10 | 59 |
| 2000 | 12 | 57 |
| 2001 | 8 | 50 |
| 2002 | 10 | 59 |
| 2003 | 14 | 67 |
| 2004 | 15 | 62 |
| 2005 | 13 | 57 |
| 2006 | 12 | 60 |
| 2007 | 12 | 57 |
| 2008 | 8 | 57 |
| 2009 | 7 | 64 |

Table 3.2.3: Size of the sub-sample used in Ye et al (2007)'s analysis.

|  | years |  |  |  |  |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| tons | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 0 | 0.71 | 0.71 | 0.70 | 0.70 | 0.73 | 0.72 | 0.80 | 0.80 | 0.80 |
| 1 | 0.72 | 0.72 | 0.72 | 0.72 | 0.75 | 0.74 | 0.82 | 0.82 | 0.82 |
| 2 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.73 | 0.78 | 0.78 | 0.78 |
| 3 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.73 | 0.77 | 0.77 | 0.78 |
| 4 | 0.80 | 0.80 | 0.80 | 0.80 | 0.81 | 0.82 | 0.83 | 0.83 | 0.84 |
| 5 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.84 | 0.84 | 0.84 |
| 6 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |

Table 3.2.4: Correlation coefficient between survey and commercial indices of abundance for different values of number of years (columns) and median catch per year (rows).

|  | GLM | Survey | Model free | LM |
| ---: | ---: | ---: | ---: | ---: |
| GLM | 1.00 | 0.83 | 0.95 | 0.90 |
| Survey | 0.83 | 1.00 | 0.84 | 0.83 |
| Model free | 0.95 | 0.84 | 1.00 | 0.95 |
| LM | 0.90 | 0.83 | 0.95 | 1.00 |

Table 3.2.5: Correlation between 3 methods to estimate abundance using data from 1994 to 2007.

|  | Survey | Model free | LM |
| ---: | ---: | ---: | ---: |
| Survey | 1.00 | 0.80 | 0.76 |
| Model free | 0.80 | 1.00 | 0.95 |
| LM | 0.76 | 0.95 | 1.00 |

Table 3.2.6: Correlation between 3 methods to estimate abundance using data from 1994 to 2009.

## Analysis of co-variance

```
Analysis of Variance Table
Response: log(CATCH)
\begin{tabular}{lrrrrrl} 
& Df & Sum Sq Mean Sq & F value \(\operatorname{Pr}(>F)\) \\
YEAR & 15 & 128.27 & 8.55 & \(26.9090<2 \mathrm{e}-16 * * *\) \\
log(EFFORT) & 1 & 604.08 & 604.08 & 1900.8321 & \(<2 \mathrm{e}-16 * * *\) \\
YEAR:log(EFFORT) & 15 & 3.44 & 0.23 & 0.7216 & 0.7621 \\
Residuals & 271 & 86.12 & 0.32 & & & \\
--- & & & & & & \\
Signif. codes: & 0 & \(* * *\) & \(0.001 * *\) & \(0.01 *\) & 0.05 & 0.1
\end{tabular}
```

Parameters of a simple linear model

Call:
$\operatorname{lm}(f o r m u l a=\log (C A T C H) ~ \sim ~ Y E A R ~+~ l o g(E F F O R T), ~ d a t a ~=~ d f 1) ~$

Residuals:

| Min | 1Q | Median | 3Q | Max |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| -2.32642-0 | .308690 | $0.02627 \quad 0.40$ | 5031.4 | 46246 |  |
| Coefficients: |  |  |  |  |  |
|  | Estimate Std. Error t value $\operatorname{Pr}(>\|\mathrm{t}\|)$ |  |  |  |  |
| (Intercept) | 3.25561 | 10.19619 | 16.594 | < 2e-16 | *** |
| YEAR1995 | 0.19218 | $8 \quad 0.22019$ | 0.873 | 0.3835 |  |
| YEAR1996 | 0.19882 | $2 \quad 0.20639$ | 0.963 | 0.3362 |  |
| YEAR1997 | 0.13792 | $2 \quad 0.20262$ | 0.681 | 0.4966 |  |
| YEAR1998 | 0.10654 | $4 \quad 0.19821$ | 0.538 | 0.5913 |  |
| YEAR1999 | -0.03770 | $0 \quad 0.20861$ | -0.181 | 0.8567 |  |
| YEAR2000 | -0.28377 | $7 \quad 0.20273$ | -1.400 | 0.1627 |  |
| YEAR2001 | -0.48917 | $7 \quad 0.21746$ | -2.249 | 0.0252 | * |
| YEAR2002 | -0.42212 | $2 \quad 0.21132$ | -1.998 | 0.0467 | * |
| YEAR2003 | 0.21112 | 20.20300 | 1.040 | 0.2992 |  |
| YEAR2004 | 0.25106 | $6 \quad 0.19640$ | 1.278 | 0.2022 |  |
| YEAR2005 | 0.79679 | $9 \quad 0.19695$ | 4.046 | 6.72e-05 | *** |
| YEAR2006 | -0.15557 | $7 \quad 0.20083$ | -0.775 | 0.4392 |  |
| YEAR2007 | 0.37011 | $1 \quad 0.20279$ | 1.825 | 0.0690 | . |
| YEAR2008 | 0.20609 | $9 \quad 0.21371$ | 0.964 | 0.3357 |  |
| YEAR2009 | -0.24155 | $5 \quad 0.23432$ | -1.031 | 0.3035 |  |
| $\log$ (EFFORT) | 1.11889 | 90.02548 | 43.920 | < 2e-16 | *** |

Signif. codes: 0 *** $0.001 * * 0.01 * 0.05$. 0.11
Residual standard error: 0.5596 on 286 degrees of freedom
Multiple R-squared: 0.891,Adjusted R-squared: 0.8849
F-statistic: 146.2 on 16 and 286 DF, p-value: < $2.2 \mathrm{e}-16$

# Appendix 3.3: Length-based estimates of Von Bertalanffy's parameters for Torres Strait rock lobster (Panulirus ornatus) 

### 3.3.1 Introduction

The Torres Strait stock assessment currently requires Von Bertalanffy growth function (VBGF) parameters to convert numbers at age into biomass (Ye et al, 2008). Growth parameters were estimated by Phillips et al (1992) from mark-recapture data collected between 1981 and 1986 (Trendall et al, 1988). Since then, no additional tagging experiment has been conducted. Instead, length frequency distributions have been collected each year since 1989, during scientific surveys designed to estimate lobster abundance in Torres Strait (Ye et al, 2005; Pitcher et al, 1992). These data showed variation of length at age in time and space (Skewes et al, 1997a) but were never used to estimate VBGF parameters.

Finite mixture distributions is a well documented topic (Everitt and Hand, 1981) previously applied in fishery research to estimate growth parameters from length frequency data (Fournier et al, 1990). The distribution of length for each cohort is modeled as a normal distribution and their superposition is fitted by maximum likelihood assuming mean length at age follows a Von Bertalanffy growth function (Von Bertalanffy, 1957). This likelihood method was shown to provide the same parameter estimates than those from tag return data at a fraction of the cost of a mark-recapture experiment. A mixture model (Venables and Ripley, 2003) was applied to all lobster length frequency data collected since 1989 to estimate VBGF parameters by maximum likelihood. Several models describing specific assumptions about sex and cohort-specific variation in growth were compared to determine which hypothesis was most supported by the data.

### 3.3.2 Data and method

Length frequency data The population of rock lobster (Panulirus ornatus) in Torres Strait has a peculiar spawning behaviour characterized by an annual emigration, in which juvenile lobsters walk 500 km North-East into the Gulf of Papua New Guinea to breed around Yule Island (Moore and MacFarlane, 1984). They start to migrate at an age of 2.5 years but a fraction of males postpone their departure for one or more years (Skewes et al, 1997b; Trendall et al, 1988). Since 1989, population abundance was estimated using a visual census survey (Pitcher et al, 1992) during which length frequency distributions were collected. Tail width (TW) of a sample of lobsters were measured annually in May-June between 1989 and 2009. In addition, four Length Frequency Distributions (LFD) were collected in November between 2005 and 2008. These mixture distributions are bi-modal.

9871 TW measurements (Tab. 3.3.1), in mm, were converted into carapace length (CL, in mm) to work with body size measurements consistent with Phillips et al (1992) and allow for comparisons. Three allometric relationships, estimated from over 10.000 measurements (unpublished data), were used to convert TW: the first two are sex-specific while the last was estimated combining data from both sexes

For females

$$
\begin{equation*}
\mathrm{CL}=1.371 \times \mathrm{TW}+2.485 \tag{1}
\end{equation*}
$$

For males

$$
\begin{equation*}
\mathrm{CL}=1.493 \times \mathrm{TW}-0.132 \tag{2}
\end{equation*}
$$

For both sexes combined

$$
\begin{equation*}
\mathrm{CL}=1.433 \times \mathrm{TW}+1.089 \tag{3}
\end{equation*}
$$

Mixture model Each LFD displayed a clear bi-modal distribution. They were assumed to represent two groups of individuals with an age difference of one year. Each LFD was fitted with a mixture of two Gaussian distributions to estimate mean carapace length ( $\mu$, in mm ) and standard deviation ( $\sigma$, in mm) of each age-group as well as the proportion $(p)$ of measurements belonging to the first age-group. Furthermore, mean carapace length was assumed to follow a Von Bertalanffy (1957) growth equation

$$
\begin{equation*}
\mu_{j}=\mathrm{L}_{\infty}\left[1-\exp \left(-k \times\left(t-t_{0}\right)\right)\right] \tag{4}
\end{equation*}
$$

where age ( $t$, in days) of individuals belonging to a particular age-group ( $j=0,1$ or 2 ) was assumed to be equal to the sum of (a) the day of the year corresponding to the middle date of each survey and (b) a multiple of 365 days consistent with the age group $(j)$.

Parameter estimates were obtained by maximizing the log-likelihood function given by Venables and Ripley (2003) :

$$
\begin{equation*}
L=\sum_{s=1}^{q} \sum_{i=1}^{n} \log \left(\frac{p_{s}}{\sigma_{s, j}} \phi\left(\frac{l_{s, i}-\mu_{s, j}}{\sigma_{s, j}}\right)+\frac{1-p_{s}}{\sigma_{s, j+1}} \phi\left(\frac{l_{s, i}-\mu_{s, j+1}}{\sigma_{s, j+1}}\right)\right) \tag{5}
\end{equation*}
$$

where $\phi$ represents the density of a normal distribution; $i$ a particular measurement; $j$ denotes age-groups with $j=0$ when fitting a sample collected in November and $j=1$ when fitting a sample collected in April-July. Finally, $n$ is the number of measurements and $q$ the number of survey samples $(1 \leq s \leq 25)$.

Several models were fitted to investigate which assumptions were best supported by the data. The simplest model assumed constant growth throughout the whole time series. It was fitted to data grouped by sex (156 parameters) or not ( 78 parameters) to evaluate the hypothesis of growth sexual dismorphism using a likelihood ratio test. A more complex model that assumes the VBGF parameter $t_{0}$ is cohort specific ( 22 cohorts in total, Tab. 3.3.2) was fitted to all data grouped by sex (198 parameters). Similarly, the hypothesis that growth rate $(k)$ varies between cohorts was investigated through fitting a model with 198 parameters.

VBGF parameters comparison Phillips et al (1992) provided point estimates of VBGF parameters, $\mathrm{L}_{\infty}$ and $k$, using 129 lobsters tagged between 1980 and 1983 (Bell et al, 1987). These were compared to current model estimates that assumed constant growth fitted to all length frequency data. The comparison was done using the log-likelihood function to draw a confidence region, in the plane $\left(\mathrm{L}_{\infty}, k\right)$, around the best estimates (Brandt, 1998). The boundary of this region was set using the $95 \%$ quantile of the $\chi^{2}$ distribution with (5030 $-78)$ and (4837-78) degrees of freedom, respectively for female and male, to determine whether Phillips et al (1992)'s differed significantly.

### 3.3.3 Results

The hypothesis of growth sexual dimorphism in Torres Strait lobster was investigated with model selection based on a likelihood ratio test. The minimum negative log-likelihood value was smaller for the model that assumed sexual dimorphism (Tab. 3.3.5). A likelihood ratio test $\left(\chi_{78 \mathrm{df}}^{2}=242, \mathrm{P}=0\right)$ supported the hypothesis of sexual dimorphism. $L_{\infty}$ was estimated to be larger for males than for females (Tab. 3.3.6), although the difference is smaller than 2 standard deviations (S.D.). Growth rate ( $k$ ) estimates were similar for both sexes, of the order of magnitude of 0.3 year ${ }^{-1}$. The location parameter $\left(t_{0}\right)$ estimates indicated that lobster lengths are negligibly small from mid-April to mid-May. Sex-specific estimates of $\mathrm{t}_{0}$ are within 2 S.D. of each other. These results indicated a small difference of caparace length at age between sex, with males being slightly larger than females (Fig 3.3.7).

Models that assumed growth varied between cohorts were found to better fit the data than those that assumed constant growth throughout the whole time series (Tab. 3.3.5). The smallest negative log-likelihood value was found assuming the growth rate parameter $(k)$ was cohort- and sex-specific. Figures 3.3.1-3.3.4 compare mixture distribution fits obtained using three main assumptions (1) constant growth for all cohorts; (2) cohort-specific variation of settlement time (using variable $\mathrm{t}_{0}$ ); and (3) cohort-specific variation of growth rate $(k)$.

Estimates of cohort-specific $t_{0}$ were systematically larger for males than females (Fig. 3.3.5). This result is rather counterintuitive for a population that depends on the Coral Sea gyre to redistribute larvae from the spawning ground to the Torres Strait, a process which is unlikely to be sex-selective. Sex and cohort-specific estimates of $k$ varied consistently through time (Fig. 3.3.6). Estimates of female growth rates were systematically larger than male. But the uncertainty associated with these estimates was estimated to exceed the growth rate difference between sexes.

VBGF parameter estimates were compared to Phillips et al (1992)'s estimates of $\mathrm{L}_{\infty}$ and $k$ by drawing, in the $\left(\mathrm{L}_{\infty}, k\right)$ plan, a $95 \%$ confidence region around the best estimates of the model that assumed constant growth through time. This comparison showed that both female and male sets of VBGF parameters estimated by Phillips et al (1992) fell within the $95 \%$ confidence region (Fig. 3.3.8) indicating that estimation from LFDs did not differ significantly from those estimated using tagging data collected between 1980 and 1983.

### 3.3.4 Discussion

Results from this analysis of length frequency data to estimate VBGF parameters are consistent with Trendall et al (1988) who found that "there was little difference between the growth of male and female lobsters until a size of approximately 120 mm CL, after which male lobsters grew to a larger size than females". Compared to point estimates reported by Phillips et al (1992), $\mathrm{L}_{\infty}$ estimates from this analysis are approximately $20-30 \%$ larger and $k$ approx. $30-50 \%$ smaller. The comparison between these two pairs of parameters using a $95 \%$ confidence region drawn around the maximum likelihood parameters showed that they were not significantly different.

Von Bertalanffy (1957) created a model that describes the variation of size of organisms with indefinite growth and represented the sizes reached by the oldest individual using the asymptotic length $\mathrm{L}_{\infty}$. The present dataset described this feature poorly because all sexually mature adults died after the exhausting 500 km long migration towards their spawning ground. This lack of data describing the asymptote of the model translates into $\mathrm{L}_{\infty}$ estimates with large uncertainty. Since the three parameters are correlated in the estimation process,
missing information to characterize one aspect of the model translates into large uncertainty in other aspects of the model, such as growth rate $(k)$. More precise estimates of growth rates could be estimated using an alternative model that focuses on the observed data. Lack of data that describe $\mathrm{L}_{\infty}$ is very common in fishery research. This includes the cases of studies involving over-exploited stocks where mortality rates are so high that the chance of individuals surviving until older ages and larger sizes is too low for these age/size classes to be observed.

An attempt to fit a mixture of 3 Gaussians to each length frequency distribution resulted in un-realistic results: in most cases, the third mode was estimated to lie inbetween two clearly visible modes, whereas it was expected to fit to a range of larger CL. Moreover, standard deviations of this additional mode were often estimated to be much smaller than the other two. As a consequence, the resulting VBGF parameter estimates differed markedly from previous estimates. Nevertheless, a mixture of 3 Gaussian distributions always achieved smaller minimum negative likelihood values and would be selected as the best fit based on a likelihood ratio test alone. Further assumptions need to be included in this model to achieve realistic growth estimates using mixtures of 3 Gaussian distributions. Such additional constraints could be to constrain the standard deviations to increase as a linear function of means (Fournier et al, 1990) or to vary them as a random effect.

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Female, 1992

(c)

Figure 3.3.1: Comparison of female 1992 length frequency distribution fit with a mixture of 2 Gaussian distributions using different assumptions: (a) equal growth for all cohorts (b) $\mathrm{t}_{0}$ cohort specific (c) k cohort specific.


Figure 3.3.2: Comparison of female 2002 length frequency distribution fit with a mixture of 2 Gaussian distributions using different assumptions: (a) equal growth for all cohorts (b) $\mathrm{t}_{0}$ cohort-specific (c) k cohort-specific.


Male, 1989

(c)

Figure 3.3.3: Comparison of male 1989 length frequency distribution fit with a mixture of 2 Gaussian distributions using different assumptions: (a) equal growth for all cohorts (b) $\mathrm{t}_{0}$ cohort-specific (c) k cohort-specific.


Figure 3.3.4: Comparison of male 2001 length frequency distribution fit with a mixture of 2 Gaussian distributions using different assumptions: (a) equal growth for all cohorts (b) $\mathrm{t}_{0}$ cohort-specific (c) k cohort-specific.

Cohort-specific to for females


Cohort-specific to for males



Figure 3.3.5: Cohort-specific $\mathrm{t}_{0}$ estimates.


Figure 3.3.6: Cohort-specific $k$ estimates.


Figure 3.3.7: Estimated sex-specific and combined VBGF for individual up to 3 years old.


Figure 3.3.8: Comparison between $95 \%$ confidence region of VBGF parameters $\mathrm{L}_{\infty}$ and k given by the model that assumes constant growth between cohorts (solid line) and Phillips et al (1992)'s estimates (cross).

|  |  | Female |  | Male |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Survey date | Nb. of obs. | $\min$ | $\max$ | $\min$ | $\max$ |
| $30 / 06 / 1989$ | 816 | 36 | 136 | 33 | 136 |
| $20 / 06 / 1990$ | 521 | 32 | 123 | 16 | 137 |
| $09 / 06 / 1991$ | 655 | 32 | 115 | 31 | 131 |
| $12 / 06 / 1992$ | 851 | 30 | 123 | 34 | 133 |
| $05 / 07 / 1993$ | 334 | 14 | 119 | 33 | 127 |
| $06 / 07 / 1994$ | 599 | 41 | 117 | 36 | 127 |
| $22 / 06 / 1995$ | 458 | 35 | 117 | 33 | 122 |
| $23 / 05 / 1996$ | 367 | 29 | 108 | 28 | 126 |
| $14 / 06 / 1997$ | 457 | 36 | 119 | 37 | 129 |
| $23 / 06 / 1998$ | 386 | 37 | 123 | 34 | 127 |
| $04 / 06 / 1999$ | 375 | 32 | 118 | 28 | 133 |
| $29 / 05 / 2000$ | 231 | 32 | 116 | 32 | 124 |
| $15 / 06 / 2001$ | 148 | 38 | 116 | 35 | 117 |
| $29 / 05 / 2002$ | 272 | 29 | 116 | 37 | 123 |
| $28 / 05 / 2003$ | 499 | 35 | 126 | 38 | 120 |
| $29 / 04 / 2004$ | 340 | 36 | 121 | 31 | 116 |
| $03 / 05 / 2005$ | 232 | 26 | 114 | 30 | 127 |
| $24 / 11 / 2005$ | 302 | 22 | 106 | 19 | 118 |
| $30 / 07 / 2006$ | 306 | 38 | 120 | 17 | 134 |
| $27 / 11 / 2006$ | 395 | 18 | 104 | 19 | 120 |
| $31 / 05 / 2007$ | 339 | 34 | 128 | 27 | 129 |
| $10 / 11 / 2007$ | 327 | 22 | 103 | 17 | 129 |
| $27 / 05 / 2008$ | 207 | 27 | 118 | 33 | 129 |
| $27 / 11 / 2008$ | 216 | 19 | 112 | 21 | 122 |
| $12 / 05 / 2009$ | 238 | 35 | 113 | 38 | 112 |

Table 3.3.1: Carapace length (in mm ) data summary.

| Survey year | Age group 0 | Age group 1 (mid-year) | Age group 1 (end of year) | Age group 2 |
| :--- | :---: | :---: | :---: | :---: |
| 1989 | NA | C2 | NA | C1 |
| 1990 | NA | C3 | NA | C2 |
| 1991 | NA | C4 | NA | C3 |
| 1992 | NA | C5 | NA | C4 |
| 1993 | NA | C6 | NA | C5 |
| 1994 | NA | C7 | NA | C6 |
| 1995 | NA | C8 | NA | C7 |
| 1996 | NA | C9 | NA | C8 |
| 1997 | NA | C10 | NA | C9 |
| 1998 | NA | C11 | NA | C10 |
| 1999 | NA | C12 | NA | C11 |
| 2000 | NA | C13 | NA | C12 |
| 2001 | NA | C14 | NA | C13 |
| 2002 | NA | C16 | NA | C14 |
| 2003 | C19 | C18 | NA | C15 |
| 2004 | C20 | C19 | C18 | C16 |
| 2005 | C21 | C20 | C19 | C18 |
| 2006 | NA | C22 | C20 | C19 |
| 2007 |  | C21 | C20 |  |
| 2008 |  | NA | C21 |  |
| 2009 |  |  |  |  |

Table 3.3.2: Tracking which cohorts are represented in the data.

| Mid date | $p$ | $\mu_{j}$ | $\mu_{j+1}$ | $\sigma_{j}$ | $\sigma_{j+1}$ |
| :--- | :---: | :---: | :---: | :---: | :---: |
| $30 / 06 / 1989$ | 0.4021 | 59 | 94 | 10.7 | 10.3 |
| $20 / 06 / 1990$ | 0.691 | 58 | 94 | 12.5 | 9.4 |
| $09 / 06 / 1991$ | 0.7793 | 57 | 93 | 11.4 | 10.6 |
| $12 / 06 / 1992$ | 0.6198 | 57 | 93 | 10 | 11.1 |
| $05 / 07 / 1993$ | 0.6767 | 60 | 95 | 10.5 | 11.3 |
| $06 / 07 / 1994$ | 0.819 | 60 | 95 | 9.2 | 8.5 |
| $22 / 06 / 1995$ | 0.7195 | 58 | 94 | 12.1 | 9.3 |
| $23 / 05 / 1996$ | 0.8718 | 55 | 91 | 11.6 | 6.8 |
| $14 / 06 / 1997$ | 0.7056 | 57 | 93 | 9.5 | 13.3 |
| $23 / 06 / 1998$ | 0.3181 | 59 | 94 | 9.3 | 13 |
| $04 / 06 / 1999$ | 0.8539 | 56 | 92 | 10.2 | 10.1 |
| $29 / 05 / 2000$ | 0.7713 | 56 | 92 | 10.8 | 7.5 |
| $15 / 06 / 2001$ | 0.7764 | 58 | 93 | 10.8 | 8.1 |
| $29 / 05 / 2002$ | 0.7476 | 56 | 92 | 9.8 | 9.4 |
| $28 / 05 / 2003$ | 0.5275 | 56 | 92 | 9.2 | 10.7 |
| $29 / 04 / 2004$ | 0.6082 | 52 | 89 | 8.8 | 11.8 |
| $03 / 05 / 2005$ | 0.3594 | 53 | 90 | 11.1 | 10.3 |
| $24 / 11 / 2005$ | 0.2918 | 32 | 75 | 5.3 | 14.2 |
| $30 / 07 / 2006$ | 0.8721 | 63 | 97 | 9.9 | 10.5 |
| $27 / 11 / 2006$ | 0.1761 | 33 | 75 | 8.6 | 11.1 |
| $31 / 05 / 2007$ | 0.6105 | 56 | 92 | 10.2 | 12 |
| $10 / 11 / 2007$ | 0.0813 | 30 | 73 | 6.2 | 11 |
| $27 / 05 / 2008$ | 0.5636 | 56 | 92 | 9.7 | 11.6 |
| $27 / 11 / 2008$ | 0.2943 | 33 | 75 | 7.2 | 10.8 |
| $12 / 05 / 2009$ | 0.6904 | 54 | 90 | 9.8 | 9.3 |

Table 3.3.3: Parameter estimates of a mixture of 2 Gaussian distributions fitted to female carapace length frequency data. $j$ denotes a specific age-group, $j=0$ or 1 .

| Mid date | $p$ | $\mu_{j}$ | $\mu_{j+1}$ | $\sigma_{j}$ | $\sigma_{j+1}$ |
| :--- | :---: | :---: | :---: | :---: | :---: |
| $30 / 06 / 1989$ | 0.4434 | 61 | 100 | 11.6 | 16.1 |
| $20 / 06 / 1990$ | 0.7071 | 60 | 99 | 13.4 | 13.9 |
| $09 / 06 / 1991$ | 0.7661 | 59 | 98 | 11.7 | 16.6 |
| $12 / 06 / 1992$ | 0.672 | 59 | 98 | 12 | 16.2 |
| $05 / 07 / 1993$ | 0.7127 | 62 | 100 | 12 | 15.8 |
| $06 / 07 / 1994$ | 0.8322 | 62 | 100 | 10 | 15.3 |
| $22 / 06 / 1995$ | 0.761 | 60 | 99 | 11.7 | 11.5 |
| $23 / 05 / 1996$ | 0.8384 | 57 | 97 | 13.2 | 18.9 |
| $14 / 06 / 1997$ | 0.7747 | 59 | 98 | 10.9 | 16.3 |
| $23 / 06 / 1998$ | 0.5074 | 60 | 99 | 10.6 | 17.2 |
| $04 / 06 / 1999$ | 0.8629 | 58 | 98 | 13.6 | 18.8 |
| $29 / 05 / 2000$ | 0.7952 | 57 | 97 | 10.4 | 13.9 |
| $15 / 06 / 2001$ | 0.9299 | 59 | 99 | 11.7 | 16.4 |
| $29 / 05 / 2002$ | 0.7817 | 57 | 97 | 10.3 | 14.1 |
| $28 / 05 / 2003$ | 0.5395 | 57 | 97 | 10 | 11.7 |
| $29 / 04 / 2004$ | 0.7102 | 54 | 94 | 9.7 | 12.2 |
| $03 / 05 / 2005$ | 0.3244 | 54 | 95 | 10.8 | 15.5 |
| $24 / 11 / 2005$ | 0.2024 | 32 | 78 | 6.4 | 18.9 |
| $30 / 07 / 2006$ | 0.9514 | 65 | 103 | 12.7 | 17.6 |
| $27 / 11 / 2006$ | 0.1521 | 32 | 79 | 6 | 13.2 |
| $31 / 05 / 2007$ | 0.6719 | 57 | 97 | 9.8 | 14.7 |
| $10 / 11 / 2007$ | 0.1124 | 30 | 77 | 6.9 | 16.2 |
| $27 / 05 / 2008$ | 0.6918 | 57 | 97 | 10.8 | 19.1 |
| $27 / 11 / 2008$ | 0.3012 | 32 | 79 | 6.5 | 18.3 |
| $12 / 05 / 2009$ | 0.7555 | 55 | 95 | 8.3 | 9.7 |

Table 3.3.4: Parameter estimates of a mixture of 2 Gaussian distributions fitted to male carapace length frequency data. $j$ denotes a specific age-group, $j=0$ or 1 .

|  | min. -log likelihood | Nb of param. | AIC |
| ---: | ---: | ---: | ---: |
| Sex dimorphism - k cohort specific | 41847 | 198 | 84090 |
| Sex dimorphism - t0 cohort specific | 42257 | 198 | 84910 |
| Sex dimorphism - constant growth | 42439 | 156 | 85190 |
| No sex dimorphism - constant growth | 42560 | 78 | 85276 |

Table 3.3.5: Results of mixture models fit to length frequency data assuming each was composed of 2 Gaussian distributions. Results were ordered by increasing AIC values from top to bottom.

|  | Linf | k | t 0 |
| :--- | :---: | :---: | :---: |
| Cte growth - Female | $189 \pm 15$ | $0.00087 \pm 0.00011$ | $111 \pm 14$ |
| Cte growth - Male | $210 \pm 21$ | $0.00083 \pm 0.00012$ | $128 \pm 12$ |
| Cte growth - All sex | $197 \pm 11$ | $0.00086 \pm 8 \mathrm{e}-05$ | $122 \pm 9$ |
| Cohort specific t0 - female | $290 \pm 48$ | $0.00047 \pm 1 \mathrm{e}-04$ | $66 \pm 30$ |
| Cohort specific t0 - male | $298 \pm 31$ | $0.00051 \pm 7 \mathrm{e}-05$ | $90 \pm 27$ |
| Cohort specific k - female | $221 \pm 24$ | $0.00069 \pm 4 \mathrm{e}-05$ | $93 \pm 16$ |
| Cohort specific k - male | $225 \pm 28$ | $0.00067 \pm 4 \mathrm{e}-05$ | $95 \pm 14$ |
| Phillips et al (1992), female | 144 | 0.0016 | NA |
| Phillips et al (1992), male | 166 | 0.0012 | NA |

Table 3.3.6: Results of mixture models fit to length frequency data assuming each was composed of 2 Gaussian distributions.

## 4. BENEFITS

Research from this project directly benefits fishery managers, Torres Strait Islanders and commercial lobster fishers by providing essential lobster abundance data, assessment of the status of the stock, development of more reliable stock assessment methods, and assessment of stock sustainability under current and future fishery practices. The introduction of the new integrated fishery model provides greater certainty to stock status assessments due to the incorporation of all fishery-independent and dependent data sources

The relative abundance indices provide a long-term fishery-independent assessment of trends in recruitment and stock abundance and forecasts of stock and recruitment. The standardisation of these fishery-independent indices, accounting for changes in sampling design and protocol, provides greater confidence in the trends of abundance.

The continuation of the research program to monitor the age composition of the commercial catch will benefit managers and stakeholders by providing baseline data for future comparisons of fishing selectivity, under the quota managed system. This data also increases the reliability of fishery modelling and stock status assessments.

A GLM of a sub-set of TVH catch and effort data (Ye and Dennis, 2009) was developed to provide indices of lobster abundance for comparison with fishery-independent indices. The two data sources were comparable providing increased confidence in the utility of both sources as actual indices of abundance. However, the TRL RAG raised concerns that the recent voluntary licence surrender may impact on the commercial CPUE estimates given the smaller number of vessels available to sub-set from. The analysis of alternative, less complex methods that do not require sub-setting to calculate CPUE estimates showed that the results were comparable with the GLM derived estimates and could be used for future inputs to the integrated fishery model.

## 5. FURTHER DEVELOPMENT

The results of the Torres Strait lobster research are communicated widely to managers, Torres Strait Islanders and stakeholders at TRL working group meetings, TRL RAG meetings, national and international conferences and in peer reviewed journal articles. Each of these forums prioritises the research required to develop the results of the current research program. Future research proposals will incorporate even wider dissemination of results to Torres Strait islanders through communication channels and islander participation. An information road trip to be undertaken during August 2010 will incorporate several island communities and allow feedback on the issues important to each community.

The monitoring of the age composition of the catch was initiated in 2007 with a two year project funded by AFMA. This program has been continued as part of the current proposal but a reliable source of continuous funding should be sought to ensure this monitoring program continues in the future.

Aspects of the new Integrated model will be further refined and developed in the near future, including incorporation of results from the catch at age, commercial CPUE and lobster growth parameter tasks reported here. The new Integrated model will also be used as an Operating Model within a Management Strategy Evaluation (MSE) approach. The development of a MSE has been proposed because it will assist not only in evaluating the effectiveness of the current management strategy, but can be used to test and communicate a wide range of different scenarios.

## 6. ACHIEVEMENT OF OUTCOMES

A fishery-independent survey of the Torres Strait rock lobster population was completed during this project. The survey data together with the commercial catch at age and standardised CPUE statistics are the primary data sources for the new approach to lobster population dynamics and the long-term sustainable productivity of the lobster fishery. The updated survey data series now covers 21 years (mid-1989 to mid-2010). This extended data-set provides the essential information for stock assessment and management of the lobster fishery. The new results provide estimates of current stock status and fishing capacity of the fleet, and therefore, necessary management actions can be taken to ensure the sustainability and desirable production level of the fishery.

The results of this project have been presented at a number of key meetings including the TRL Working Group meeting and the TRL Resource Assessment Group meeting and these results have influenced the industry, managers and stakeholders to adopt more effective and precautionary measures in managing the lobster fishery; for example, setting TAC based on pre-defined decision rules. Updated results of the stock assessment and TAC estimation will be presented at the October TRL RAG meeting.

## 7. RECOMMENDATIONS

The mid-year surveys, conducted since 1989, are a valuable time series and provide essential inputs for stock assessment of the Torres Strait lobster fishery. While potentially useful as an additional series, the CPUE data don't give an estimate of the number of $1+$ lobsters for the following year, and hence are inadequate on their own. The recent inclusion of the pre-season survey data substantially improves predictive ability, and this data will be critical once the quota management system is implemented.

The new Integrated model is the preferred method for setting TACs under the future quota management system. It deviates from the previous three stage approach to the setting of the TAC because it integrates all available information in a single self-consistent framework. This facilitates an understanding of the way in which data inputs ultimately translate into an assessment of resource status and productivity, sustainable catch levels and hence TAC estimates. It is recommended that the model TAC estimate is used as the final TAC for the forthcoming year, subject to pre-specified harvest control rules that pertain to the status of the stock relative to the target level. The preliminary TAC for the following year should be set more conservatively by selecting the lower end of the $75 \%$ confidence interval so that there is a low probability that it will be higher than the Final TAC.

The TAC setting process should be adaptively revised and modified each year, taking new data into account. The effectiveness of the harvest control rules in achieving management objectives should be examined using a Management Strategy Evaluation (MSE) approach.

Initial groundwork has been laid to better communicate the details of the stock assessment process, and this aspect will be developed further.

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## 9. ABBREVIATIONS \& GLOSSARY

AFMA. Australian Fisheries Management Authority.
CPUE. Catch per Unit effort.
CSIRO. Commonwealth Scientific and Industrial Research Organisation.
GLM. Generalised Linear Model
MSE. Management Strategy Evaluation
PNG NFA. Papua New Guinea National Fisheries Authority.
PZJA. Protected Zone Joint Authority.
QMS. Quota management system.
TAC. Total allowable catch.
TSRA. Torres Strait Regional Authority.

## 10. APPENDIX 1: INTELLECTUAL PROPERTY

Data collected during the mid-year and pre-season population surveys, including lobster counts, lobster size-frequency, seabed abiotic and biotic components and environmental variables are currently stored at the CSIRO Marine Laboratories, Cleveland as CMAR is the current custodian of AFMA funded research data. This data would be made available to other research agencies through written approval from AFMA.

## 11. APPENDIX 2: STAFF

| É. Plagányi-Lloyd, PhD | Stock assessment/fishery modelling |
| :--- | :--- |
| W. Venables, PhD | Statistical analyses |
| M. Kienzle, MSc | Statistics/population dynamics |
| D. M. Dennis, BSc Hons | Lobster ecologist/dive coordinator/analysis |
| M. D. E. Haywood, Bsc | GIS analysis/advanced diving/fieldwork |
| I. Mcleod, BSc | GIS/Advanced diving/fieldwork |
| M. Tonks, BSc | Advanced diving/fieldwork |


[^0]:    ${ }^{1}$ converted from 100 mm tail length (z) using $\mathrm{L}=0.778 \times \mathrm{z}+0.014$

[^1]:    ${ }^{2}$ partial characterisation because the proportion of age-group $2^{+}$in the catch in December was fixed to $100 \%$.

