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Evaluating the potential use of change-in-ratio and index removal techniques for determining harvest rates and efficiency increases in the Western Rock Lobster Fishery

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1.0 Non-technical summary

2009/019 Evaluating the potential use of change-in-ratio and index removal techniques for determining harvest rates and efficiency increases in the Western Rock Lobster Fishery

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Objectives:

1. Assess current data sources and their potential for estimating harvest rates and increases in efficiency in the western rock lobster fishery using change in ratio and index removal techniques.
2. Evaluate whether additional sources of information are needed to produce more robust estimates of harvest rate and efficiency increase.
3. Assess whether the estimates of harvest rate and fishing efficiency are reliable and could be used for the management of the western rock lobster fishery.

Outcomes achieved to date

This project developed and explored methodology intended to enable the production of more reliable estimates of fishing efficiency increases and harvest rate, such that these estimates might be available for use by fisheries scientists, thereby improving the quality of the management decisions taken, and facilitating the sustainable management of the fishery. If the approach had proved successful, the production of more robust measures of efficiency increase and harvest rate for use as input into the integrated stock assessment model would have improved the reliability of management strategy evaluations and model predictions. The analyses, which were conducted in this study, demonstrated, however, that trends within the fishing season of estimates of exploitation rates derived by applying change-in-ratio (CIR) and index-removal (IR) methods to logbook data from the Western Rock Lobster fishery in different depth zones and regions were inconsistent and, for much of the fishing season, clearly biased (negative estimates). These results were attributed to moulting into and between the undersized and legally-retainable categories of lobsters and changes in catchability within the fishing season. Additional information on such moulting events and changes in catchability is required to allow robust estimation of exploitation rates. As an index of harvest rate is a key measure in the decision rules framework for this fishery, the acquisition of such information would enhance the accuracy of stock assessments obtained using the integrated fishery model. The resulting increase in the reliability of stock assessments would directly benefit the fishery through improved decision making outcomes. A research study, such as a multi-year, multi-season tagging project, should be undertaken to provide the data required to adjust for the effects of moulting and catchability changes and thereby to improve estimates of exploitation rate produced by both CIR and IR and within the integrated assessment model.

Decisions regarding management of Western Australia's fishery for Western Rock Lobster are based primarily on scientific advice derived from stock assessment models and analyses of fisheries and research data. The key indicators of stock and fishery status that have been produced by these stock assessment models have been estimates of the spawning biomass of mature female lobsters and of the level of exploitation to which lobsters in the different management zones have been subjected. The level of exploitation represents the proportion of the population within a specified region that are removed within a specified time period by fishing. For many years, the estimates of exploitation that have been produced by the assessment models have indicated that the Western Rock Lobster fishery has been heavily exploited, *i.e.* a large proportion of the available lobsters are removed by fishers during each fishing season. The assessment models that are used for the fishery are complex, however, and, for a number of years, because of the importance of the exploitation estimates in assessing the sustainability of the fishery, managers have stressed the need for fisheries scientists to investigate alternative approaches for producing estimates of the rate of exploitation such that the accuracy of the estimates produced by the assessment models might be confirmed.

This study explored the potential of using several alternative methods of analysing logbook data to estimate exploitation rates for the Western Rock Lobster fishery. In particular, the study focused on two methods that previously had been applied to data from Tasmania's Southern Rock Lobster fishery, i.e. the Change-in-Ratio (CIR) and Index-Removal (IR) approaches.

The CIR method makes use of the fact that removal of legally-retainable lobsters by fishing will reduce the ratio of the number of these lobsters relative to the number of undersized lobsters.

The method assumes that removal by fishing is the only factor that can affect the ratio. Under this assumption, if the initial numbers of both legally-retainable and undersized lobsters are 1000, for example, and 200 legally-retainable lobsters are removed in the course of a month, then the ratio of legally-retainable to undersized lobsters in the population will decline from 1 to 1 to 0.8 to 1. From these two ratios, it is thus possible to estimate the exploitation rate, which is, in this case, 200/1000 = 20% per month. For the Western Rock Lobster fishery, ratios of legally-retainable to undersized lobsters were determined from logbook data at the beginning and end of each time period, and these ratios were used to calculate the exploitation rate.

The IR method estimates the exploitation rate from the change in catch per unit of effort (cpue) of the legally-retainable lobsters over a specified period, based on the assumption that the only factor that affects the cpue is the removal of legally-retainable lobsters by fishers. Thus if the initial cpue is 2 lobsters per pot lift, and removal of catch by fishers over the course of a month causes this to decline to 1.5 lobsters per pot lift, then the exploitation rate may be estimated to be (2 - 1.5) / 2 = 25% per month. For the Western Rock Lobster fishery, catch rates of legally-retainable lobsters were determined from logbook data at the beginning and end of each time period, and these cpues were used to calculate the exploitation rate.

The issue explored in the study was whether the assumptions that the only factor involved in causing the change in ratio or cpue was removal of lobsters by fishing, or whether other factors such as moulting of lobsters into the undersized and legally-retainable categories of lobsters or change in catchability were of sufficient magnitude to introduce marked bias into the estimates of exploitation rate. Trends in the estimates of exploitation produced using the CIR and IR techniques were therefore examined and estimates were compared to determine whether it was possible to identify a time period in which the assumptions of the CIR and IR method were sufficiently well-satisfied to produce reliable and consistent estimates of exploitation rates. Detailed exploration of the trends revealed both bias and inconsistency in the estimates of exploitation rate, however, and it was therefore concluded that, using logbook data alone, neither the CIR nor IR methods would produce reliable estimates of exploitation rate.

The above result suggests that the integrated assessment model, *i.e.* the model currently used for stock assessment, is also influenced by the effects of moulting and within-season catchability change on logbook data and that, to improve model estimates of exploitation, there would be value in supplying information on these factors to the model through input of an appropriate additional data source. Such information would facilitate adjustment of the logbook data and thereby allow more reliable estimation of exploitation through use of the CIR and IR approaches or through fitting the integrated model for the Western Rock Lobster fishery. It is therefore recommended that multi-year, multi-season tagging studies, which would provide the necessary data, be undertaken to provide the information that would improve future analyses.

Keywords: Change-in-ratio, index-removal, exploitation, Western Rock Lobster

2.0 Acknowledgments

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3.0 Background

Until 2009/10, the level of exploitation in the Western Rock Lobster (*Panulirus cygnus*) fishery was managed by controlling the total allowable level of effort (TAE). In 2010/11, however, managers changed the approach that was employed through moving from input to output controls. Thus, from 2010/11, fishers were allocated individual catch limits. While the sustainable management of any fishery relies heavily on accurate stock assessment, the need to determine the total allowable catch for the Western Rock Lobster (WRL) fishery, such that catch limits can be allocated, increases the demand for timely and accurate stock assessment. Such assessment for the WRL fishery requires the determination of sound estimates of the amount of fishing effort that fishers have employed and, using these estimates, calculation of accurate estimates of annual exploitation. A fundamental issue for stock assessment is how fishing effort should be measured as ideally, this measure should provide an index of fishing mortality. If fishing effort did provide such an index, measures of catch per unit of fishing effort (cpue) calculated using this measure could be assumed to provide an index of the abundance of exploitable (vulnerable) rock lobsters in the population.

The number of pot lifts undertaken by fishers, which is the value reported by fishers and is thus a direct measure of nominal effort, does not provide a consistent index of fishing mortality, i.e. annual fishing mortality is not directly proportional to nominal annual effort. Nominal effort fails to take into account how effort is employed over space and time with respect to the spatio-temporal distribution of exploitable (vulnerable) lobsters, and how the vulnerability of those lobsters changes both spatially and through the course of the fishing season. For example, fishing with 100 pots (traps), half set on sand and the other on reef is likely to produce a total catch very similar to that taken by 50 pots set on reef. Although the same catch has been achieved, markedly different estimates of catch per unit of nominal effort (cpue), *i.e.* nominal "catch rate", would result if these measures of nominal effort were related to the observed catch when analysing the data for the fishery. If the resulting estimates of nominal catch rates were then assumed to represent an index of population abundance, the two estimates obtained for the above example would suggest the presence of very different trends in population abundance. Broad differences in the spatio-temporal distribution of fishing relative to the distribution of the lobsters can be taken into account through the use of a spatial fishery model with greater temporal resolution, such as that which is currently used for the WRL fishery. There are, however, numerous factors relating to the finer spatial and temporal scale of fishing with respect to lobster distribution, to the environment, and to the tactics employed by different fishers that currently are not taken into account in the fishery model. A measure of the influence of these factors on effort is required. The adjustment of effort for these factors would result in a measure of effective effort that would be more closely correlated with fishing mortality, and thus would provide an estimate of standardised cpue that would provide a far more reliable index of abundance. Calculation of effective effort would thus allow direct comparisons of cpue between time periods to provide information on changing abundance of lobsters. While attempts to standardise fishing effort in the Western Rock Lobster have been undertaken in attempts to take effort creep into account, fishery managers remained keen to explore other more “independent” approaches of estimating exploitation rate.

Determining changes in fishing efficiency is difficult and has been the aim of a number of studies in the WRL and other fisheries. Initial estimates of efficiency changes in the lobster fishery (Brown *et al*. 1995; Fernandez *et al.* 1997) were based on changes in cpue between vessels with and without various technologies, *e.g.* colour echo sounders. Although good for evaluating the relative influence on fishing power of such technology, this method fails to determine the influence of such factors as gains in knowledge or the movement of pots from poorer to better fishers. More recently, Wright *et al.* (2006) used depletion analysis to examine changes in fishing efficiency and, as a by-product, produced the first estimates of harvest rate indices for the WRL fishery that had been derived using methods external to those employed in fishery models. A major limitation of the depletion technique, however, is the requirement that all cpue data employed in the analysis must be adjusted for changes in catchability resulting from external factors such as water temperature and swell. Incorrect adjustment, or failure to correct for all factors, can produce significant bias in the results from the depletion analysis.

The bias associated with change in catchability can possibly be overcome, however, through use of change-in-ratio (CIR) analysis, a traditionally land-based, statistical technique that was used for the Tasmanian Southern Rock Lobster (SRL) fishery by Frusher *et al.* (1997, 1998). This method, which made use of the change in the ratio of legal-sized to sub-legal sized lobsters as a result of catch removals, was combined with an index removal (IR) approach (the change in cpue resulting from catch removals) to produce robust estimates of residual biomass, exploitation rate and increases in fishing efficiency in the Tasmanian SRL fishery, from data sources similar to those available for the WRL fishery. The success of these methods when applied during early analyses of data for the Tasmanian lobster fishery suggested that there might be considerable value in investigating whether the approaches could be employed to analyse data for the WRL fishery. Accordingly, a successful application for such a study was made to the FRDC, and it is the results of that study that are the subject of this report.

4.0 Need

At the time at which the application for this study was submitted, the WRL Industry was moving from a decision-rule framework based solely on the estimate of the level of the breeding stock to a more robust two-dimensional approach that incorporated estimates of both breeding stock and harvest rate. Such an approach represented best practice fisheries management and was consistent with Commonwealth Fisheries Harvest Strategy Policy (http://www.daff.gov.au/fisheries/domestic/harvest_strategy_policy). The proposed decision-rule framework had been examined during a review on stock assessment methodologies used in the WRL fishery. The review panel had supported this new direction but highlighted the importance of having robust estimates of the indices on which this framework was to be based, especially estimates relating to the sensitivity of the (empirical and model-derived) breeding stock indices and harvest rates with respect to fishing efficiency. Due to speculation surrounding the then current estimates of efficiency creep, the panel had recommended exploring whether these indices could be determined using different techniques. Further development of these indices had been incorporated subsequently in the "Action Plan" to meet the requirements of the Marine Stewardship Council. Recent concern surrounding the low levels of puerulus settlement that had been observed, and the possibility that these might in some way have been linked to breeding stock levels, had heightened the need for the development of reliable estimates of harvest rate and assessments of the magnitude of efficiency creep. Subsequent trends in puerulus settlement, accompanied by a marked reduction in levels of recent annual recruitment to the fishery had confirmed the need for improved estimates on the levels of exploitation to which the WRL fishery had been subjected.

CIR and IR techniques have the potential to produce robust estimates of exploitation rate, as is illustrated by application in other fisheries, such as Tasmania's SRL fishery (Frusher *et al*., 1997, 1998). However, the success of these methods depends on the specific data sources available, the biology of the target species and its vulnerability to fishing, and the spatio-temporal pattern of fishing operation and management regulations, and thus the approaches may not be directly transferable to other fisheries. Consequently, the value of these techniques when applied to data for the WRL fishery needs to be thoroughly examined to determine whether they could be used to generate robust estimates suitable for use in the management of this fishery. If the approaches are considered capable of producing reliable estimates of annual exploitation rates, they will provide valuable additions to the methods currently being used to monitor changes in fleet efficiency.

5.0 Objectives

The objectives of this study were:

1. Assess current data sources and their potential for estimating harvest rates and increases in efficiency in the western rock lobster fishery using change in ratio and index removal techniques.
2. Evaluate whether additional sources of information are needed to produce more robust estimates of harvest rate and efficiency increase.
3. Assess whether the estimates of harvest rate and fishing efficiency are reliable and could be used for the management of the western rock lobster fishery.

6.0 Methods

The structure of this section is as follows.

1. a review of the basic concepts of CIR and IR methods;
2. a brief summary of the way in which these methods have been applied to lobsters, and in particular, the Tasmanian SRL Fishery;
3. a brief list of other fisheries to which the CIR and IR methods have been applied; and
4. the approach used to explore whether the methods could be applied to obtain reliable estimates of exploitation for the Western Rock Lobster fishery.

6.1 Basic concepts of change in ratio and index removal methods

6.1.1 Change-in-ratio estimates

It is assumed that:

1. the population is composed of two different types of animals (sub-legal and legal lobsters);
2. samples of the population are taken before and after removing known numbers of individuals of each type from the population;
3. the population is closed to recruitment, migration and natural mortality, *i.e.* the only changes to the population are those that are associated with the removals;
4. the catchabilities of the two types of animals at each survey are the same, but may differ between surveys; and
5. the removals are of magnitudes that will produce a change in the ratio of individuals of the two types.

Note that the magnitude of the change in the ratio will determine the precision of the estimate of population size and/or exploitation. Note also that, as shown by Frusher *et al.* (2007, 2008), change-of-ratio estimates of exploitation do not require that the catchabilities of the two types of individuals are equal if one type is unexploited, but merely that the ratio of the catchabilities remains constant within the two surveys.

The two types of individuals may be assigned the labels x and y. Following the notation presented in the review by Pollock and Hoenig (1998), the initial numbers of individuals of type x and y may be denoted by X_1 and Y_1, respectively, the final numbers by X_2 and Y_2, respectively, and the total number in the population before and after the removals as N_1 and N_2, respectively. The proportion of individuals of type x is denoted by P_1 while the final proportion is P_2. Thus, $P_1 = X_1 / N_1$ and $P_2 = X_2 / N_2 = (X_1 - R_1)/(N_1 - R) = (P_1 N_1 - R_1)/(N_1 - R)$,

where the removals of type x, type y and both x and y are R_x, R_y and R, respectively. The initial number of individuals in the population may be estimated as

$$\hat{N}_1 = \frac{\left(R_x - R\hat{P}_2\right)}{\left(\hat{P}_1 - \hat{P}_2\right)}$$

and the overall exploitation rate u may be estimated as $\hat{u} = R / N_1$, while the exploitation rate of animals of type x is $\hat{u}_x = R_x / X_1 = R_x / \left(\hat{P}_1 \hat{N}_1\right)$ and that of individuals of type y is $\hat{u}_y = R_y / Y_1 = R_y / \left[\left(1 - \hat{P}_1\right)\hat{N}_1\right]$

In the particular case in which the animals of type x are unexploited, i.e. $R_x = 0$, $\hat{N}_1 = \dfrac{R\hat{P}_2}{\left(\hat{P}_2 - \hat{P}_1\right)}$ and $\hat{u} = 1 - \dfrac{P_1}{P_2}$, $\hat{u}_x = 0$, and $\hat{u}_y = \dfrac{\hat{P}_2 - \hat{P}_1}{\hat{P}_2\left(1 - \hat{P}_1\right)}$

That is, in this case, it is not necessary to know the number of animals that were removed from the population.

6.1.2 Index-removal estimates

It is assumed that:

1. The population is closed to recruitment, migration and natural mortality, and is affected only by the removal of individuals in a period between two samples;
2. All animals have the same probability of capture, which is constant for both sampling occasions; and
3. Sampling is with replacement or a negligible number of animals are removed during each sampling period, i.e. sampling does not affect the index of abundance calculated on each of the two sampling occasions.
4. The removal is of sufficient magnitude to produce a change in abundance from that present at the time of the first sample.

The number of animals in the initial population N_0 may be estimated as

$\hat{N}_0 = \hat{R}\dfrac{\hat{c}_1}{\hat{c}_1 - \hat{c}_2}$, where $\hat{c}_1$ and $\hat{c}_2$ are estimates of the catch per unit of effort (or other index of abundance) at times immediately preceding and following the removal, and $\hat{R}$ is the estimated number of animals removed from the population. The exploitation rate u may be estimated as $\hat{u} = \dfrac{\hat{R}}{\hat{N}_0}$.

Again, if the number of animals removed from the population is unknown, it is possible to derive an equation from which the exploitation rate may be estimated, i.e. $\hat{u} = \dfrac{\hat{c}_1 - \hat{c}_2}{\hat{c}_1}$.

6.2 Application of methods to Lobster fisheries

Preliminary results of a 1992-96 study to estimate the exploitation rates of Southern Rock Lobster (*Jasus edwardsii*) off the east and southern coasts of Tasmania are reported by Frusher *et al.* (1998), while the results of further analyses of data that also included a fourth year of more intensive sampling are reported by Frusher *et al.* (1997) [*Note that the timing of review and publication resulted in the apparent inconsistency between these publication dates*]. The study made use of the change in ratios of legal-size to two size classes of sub-legal size lobsters that resulted between the value calculated using data from a pre-season October survey and that derived from data collected in subsequent surveys following exploitation by the fishery. For female lobsters, the second survey occurred in March, prior to the typical period of moulting by those females, while, for male lobsters, the second sample was taken in July-August, prior to the typical period of moulting of those males. Frusher *et al.* (1998) reported that, as most moulting occurs outside the fishing season (synchronous moulting of large lobsters), little recruitment to the fishery would be experienced. As natural mortality for Southern Rock Lobster is considered to be low, *i.e.* M<0.15 year^{-1}, Frusher *et al.* (1998) considered the decline in catch rates over the fishing season to be due to exploitation. In addition to the collection of catch rate and size composition data for each of the preseason and post-exploitation surveys, Frusher *at al.* (1998) also undertook a tagging study, using the estimates of proportions moulting derived from this to adjust the estimates of exploitation rate derived using the CIR and IR approaches.

Frusher *et al.* (1998) restricted their analysis for the data from the survey sites on the south coast of Tasmania to males as, in this region, only individuals of this sex attain the minimum legal carapace length. Tagging results demonstrated that, at some sites on the east coast of Tasmania, male lobsters moulted between the preseason and post-exploitation surveys. Adjustment for the estimates of moulting derived from the tagging component of the study increased the estimates of exploitation for both females and males, particularly those calculated using the IR approach. The preliminary analysis reported by Frusher *et al.* (1998) suggested that the number of pots employed in the preseason and post-exploitation surveys was unable to produce sufficiently precise estimates to be able to detect with confidence a 25-30% decline in exploitation, such as that likely to have been experienced by the Southern Rock Lobster fishery as a result of changes in the fishing season and fishing pattern between 1992-93 and 1993-94. Accordingly, the number of pots used to collect samples at the southern sites for the pre-season and post-exploitation surveys was increased from 125 in 1992-93 to 395 in 1995-96 in an attempt to increase precision of the surveys (Frusher *et al.*, 1997).

The precision of the estimates of exploitation obtained using the results from the 1995-96 surveys improved from that of the estimates of previous seasons as a result of the increased sampling intensity (Frusher *et al.*, 1997). As the extended study was focused on the southern survey sites, and did not employ data from the sites on the east coast of Tasmania, only the exploitation of male lobsters could be assessed. Research sampling was undertaken at two different sites within each of two depth zones in October-November, prior to the start of the fishing season, and in March, well into the fishing season at a time when approximately 85% of the commercial catch was expected to have been taken. Standardized pots of the type used by commercial fishers were employed and the lobsters that were caught in the samples were sexed and measured, then tagged and released. Tagging studies had demonstrated that the male lobsters would have completed their annual moult prior to the pre-season survey, and would therefore not change size between the two surveys. For the CIR analysis, the individuals in the samples were categorized as being of sizes less than the minimum legal size (110 mm CL) or greater than or equal to this size. Frusher *et al.* (1997) explored use within this analysis of those individuals that fell within 4, 10 and 50 mm of the minimum legal carapace length but found the associated size-specific catchability to have little effect on the results. Frusher *et al.* (1997) noted that a larger sample size would be required when exploitation rates were low to produce estimates of exploitation with the same precision as those produced with smaller samples when exploitation was high (and when the effect on the ratio of legal- to sub-legal-sized lobsters and decline in catch rates between the two survey times was greater).

Despite the initial promise suggested by the above studies, following a more extensive FRDC study of the potential for the use of CIR and IR techniques in providing estimates of exploitation rate for Tasmania's Southern Rock Lobster fishery, Frusher *et al.* (2003) concluded that the methods could not provide consistent and accurate estimates under changing management scenarios. Marked changes in catchability throughout the year violated the assumptions of the IR approach, while within season moulting and recruitment affected the estimates produced by the CIR method. Frusher *et al.* (2003) concluded that, provided there was improved industry co-operation in returning tags, multi-year tagging methods could overcome the catchability and moulting issues that biased the estimates produced using the CIR and IR approaches.

The data from the above studies of the Tasmanian Southern Rock Lobster fishery have subsequently been employed by Frusher *et al*. (2007) and Ihde *et al.* (2007a, b) to explore assumptions relating to catchability and to develop an improved multi-year IR estimator. In other crustacean fisheries, the CIR and index removal methods have been employed for population estimation of Dungeness crab in south-eastern Alaska (Bishop *et al*., 2010) and in the Atlantic Canada *Homarus americanus* fishery (Claytor and Allard, 2003). A continuous-sampling CIR approach was applied in the latter fishery. For this, the population was considered to be separated into lobsters that were of legal size and a reference category that was of sub-legal size. Samples were collected throughout the fishing season simultaneously with fishing, rather than prior to and after fishing, or at some point within the fishing season. The data from samples were obtained from standardized pots constructed with a small mesh which were set by a subset of commercial fishers (5 to 19 volunteers in each region) in locations selected by those fishers at which juvenile lobsters were likely to be caught. The fishers recorded the size and sex of each lobster caught in each of the (two to five) pots that they fished.

6.3 Application to other fisheries

6.3.1 Juvenile striped sea bass *(Morone saxatilis)* in the Hudson River, New York City

The CIR method was extended by Heimbuch and Hoenig (1989) to allow for application to a closed population of juvenile striped sea bass (*Morone saxatilis*) distributed over several defined regions, where fish could move among those regions. Using this approach, the authors successfully estimated the proportion of the population that occurred within a region of the river to be filled during proposed highway construction.

6.3.2 Snow Crab *(Chionoecetes opilio)* in St Mary's Bay, Newfoundland

The CIR and index removal approaches were applied by Dawe *et al.* (1993) to data for snow crab (*Chionoecetes opilio*) in St Mary's Bay, Newfoundland, where the assemblage of individuals in this area was considered to remain relatively discrete from other assemblages. The crabs were separated into an undersized category containing individuals with carapace widths from 78 to 95 mm, and a legal-sized category with carapace widths greater than or equal to 95 mm. Crabs with carapace widths less than 78 mm were excluded from the analysis due to their lower catchability. Research sampling was undertaken before and after the fishing season using sampling units comprising two small-mesh (25 mm stretched-mesh) and four large-mesh (133 mm stretched-mesh) traps, where the latter were of the type used by commercial fishers. Approximately 40 randomly-located sets of the sampling units were made in depths greater than 40 m on each sampling occasion. Catches were sampled at processing plants throughout the very short fishing season. In a subsequent study, Chen *et al.* (1998) investigated the bias associated with the size-selectivity of survey sampling gear and recommended that separate estimates of exploitation should be calculated for each size class to assess whether catchability is size-dependent, and if so, that this might be taken into account by assuming the catchability coefficients to be a function of size.

6.3.3 Sea scallops *(Placopecten magellanicus)* on Georges Bank.

The efficiency of dredges employed to harvest sea scallops (*Placopecten magellanicus*) on the Georges Bank over a five month period in 1999, following a five-year multi-species fishing ban, was estimated by Gedamke *et al.* (2005) using an IR approach. Detailed survey data had been collected for the region both prior to and at the end of the fishing period and these data, combined with details of the catch that was removed, provided the data required for the analysis.

6.4. Assessing the applicability of the approaches for the Western Rock Lobster fishery

The CIR and IR analyses undertaken for the Western Rock Lobster fishery employed data on the changes in the commercial catch rates of legal lobsters, *i.e.* those that could be retained legally and landed by commercial fishers, both on their own and as a ratio of the catch rate of sub-legal-sized (undersize) lobsters. Catch rates were based on data from fishers' monthly returns, voluntary logbooks and commercial monitoring. Changes in these catch rates (on their own and relative to each other) were used to estimate the rate at which legal lobsters were being removed, *i.e.* the exploitation rate.

Because of the different spatial and temporal scales used in collecting size composition data, catch rate data, and catch data for the Western Rock Lobster fishery, it was not possible to obtain accurate estimates of the number of those rock lobsters removed from the fishery that would have been responsible for the change in catch per unit of effort or change in size composition. Catch data for the Western Rock Lobster fishery are obtained from mandatory monthly statistical returns of catches and fishing effort (within each 1 degree geographical grid square) that are reported by fishers (monthly returns). Voluntary logbook data, on the other hand, are submitted by only a (large) subset of the total number of fishers, who report daily catch and effort data from each of the depth ranges in which they have fished (daily returns). The spatial resolution of the daily logbook data is 10 minutes of latitude by 30 minutes of longitude. While the daily logbook data include details of the number of sub-legal-sized lobsters that are caught and released, estimates of the catches of legally-retainable lobsters are reported only in terms of mass, rather than numbers. For use in CIR and IR analysis, it is necessary to convert the recorded masses to the equivalent numbers of individuals before calculating indices of abundance. Data for this transformation were derived from the monthly size composition data for the fishery. These data, which represent the distribution of the carapace lengths, sex, and, for females, reproductive state, *i.e.* ovigerous, tar-spotted (mated), possessing pleopods in a setose state, etc., within each of the depth zones for each of a number of broad geographical regions were collected during monthly research sampling of catches on board fishing vessels operating from selected ports distributed throughout the fishery.

In summary, the mean body mass of legally-retainable lobsters for each depth zone and month were calculated from length monitoring data. The masses of legally-retainable lobsters recorded for each day, block and depth zone in the daily logbooks were then converted to numbers by dividing by the monthly estimate of the mean body mass of these lobsters in the corresponding depth zone and (broad) geographic region. The ratios and catch per unit of fishing effort of lobsters within the sub-legal-sized and legally-retainable categories were then calculated, and the resulting estimates were smoothed using moving averages (five-point moving average). Estimates of putative exploitation rates were calculated using the formulae from both CIR and IR approaches, and results were again smoothed using moving averages. It should be noted that, because of the inconsistencies in spatial and temporal resolution of the different data sets, values of the removed catch could not be estimated for use in the CIR or IR analyses for the Western Rock Lobster fishery. For this reason, the analyses in this study were restricted to the calculation and comparison of putative estimates of exploitation rate, as such estimates do not require data on catch removals. The resulting estimates of exploitation rate were plotted and used to explore the differences among the trends of the estimates produced by the CIR and IR methods in different depth zones, years and regions. Rather than separating the detailed description of the methods from the associated results, it was considered more appropriate to provide the relevant descriptions with the results in the section below.

7.0 Results/discussion

7.1 Exploratory analysis of fishery-dependent at-sea length-monitoring data

The monthly at-sea length monitoring data collected by research staff from the catches of commercial boats operating out of selected ports were subjected to exploratory data analysis. At the time of the analysis (July 2010), this data set comprised 364,729 length records (Table 1). The exploratory data analyses for the length-monitoring data collected on board commercial fishing vessels were focused on the Dongara, Fremantle and Abrolhos regions, with the size composition of the lobsters caught in the waters of the Fremantle region being assumed to be represented by the pooled data for Fremantle, Mandurah, and Lancelin, and that for the Dongara region being assumed to be represented by the pooled data for Dongara and Geraldton. Samples from depth ranges of 0-10 and 10-20 fathoms were pooled to represent the length data from the shallow depth range considered within the assessment model and, similarly, samples from depths greater than 20 fathoms were pooled to represent the length compositions of lobsters taken from the deeper depth range.

Table 1. Number of length measurements for each region contained within the monthly at-sea length-monitoring data collected from catches of commercial fishers operating from various locations.

Location code	Location	Number of records
A	Abrolhos	29951
C	Cervantes	519
D	Dongara	81697
F	Fremantle	78318
G	Geraldton	2545
H	Hillarys	657
J	Jurien	82777
K	Kalbarri	15583
L	Lancelin	71557
M	Mandurah	411
S	Snag	596
U	Augusta	118

Lobsters were classified as being of legal size if they satisfied the criteria specified in Table 2, otherwise they were considered to be of sub-legal size. Note that this represents a slight approximation for the situation pertaining to the 1992/93 season, in which slightly different management arrangements were in place. As this study was intended to provide only a broad indication of the potential of the CIR and index removal methods, however, the impact of this approximation is negligible.

Table 2. Criteria used to determine whether Western Rock Lobsters were of legal size.

Fishing season	Month	Carapace length (mm)
≤ 1992/93	Any	≥ 76
≥ 1993/94	1 or ≥ 11	≥ 77
≥ 1993/94	≥ 2 and ≤ 6	≥ 76

The length records for the undersized lobsters were selected and classified into four mm length bins, and the data aggregated to derive frequencies of undersize lobsters within each length bin. The frequency within each length bin was then expressed as a proportion of the total frequency of undersized lobsters in the length composition collected for the location and depth within the month and fishing season. Differences between the proportions within each length bin in consecutive months for the same location and depth range were calculated by subtracting the proportion for the second month from that for the first of the pair of months. The values of these differences over consecutive length bins were plotted for each pair of consecutive months within each depth zone and region.

If the proportion in the length bin in the second of the pair of months is of similar magnitude to that observed in the first of the pair of months, it would be expected that the difference would be zero. A high positive value would indicate that the proportion within the length bin in the first of the pair of months was considerably greater than that in the second of the pair of months, suggesting that there had been a movement (*i.e.* emigration, mortality, or growth) of lobsters of that size group from the length bin between the two months. A high negative value would indicate that the proportion within the length bin in the first of the pair of months was considerably less than that in the second of the pair of months, suggesting that there had been an influx (*i.e.* immigration, or growth) of lobsters of that size group from the length bin between the two months.

If it is assumed that the only major factor affecting the undersized lobsters is growth, a value greater than zero implies that lobsters from the length bin have grown from the length bin during the month and a negative value implies that lobsters have grown into the length bin during the month. Thus, for example, the plot in the upper pane of Fig.1 suggests that, in depth 0-20 fm in the Fremantle region during the 1971/72 fishing season, a number of lobsters from the 68-72 mm length bin may have grown into the 72-76 mm length bin between the November and December sampling occasions. In contrast, the lower pane suggests that, for the same location and depth range but in the 1973/74 fishing season, there may have been growth into the 64-68 and 68-72 length bins and growth from the 72-76 mm length bin between the same two months. It is possible to identify patterns similar to these, among a variety of other patterns, within the same location and depth range but within different fishing seasons. It is also possible to identify some consistencies between patterns in other locations and months, but no consistent patterns across years. Overall, the conclusion is that growth of undersize lobsters varies among locations, depths, and fishing seasons, with no overall consistent pattern, and that, at least at monthly intervals, the use of the numbers of undersized lobsters as a reference against which the numbers of legal sized lobsters may be compared is likely to prove unreliable. Thus, it is unlikely that a number of consecutive months could be identified within the fishing season that would yield reliable estimates of exploitation derived from the monthly length-composition data and based on change in ratio. This exploration indicated that analyses will probably need to be based on shorter time periods than one month, and will require identification of criteria to enable selection of those data likely to yield reliable estimates of exploitation.

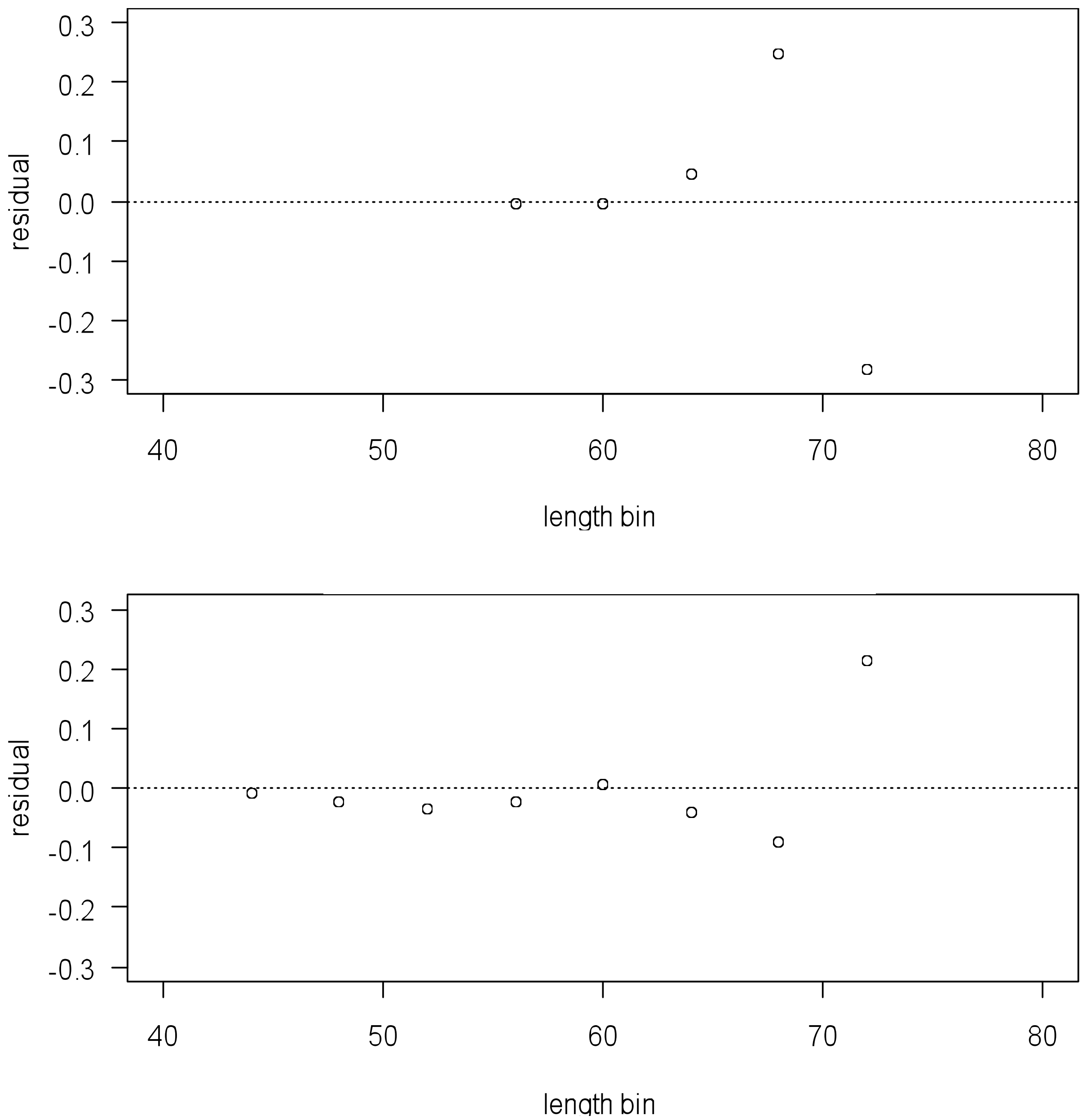


Figure 1. Residual frequency, *i.e.* proportion of lobsters in the length class in December minus proportion in the same length class in November of 1971 (top panel) and 1973 (bottom panel), versus carapace length (mm) for lobsters sampled from 0-20 fathoms at Fremantle. The length bin is denoted by the starting value of the length class.

7.2 Exploratory analysis of daily log-book data

Logbook data collected from commercial fishers operating in the WRL fishery of Western Australia provide details of the trends in the catches (by numbers) of undersized and (by mass) of legally-retainable lobsters per pot lift within different depth ranges (0-10, 10-20, 20-30, 30-40, and 40+ fathoms), regions (Dongara, Jurien, Lancelin, or Fremantle), and fishing seasons. The fishing seasons for the coastal management zones of the fishery (Zones B and C) extended from November 15 to June 30, while that for the Abrolhos Islands management zone (Zone A) ran from March 15 to June 30 of the same year. The fishing seasons considered in this study were restricted to recent years (up to 2007/08), in a period when exploitation was considered high but recruitment had not yet been impacted by the decline in puerulus settlement that has affected recent catches and required considerable adjustment to fishery regulations. Some shorter-term closures or periods of non-fishing were present within some of these seasons/regions, and the data that were used in this study were therefore constrained to the longer periods of consecutive days of fishing (to avoid missing values when calculating moving averages to smooth the data).

For the CIR method to be applied to the catch rates of undersize and legally-retainable lobsters recorded in the logbook data for the Western Rock Lobster fishery, it was first necessary to convert the mass of legally-retainable lobsters to the estimated number of legally-retainable lobsters in the catch. For this, the length composition of the legally-retainable lobsters for each month, depth range, region and fishing season was analysed to produce an estimate of the mean mass of the individual lobsters in that period, depth and location. This estimate was then divided into the mass of lobsters recorded for the month, depth range, region and fishing season to produce an estimate of the number of legally-retainable lobsters that had been caught. Using this, it was possible to explore whether the assumptions of the CIR method were likely to have been met. The transformed data were also used when exploring the assumptions for the IR technique.

Software was written to extract the length data from the database of fishery-dependent monitoring data for a selected season between 2000 and 2005, a selected region and a selected depth range, and to merge the extracted data with data extracted from the logbook database for the same season, region and depth range. The number of legal-sized and sub-legal sized lobsters and the mean (and standard error, SE) of each category were calculated. For these calculations, only those lobsters that could be retained legally by fishers were included in the legal-sized category, *i.e.* berried and setose females that would be released subsequently by fishers after they had been measured by research staff were excluded from the calculation. The following weight-length relationships were used to estimate the mass of each legal-sized lobster from its carapace length (mm) and sex.

Females: $W = 0.0000025053\, L^{2.778}$

Males: $W = 0.0000016086\, L^{2.8682}$

The mean mass (and SE) of the lobsters that could be retained legally by fishers was then calculated for use in transforming the masses of lobsters caught to estimates of the equivalent numbers that had been caught.

The above length composition data were derived from samples drawn from the commercial catches of fishers operating within the depth zone and region at the time of the visits to the region by Technical Officers from the Research Division of the Western Australian Department of Fisheries. Samples are monthly, and reflect a sampling regime that requires the collection of approximately 400 lobsters from each depth zone and region (de Lestang *et al*. 2011). It is assumed that the length compositions of the different categories of lobsters within the sample are representative of the length compositions of the corresponding categories of lobsters in the population.

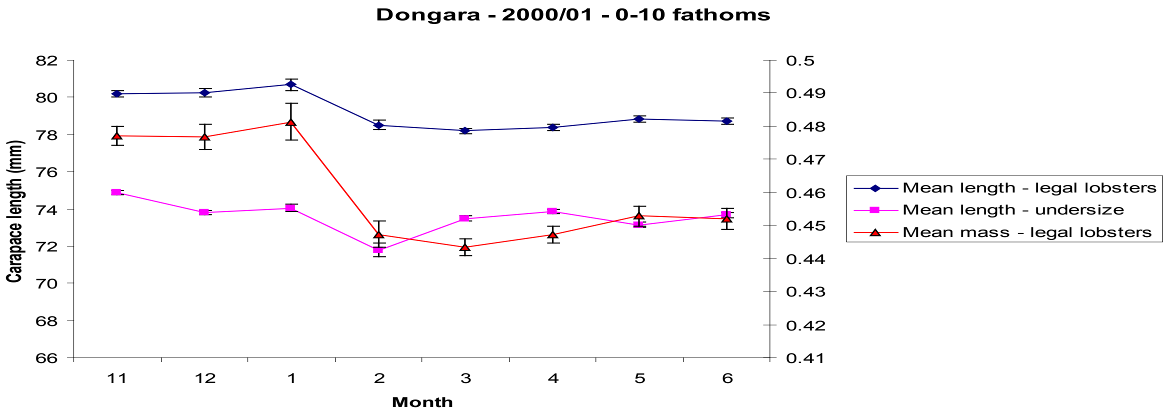


Figure 2. Mean length of undersize lobsters and mean length and mass of lobsters that can legally be landed by fishers in samples collected from catches by commercial fishers operating in 0-10 fathoms depth at Dongara in 2000/01. Error bars represent standard errors of the respective means.

An example of the type of size data that results from this analysis is presented in Fig. 2, for lobsters measured from commercial catches taken from 0 to 10 fathoms at Dongara in 2000/01. Mean length and mass of legal sized lobsters would be expected to increase through the season due to growth, but to decrease when lobsters moult from the sub-legal to legal sized categories. The prevalence of females with visible setae, tar-spots (*i.e.* sperm packets deposited by males) and those that are ovigerous will affect the size composition of the lobsters that can legally be retained, thus influencing the trends in mean length. The mean length of the undersized lobsters would be expected to decrease if smaller sized individuals moult into the sub-legal category of lobsters that are caught, and may be influenced by the moulting of lobsters from this category into the size range that may be retained legally by fishers. The trend may also be influenced by the size of migrating lobsters from shallow to deep water during November to February. The trends exhibited by data such as those presented for lobsters from 0-10 fathoms from Dongara in 2000/01 (Fig. 2) strongly suggest that a moult occurred between January and February, thereby reducing the mean length and mass of legally-retainable lobsters. The decline in the mean length of undersize lobsters that was apparent between January and February, 2001, did not persist and, by March 2001, the mean length of this category had recovered to its previous level.

Daily logbook data were extracted for the selected depth range, region and fishing season. The selected data were further filtered to exclude any records for which more than one depth range had been fished, or for which the soak time was not equal to one day. The mean number of undersized lobsters per pot lift that were caught and released and the mean mass of legally-retainable lobsters per pot lift that were caught and retained each day by the commercial fishers, who had supplied the logbook data, were calculated by dividing the total catch of each category for the day by the total number of pot lifts for the day. An estimate of the number of legally-retainable lobsters per pot lift that were caught and retained by the commercial fishers was calculated by dividing the mass per pot lift by the mean mass of the individual lobsters in the legally-retainable catch, where the latter value was that calculated for the month from the monthly sample of length composition data for the region. Note that there is an inconsistency between the temporal resolution of the logbook data (daily) and the length composition data (monthly). The spatial inconsistency of the logbook data (10 minutes latitude by 30 minutes longitude) and the length composition data (region) was resolved by assigning the logbook data to the region encompassing the geographic grid cell in which fishing occurred.

An example of the results of the transformation from mass per pot lift to estimated number per pot lift is presented in Fig. 3. While the scale of measurement has changed due to the transformation, the overall trend of the two catch rates for 0-10 fathoms at Dongara between 2 February and 30 June, 2001, is very similar. The logbook data for this depth range, region and period exhibit a decline from high catch rates experienced during the "whites" fishing season (November-December, not shown) to a relatively low catch per pot lift around day 66 (19 January) before rising to a peak around day 127 (21 March) and then declining to a relatively low value around day 203 (5 June). Because the length composition data is collected at monthly intervals, the transformation to the estimated daily number of lobsters per pot lift introduces a discontinuity between the data for consecutive calendar months.

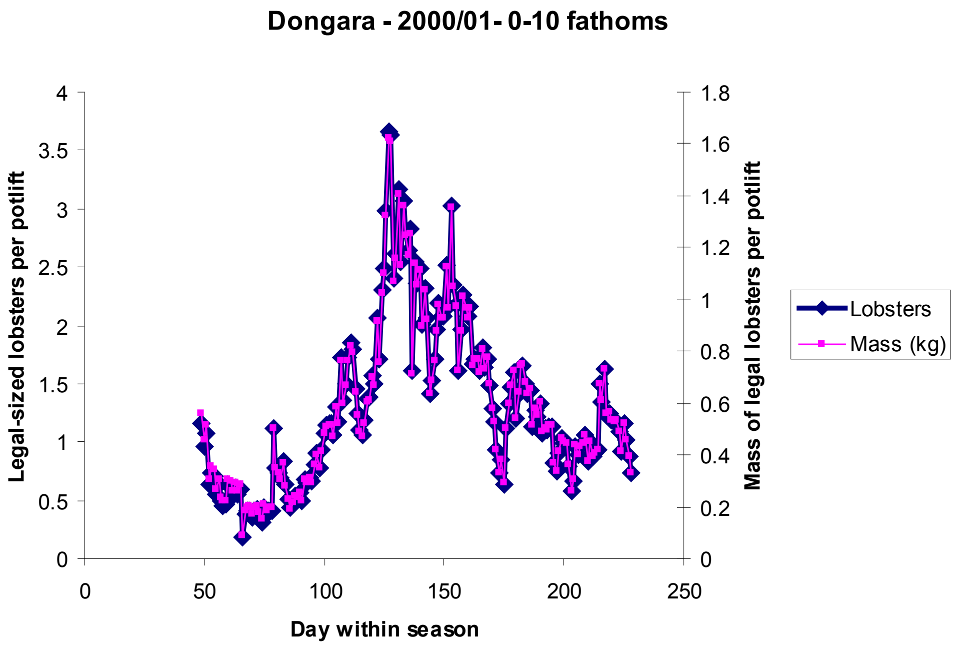


Figure 3. The estimated number and reported mass (kg) of legally-retainable lobsters per pot lift recorded in logbooks by commercial fishers operating in 0-10 fathoms at Dongara between 2 January 2001 and 30 June 2001. Note that the line representing the number of lobsters is frequently masked by the line representing the mass of lobsters. Day within season represents the time (in days) since 15 November.

This pattern shown in Figure 3 is reflected in the trend in the values of autocorrelations over different lag periods, which decline to a minimum at a lag of 69 days (Fig. 4), *i.e.* the approximate period between the minimum cpue at about day 66 and the maximum at about day 135 and reflecting a period of 137 days between the successive minima in number per pot lift on days 66 and 203 (Fig 3). The apparent presence of a higher frequency cycle with a period of about 30 days in the trend of the autocorrelation plot also suggest the presence of a lunar cycle in the estimated number per pot lift recorded for the catches at this location during this period (Fig. 4). Considerable higher frequency variation is also present in the data (Fig. 3). Note that, because of the presence of this lunar cycle in the catch rate data, a moving average of 29 days is employed later in the study to filter this and higher frequencies and thereby "standardise" catchability for the effects of moon phase when applying the IR method. It is for this reason that, for logbook data from 0-10 fathoms at Dongara in 2000/01, the analysis was restricted to the longer period of contiguous data from 2 February to 30 June, as the missing data for days (*e.g.* Christmas Day, New Year's Eve) earlier in the fishing season precluded use of the earlier data.

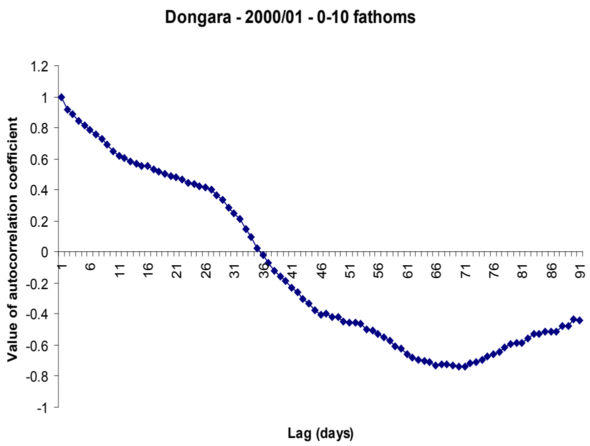


Figure 4. Autocorrelation of estimated number of lobsters per pot lift for catches made in 0-10 fathoms at Dongara between 2 January and 30 June 2001.

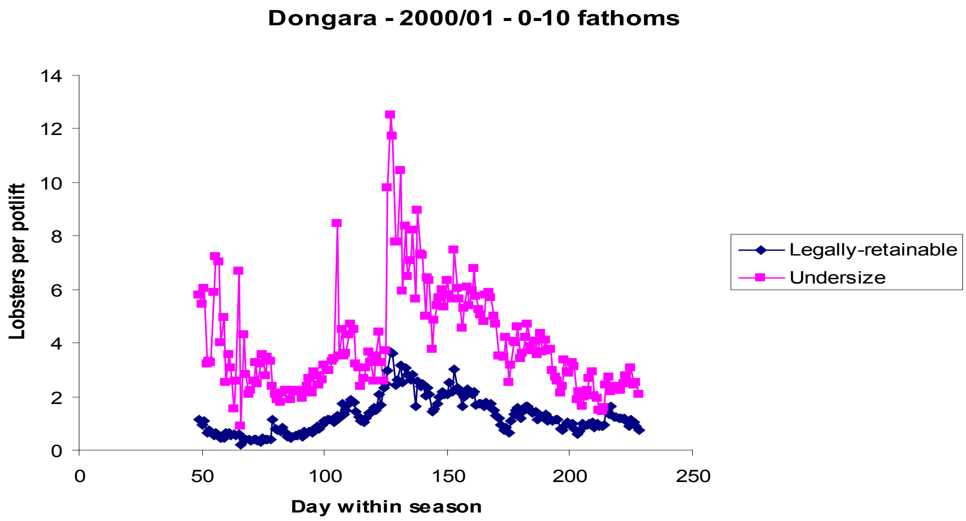


Figure 5. Estimated number of legally-retainable lobsters per pot lift and number of undersized lobsters per pot lift in catches from 0-10 fathoms at Dongara between 2 January and 30 June 2001.

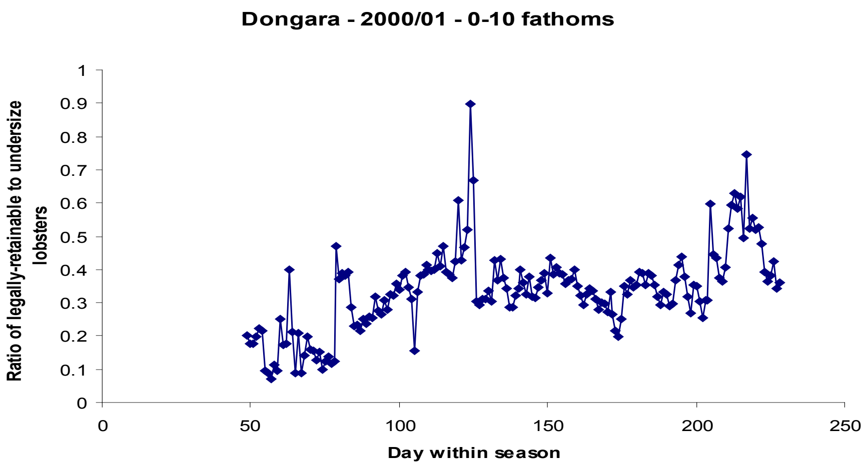


Figure 6. Ratio of the estimate of the number of legally-retainable lobsters to the number of undersized lobsters in catches from 0-10 fathoms at Dongara between 2 January and 30 June, 2001.

The temporal trends in abundance of the undersized and legally-retainable lobsters between 2 January and 30 June, 2001, were similar (Fig. 5), showing a continued decline from the high catch rates associated with the "whites" fishing season early in the fishing season, followed by a subsequent increase due to moulting and hence recruitment to the fishery, and subsequent decline as the fishing season progressed. The CIR method assumes that the two categories of animals from which the ratio is calculated are closed to recruitment, migration and loss other than that associated with known harvest. In applying the method to the WRL stock, it is assumed that the undersized and legally-retainable lobsters (Fig. 5) experience no recruitment, there is no loss through natural mortality or migration, and there is no interchange between the undersized and legally-retainable categories of lobsters. Since the undersized lobsters are not subjected to exploitation, it is further assumed that the only removals are those associated with the harvest of legally-retainable lobsters by commercial fishers.

If the above assumptions are true, it would be expected that, during the course of the fishing season, (1) catch rates of undersized lobsters would remain relatively unchanged, (2) catch rates of legally-retainable lobsters would exhibit a decline in response to the removal of catch by fishers, and (3) the ratio of legally-retainable to undersized lobsters would decline slightly. Clearly, as demonstrated by the increase in catch rates towards peak levels around day 125 of the fishing season, there is recruitment (through moulting) to both the undersized and legally-retainable categories of lobsters (Fig. 5). It is possible, however, that at other times of the year, *i.e.* during the periods of declining catch rate, the assumptions of the CIR method might be satisfied. A plot of the ratio of the number of legally-retainable lobsters to undersized lobsters (Fig. 6) reveals that, while the ratio appeared to decline slightly till day 78 (31 January), it subsequently increased until it attained a maximum of 0.89 on day 124 (18 March), before declining over the next two days to what appeared to be another period of relative stability or possibly slight decline to day 204 (6 June), before another marked increase from day 205 (7 June) to a peak of 0.74 on day 217 (19 June) and a subsequent decline to a value of approximately 0.34 on day 228 (30 June, 2001). The increase between 1 February and 18 March may be attributed to a February/March moult, which increased the relative number of legal-sized and legally-retainable individuals in the stock within this depth range and region. Similarly, the increase between 7 and 19 June may be attributed to a June moult. Both the legally-retainable and undersize components of the stock appeared to be affected by an influx of additional lobsters in each of these periods (Fig.5). While the assumptions of the CIR method may possibly be satisfied in the periods between day 49 (2 January) and day 78 (31 January) and between day 126 (20 March) and day 204 (6 June), it is not possible to determine objectively whether recruitment to the undersize component or transfer between the undersize and legally-retainable categories has ceased and, recognising that moulting occurs over a relatively extended period, which time periods of data should be employed when applying the CIR method.

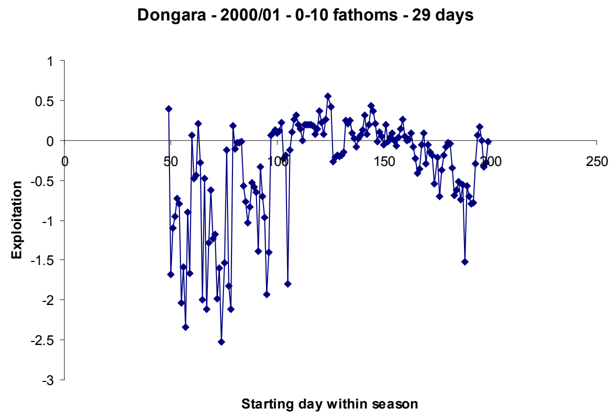
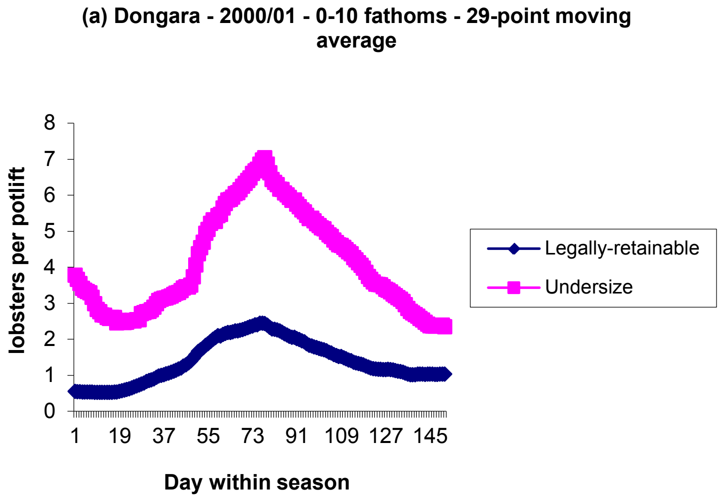


Figure 7. Estimates of exploitation over the 29-day period starting at the specified starting day within the season, derived using the CIR method and employing the number of undersized and legally-retainable lobsters per pot lift caught in 0-10 fathoms at Dongara between 2 January and 30 June 2001.



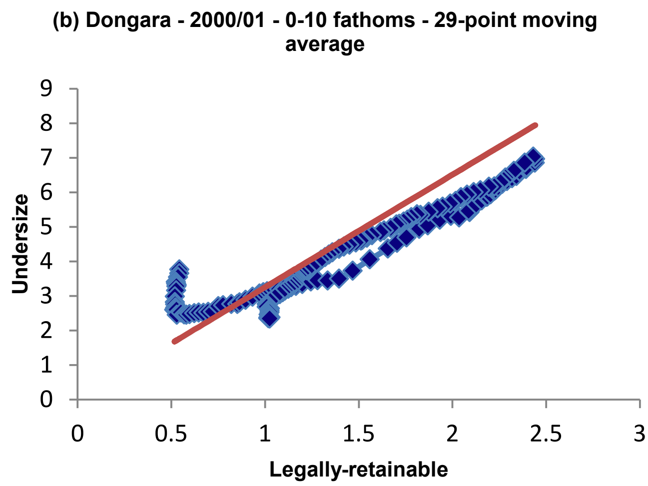


Figure 8. Centred 29-point moving average of numbers of undersized and legally-retainable lobsters per pot lift caught in 0-10 fathoms at Dongara between 2 January and 30 June, 2001. (a) Plot of time series. (b) Relationship between variables.

Estimates of exploitation over a 29-day period, which were calculated using the CIR method and employing the numbers of undersized and legally-retainable lobsters caught in 0-10 fathoms at Dongara between 2 January and 30 June, 2001, exhibited considerable variation (Fig. 7). Negative estimates of exploitation rate are nonsensical and imply a failure of the method for these respective days in the time series. The numerous negative values of exploitation at the beginning and end of the data set may be attributed to the effects of moulting and change in the relative numbers of lobsters in the two categories as a result of recruitment of lobsters to each category and the transfer of lobsters from the undersize to legally-retainable categories. The high level of daily variation makes interpretation of this curve difficult.

The number of undersized and legally-retainable lobsters per pot lift were smoothed using a centred 29-point moving average, thus removing the higher frequency variation (Fig. 8a). A consequence of this transformation is that the period over which growth of lobsters, and hence increasing catch rate, occurs is extended. Clearly, the two variables are highly correlated (Fig. 8b).

Exploitation over a 29-day period was again calculated, but this time employing the centred 29-point moving averages of the numbers of undersized and legally-retainable lobsters per pot lift. A centred 5-point moving average of the resulting estimates of exploitation over the 29-day periods was then calculated to further smooth the results (Fig. 9). The resulting trend appears to be more-readily interpreted than that of the earlier results (cf. Figs 7 & 9). The average value of exploitation over the period from day 108 (2 March) to day 161 (24 April), the period for which estimates of exploitation were positive, was 0.064, *i.e.* an instantaneous rate of total mortality of 0.84 $year^{-1}$. This estimate assumes, however, that the estimates of exploitation during this period are not increased or reduced due to an influx of numbers of undersized lobsters or of legally-retainable lobsters, *i.e.* that the assumptions of the CIR estimate are valid during this period. Clearly the assumptions are invalid for the periods over which negative estimates of exploitation were obtained.

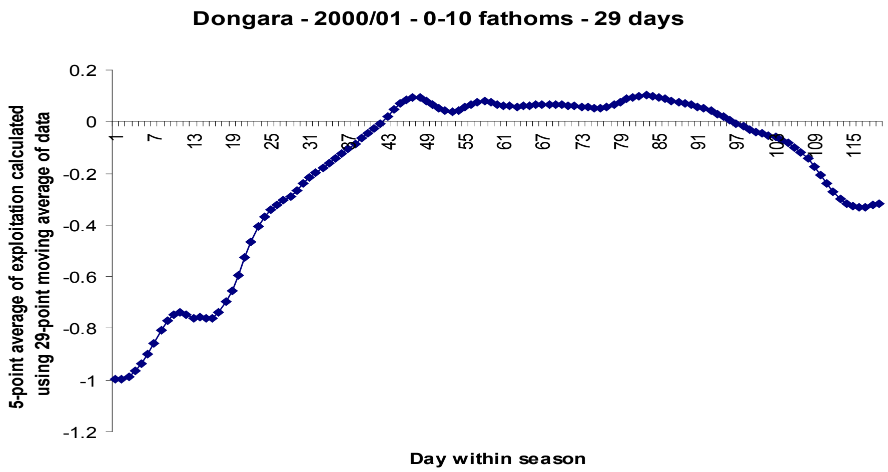


Figure 9. Centred 5-point moving average of exploitation rates calculated using centred 29-point moving averages of the combined numbers of undersized and legally-retainable lobsters per pot lift caught in 0-10 fathoms at Dongara between 2 January and 30 June, 2001.

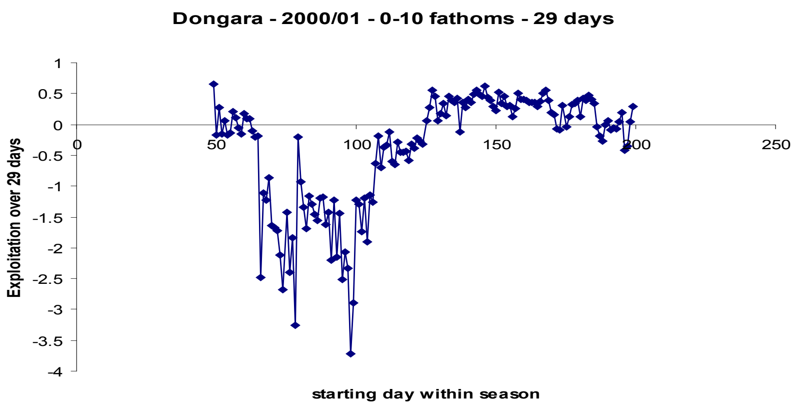


Figure 10. Estimates of exploitation over a 29 day period calculated using the IR technique and employing estimates of the number of legally-retainable lobsters per pot lift in 0-10 fathoms at Dongara between 2 January and 30 June 2001.

Estimates of exploitation calculated with the IR approach and employing the estimates of the numbers of legally-retainable lobsters per pot lift in 0-10 fathoms at Dongara between 2 January and 30 June exhibited considerable daily variation (Fig. 10). Again, it was decided to use the smoothed estimates of the numbers of legally-retainable lobsters per pot lift, *i.e.* the values derived from application of the centred 29-point moving average (Fig. 11). The results are more readily interpretable, with negative values suggesting that the assumptions of the method were invalid until at least day 122 (16 March). While estimates were positive between day 123 (17 March) and day 186 (19 May), their values increased progressively from 17 March to a maximum of 0.386 on day 156 (19 April) then progressively declined till 19 May. The average of the positive values between 17 March and 19 May was 0.2748, which corresponds to an instantaneous rate of total mortality of 4.05 year^{-1}.

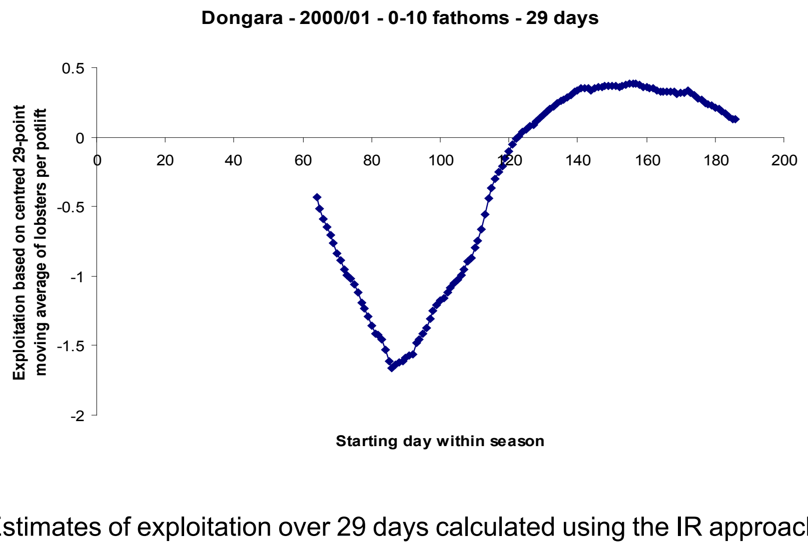


Figure 11. Estimates of exploitation over 29 days calculated using the IR approach employing centred 29-point moving average estimates of the number of legally-retainable lobsters per pot lift in 0-10 fathoms at Dongara between 2 January and 30 June 2001.

The inconsistency between the estimates obtained above by the CIR and IR methods may be explained by (1) declining catchability as temperature decreases, which would cause the results of the IR approach to be overestimated, or (2) underestimation of the exploitation using the CIR method due to failure of the assumption that the two components of the population were closed to recruitment (*i.e.* entry of new lobsters due to growth). An attempt was made to use the change in ratio to adjust the catch rate of the legally-retainable lobsters for change in catchability, but the IR approach applied to the resulting data then produced estimates that were equivalent to those of the CIR approach. While estimates of catchability can be obtained using this approach, the validity of the estimates relies on the assumption that the change in ratio method is producing accurate results and that the reason for the inconsistency is that change in catchability has influenced the estimates obtained using the IR approach.

The estimates of exploitation over a 29-day period for the above data, *i.e.* for data from 0-10 fathoms depth at Dongara in 2001, are re-presented in Fig. 12, below. The negative values that are clearly apparent in the estimates produced by the CIR method may be attributed to the effects of moulting and the resultant changes in the relative numbers of lobsters in the undersized and legally-retainable categories as a result of recruitment of lobsters to each category, and the transfer of rock lobsters from the undersized to the legally-retainable category. An alternative explanation for these negative values may be a possible change in the relative catchabilities of the rock lobsters in the two categories. The negative values of the estimates of exploitation derived using the IR approach may relate to failure of the assumptions that the "population" is closed to recruitment and that catchability is constant. The values produced by the two approaches, in the periods over which those approaches produced positive values, differed markedly in magnitude. The above results suggested that it might be necessary to constrain the analysis to those periods when the influence of growth on the undersized or legally-retainable lobsters or changes in the catchabilities of the two categories of lobsters were likely to be minimal.

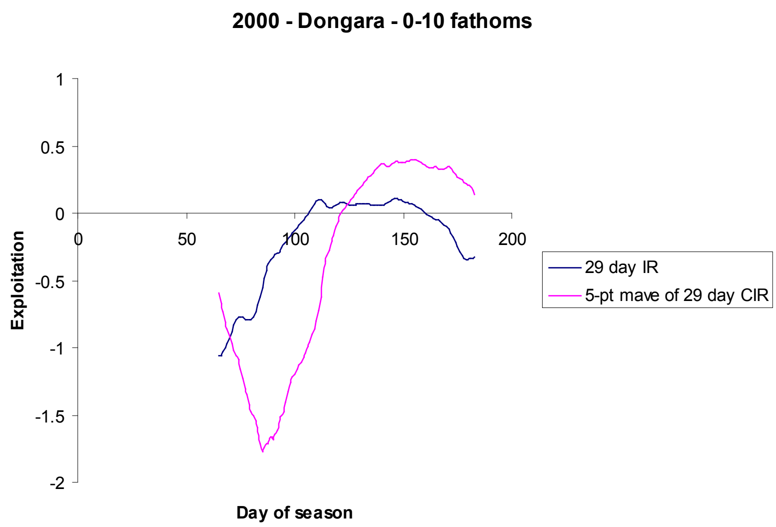


Figure 12. Smoothed estimates of "exploitation" using the IR and CIR methods over a 29-day period derived for Western Rock Lobsters in the 0-10 fathom depth range at Dongara during the 2000-01 fishing season,

The above results of the application of the CIR and IR approaches to estimate exploitation rates for the WRL data were reviewed informally with John Hoenig and Ken Pollock. It was concluded at that time that it might be useful to pursue the approaches further, by analysing data for other fishing seasons, depth zones and locations, to ascertain whether there was consistency in the trends of the estimates of exploitation rate within each data set. If such consistency existed for a common time period, it might be reasonable to consider confining the analysis to data for that period.

Analyses were conducted for data from different fishing seasons (2000-01 to 2005-06), depth zones (0-10 and 10-20 fathoms) and locations (Dongara, Jurien, Lancelin and Fremantle). The periods over which there were contiguous data, sufficient to produce smoothed estimates using the CIR and IR methods, declined until, for the 2005-06 season, no such periods existed (Fig. 13). Such periods were also limited for data from 0-10 fathoms for Fremantle (Fig. 13) and for data from 10-20 fathoms for all locations (Fig. 14). Examination of the results for those depth zones, locations and fishing seasons for which there were relatively long periods of contiguous data revealed no consistent trends in the exploitation estimates between fishing seasons at the same location or between locations and, as in the earlier analyses, negative estimates of "exploitation" were frequently produced. It was concluded from the results of this analysis that there were no consistent trends in the estimates or identifiable periods for which positive estimates of exploitation were produced that offered potential for use in deriving reliable estimates of exploitation.

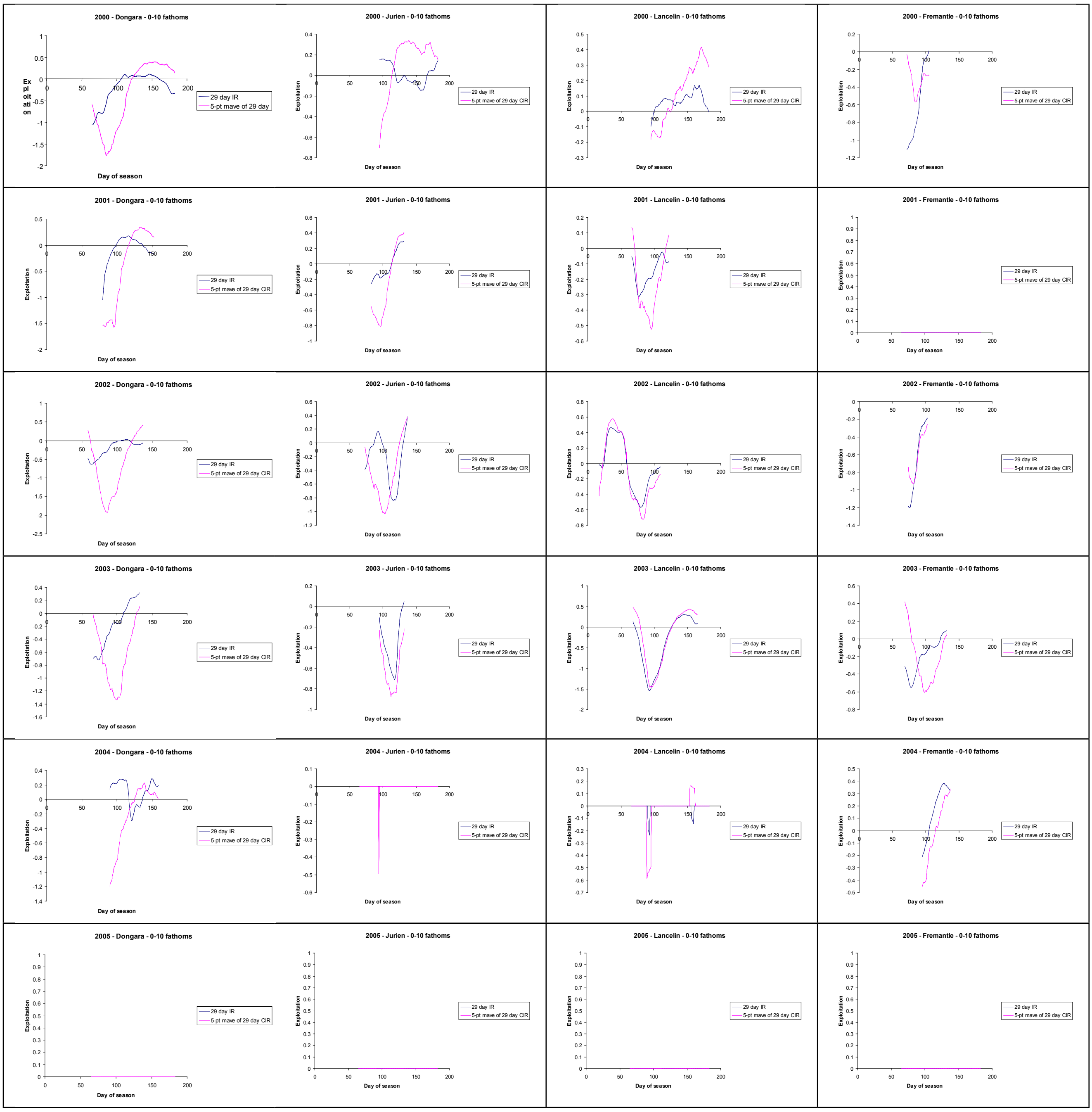


Figure 13. Smoothed estimates of "exploitation" using the IR and CIR methods over a 29-day period derived for Western Rock Lobsters in the 0-10 fathom depth range at Dongara, Jurien, Lancelin and Fremantle during the 2000-01 to 2005-06 fishing seasons. "Empty" graphs are presented when no period of contiguous points from which smoothed estimates of "exploitation" could be derived was present in the data.

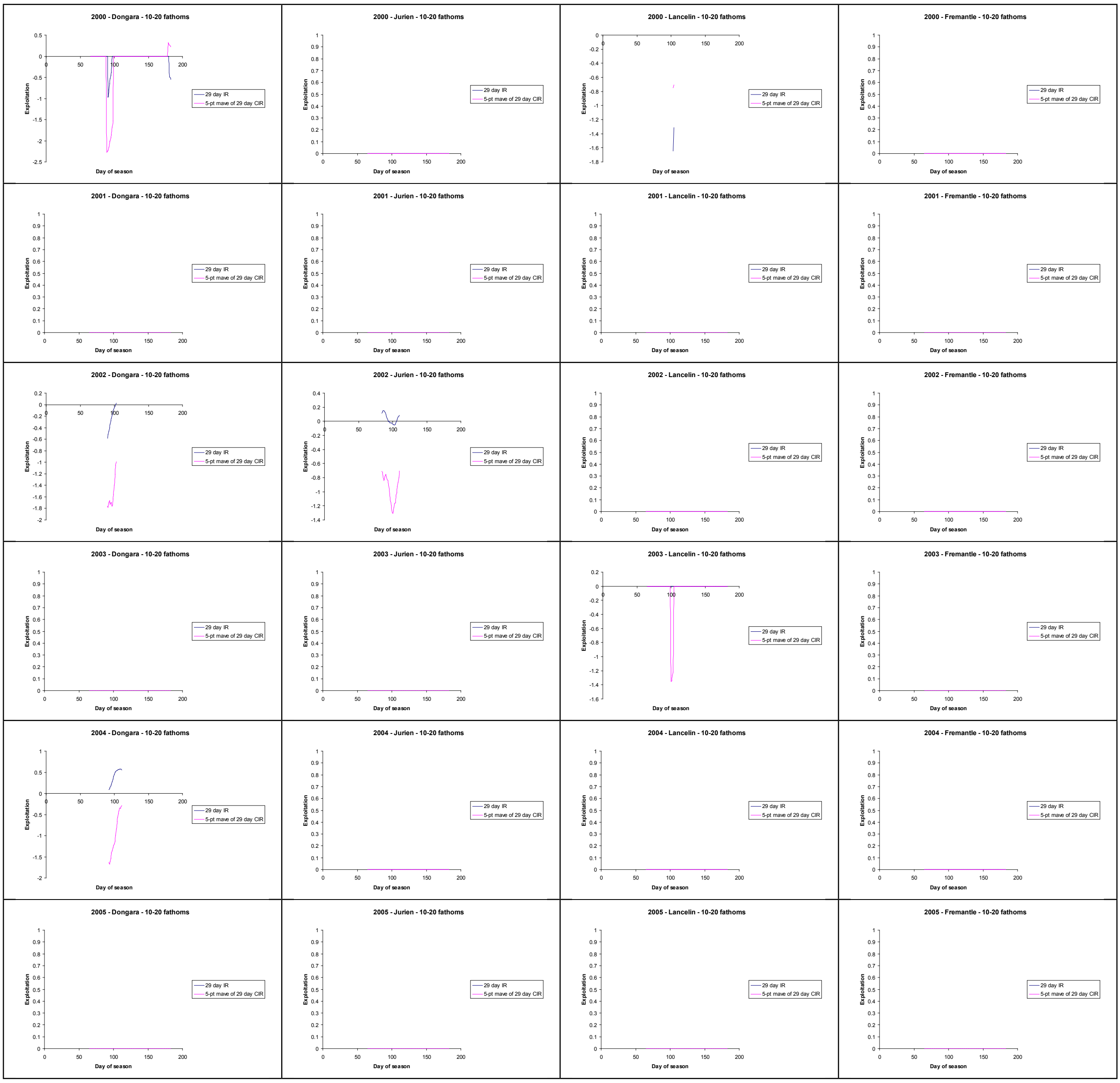


Figure 14. Smoothed estimates of "exploitation" using the IR and CIR methods over a 29-day period derived for Western Rock Lobsters in the 10-20 fathom depth range at Dongara, Jurien, Lancelin and Fremantle during the 2000-01 to 2005-06 fishing seasons. "Empty" graphs are presented when no period of contiguous points from which smoothed estimates of "exploitation" could be derived was present in the data.

It was concluded from the above that it was not possible to obtain reliable estimates of exploitation by applying the CIR or IR approaches and employing the logbook and fishery-dependent monitoring data for the Western Rock Lobster fishery. That these approaches were not able to provide estimates of harvest rate and fishing efficiency that could be used for the management of the fishery was attributed to the lack of closure of the undersized and legally-retainable categories of rock lobsters, with growth into and between these groups, and changes in catchability of one or both groups of lobsters. Failure of these assumptions and inconsistency in the numbers of lobsters moulting into the undersized and legally-retainable categories between locations and fishing seasons resulted in different trends in estimates of "exploitation" among seasons and between locations.

Removals from the Western Rock Lobster fishery are the result of capture and retention of lobsters, or of mortality following capture and release of lobsters that, because of fisheries regulations, may not legally be retained. Individuals that must be released include lobsters with carapace lengths that lie below the minimum legal size specified for the month or above the maximum legal size, "berried" (ovigerous) females, and females with visible setae, which, since 1993, have been protected with the intention of sustaining the biomass of breeding females. Capture of lobsters is made using baited pots (traps) fitted with escape gaps to reduce the vulnerability of small lobsters. Thus, the fishing gear is size-selective. Furthermore, because the baited pots are passive, the vulnerability of lobsters of different sizes, in different regions, and at different times of the fishing season determines the composition of the lobsters that are caught by fishers. Lobsters have reduced vulnerability at lower temperatures and prior to moulting, and increased vulnerability following moulting or if undergoing the migration (of "white" lobsters) between November and January.

Categories of lobsters that are distinguished in logbooks are those that must be released (because they are of sizes below the minimum legal size or above the maximum legal size for females, or are females that have visible setae) and those that are retained and landed. Monthly research samples collected from the lobsters caught by the pots (prior to sorting by fishers into those that must be released and those that may be retained) distinguish between lobsters of different sizes and sexes and among juvenile and/or unmated female lobsters and females that have been mated (and are thus bearing a "tar spot", i.e. sperm packet) or are ovigerous. Recruitment of lobsters from the undersized category occurs as a result of growth and increasing selectivity with length, while growth of lobsters beyond the minimum legal carapace length results in transition from the undersize to legal size category. Growth of lobsters from legal size to a size greater than the maximum legal size also results in a change of the category to which the lobsters belong. Mating of unmated mature female lobsters will result in a change from the unmated to mated category, while subsequent development of eggs will result in the females changing from the mated but non-ovigerous category to the ovigerous category. Subsequent moulting will "transform" mated and post-ovigerous females back to a "non-mated" state.

From the above, it is clear that, although various types of Western Rock Lobsters may be distinguished in the data from log books or research samples, the recorded numbers of lobsters in each category will vary through each fishing season due to growth, changes in selectivity and vulnerability and as a result of the reproductive cycle of female lobsters. The assumptions of closure to recruitment and "migration" and of constant catchability or vulnerability that are the basis of the simpler CIR and IR methods presented above are unlikely to be satisfied if our analysis employs data based only on the categories of lobsters that may be readily distinguished. A more robust selection of data will need to be made, such that the influences of growth and the reproductive cycle on the recorded numbers in the different categories is taken into account.

For this, it appears necessary that the categories of lobsters that are considered in the CIR or IR analyses are determined through a combination of sex, size range and, in the case of females, reproductive state, where the size range is adjusted to allow for growth within the period and thus tracks the group of lobsters through time. An appropriate adjustment will also need to be made to the removals to allow for growth through the time period. The changes in the reproductive categories into which the females fall will need to be considered in the context of the seasonal changes in the proportions of females of different sizes that are unmated, mated or ovigerous.

The difficulties encountered in the above analysis might have been resolved if additional time series of data on the quantities of lobsters moulting into the undersize and legally-retainable categories, from the undersize to the legally-retainable categories, and from these to non-retainable categories had been available, together with time series of data on the time-varying catchability of the legally-retainable category of lobsters. A well-designed tagging study, employing multiple release and recapture and analysed using an appropriate extension of the Brownie tagging model, might provide such data on catchability, growth, and relative numbers of undersize and legally-retainable rock lobsters within a selected location, together with additional data on the rate of exploitation of the latter category. The tagged lobsters could serve as a "closed" reference population at the location, against which changes in the untagged categories of undersized and legally-retainable lobsters could be assessed.

8.0 Benefits and adoption

This study has found that, without additional data relating to the relative numbers of Western Rock Lobsters that moult into the undersized and legal-sized categories of lobsters, and from the undersized to legal-sized category in different depths and regions and at different times of the year, it will not be possible to employ the CIR method to the logbook and length-monitoring data to obtain estimates of exploitation. It has also determined that data on the changes in catchability of the lobsters in the two categories in different depths and regions and at different times of the year, it will not be possible to determine exploitation rates using the IR approach. While the fact that these approaches failed to produce reliable estimates of exploitation may appear to be of little benefit to the fishery, the truth is actually quite different. The results highlight that, for models of the Western Rock Lobster fishery to utilise fully the information contained within fishing season changes in ratio or catch rate when calculating exploitation rates, they will require additional data on moulting and changes in catchability of different size classes and categories of lobsters in different depths, regions and at different times of the year. Although the current stock assessment model for the Western Rock Lobster fishery is able to estimate exploitation rates, it would appear from the results of this study that there would be benefit in collecting data that would contribute information on moulting and catchability change throughout the season. Such data might be derived from a robust tagging study.

9.0 Further development

The results of the project, which are presented in this report to the FRDC, will be available to fishers and the community through downloading the report from the Department's web site. No data were collected during the project. The data employed in the analyses were accessed from existing Departmental databases of logbook and fishery-dependent sampling data. Details of the algorithms used in the study are described in this report.

A proposal is being developed for a multi-year, multi-season tagging study to be undertaken, the objectives of which are to determine information on growth, movement, catchability, and exploitation. Such a study would provide data that would make it possible to explore whether use of CIR and IR approaches, in combination with data on moulting and catchability derived from the tagging study, would augment the accuracy of the estimates of exploitation that are determined using only the results from the tagging study. The tagging information would also enable in improved parameters in the WRL stock assessment model.

10.0 Planned outcomes

The outcomes proposed in the application for this study were dependent on the success of the project. If the CIR and IR methods had proved useful in estimating exploitation in the Western Rock Lobster fishery, it had been expected that the methodology would have enabled the production of more reliable estimates of fishing efficiency increases and harvest rate, thereby improving the quality of the management decisions taken, and facilitating the sustainable management of the fishery. By incorporating the results of the approach in the integrated stock assessment model, it was hoped that the reliability of management strategy evaluations and model predictions would have been improved.

Although the study demonstrated that the CIR and IR methods could not be employed with existing data, the study was successful in determining that, if the full information content of the within-season logbook data is to be employed in stock assessment, it will be necessary to augment the data with information relating to changes in catchability and moulting through the fishing season in each depth and region. This result is important as it identifies a critical gap in the data that are available for the lobster fishery.

11.0 Conclusion

The objectives of the study were achieved, in that (1) current data sources and their potential for estimating harvest rates and increases in efficiency in the western rock lobster fishery using CIR and IR techniques were assessed; (2) the question of whether additional sources of information are needed to produce more robust estimates of harvest rate and efficiency increase was evaluated; and (3) an assessment was undertaken of whether the CIR and IR estimates of harvest rate and fishing efficiency are reliable and could be used for the management of the western rock lobster fishery.

The study has resulted in the following:

1. Demonstration that application of the CIR method to the change in ratio of legal-sized to undersized lobsters derived from logbook data for the Western Rock Lobster fishery resulted in estimates of exploitation that were inconsistent between depths, regions and time periods, and that the estimates were often clearly biased, as revealed by negative values.
2. Demonstration that application of the IR method to the change in cpue of legal-sized lobsters as determined from logbook data for the Western Rock Lobster fishery resulted in estimates of exploitation that were also inconsistent between depths, regions and time periods, and that, as with the results from the CIR analysis, the estimates were often clearly biased, as revealed by negative values.
3. The inconsistencies and negative values obtained for the CIR estimates of exploitation rate were attributed to the failure of the assumption that the population was closed and that the only factor responsible for the change in ratio of the legal-sized to undersized lobsters was due to the removals of the former category of lobsters by the fishery. That is, the change in ratio appears to have been affected by moulting of Western Rock Lobsters into both the undersized and legal-sized categories, and between the undersized and legal sized category. Another factor that may possibly have affected the abundance of legal-sized individuals is the development of setae by mature females, which may have removed them from the legally-retainable category of lobsters. However this latter factor is likely to have been negligible because the analysis was restricted to data for the latter portion of the fishing season.
4. The inconsistencies and negative values obtained for the IR estimates of exploitation rate were attributed to the failure of the assumptions that the legally-retainable population was closed to recruitment and loss other than fishing and that catchability was constant between the start and end of the time period over which exploitation was estimated. Both moulting and catchability change may have occurred.
5. As with the Tasmanian FRDC study (FRDC 1997/101), it was concluded that additional data that would provide information on within season moulting and catchability change would need to be collected and employed within the CIR and IR analyses in order to account for the effects of these factors on the estimates of exploitation. The collection of appropriate tagging data appears to be the most effective way in which such data could be obtained.
6. The changes in catchability and moulting that appear to have affected the results of the CIR and IR analyses are also likely to be having an effect on the results of the current integrated model that is employed for stock assessment. The data collected from an appropriate tagging study would therefore improve the results of the stock assessment model.
7. It is strongly recommended that a well-designed multi-year, multi-season tagging study be designed and undertaken in each depth zone and region of the fishery, to provide data that will facilitate the estimation of exploitation rates and improve the accuracy of future stock assessments.

12.0 References

Bishop, G. H., Siddon, C. E., and Rumble, J. M. 2010. Change-in-ratio and index-removal population estimation of Dungeness Crab in southeastern Alaska. *In* Kruse, G. H., Eckert, G. L., Foy, R. J., Lipcius, R. N., Sainte-Marie, B., Stram, D. L., and Woodby, D. (editors). Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks. pp. 517-536.

Brown, R. S., Caputi, N., and Barker, E. 1995. A preliminary assessment of increases in fishing power on stock assessment and fishing effort expended in the western rock lobster (*Panulirus cygnus*) fishery. *Crustaceana,* **68**: 227-237.

Chen, C.-L., Hoenig, J. M., Dawe, E. G., Brownie, C., and Pollock, K. H. 1998. New developments in change-in-ratio and index-removal methods, with application to snow crab (Chionoecetes opilio). *In* Jamieson, G. S. and Campbell, A. (Eds.) 'Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management'. *Canadian Special Publication in Fisheries and Aquatic Science*, **125**. pp. 49-61.

Claytor, R., and Allard, J. 2003. Change-in-ratio estimates of lobster exploitation rate using sampling concurrent with fishing. *Canadian Journal of Fisheries and Aquatic Sciences*, **60**: 1190-1203.

Dawe, E. G., Hoenig, J. M., and Xu, X. 1993. Change-in-ratio and index-removal methods for population assessment and their application to snow crab (*Chionoecetes opilio*). *Canadian Journal of Fisheries and Aquatic Sciences,* **50**: 1467-1476.

De Lestang, S., Caputi, N., How., J., Melville-Smith, R., Thomson, A. and Stephenson, P. 2011. Draft Stock Assessment for the West Coast Rock Lobster Fishery. Fisheries Research Report: 217. 226 p. http://www.fish.wa.gov.au/docs/frr/frr217/frr217.pdf

Fernandez, J. A., Cross, J. M., and Caputi, N. 1997. The impact of technology on fishing power in Western Rock Lobster (*Panulirus cygnus*) Fishery. International Congress on Modeling and Simulation Proceedings (MODSIM 97), **4**:137-148.

Frusher, S. D., Hoenig, J. M., and Ihde, T. F. 2007. Evaluating catchability assumptions for change-in-ratio and index-removal estimators, with application to Southern Rock Lobster. *Fisheries Research*, **84**: 254-262.

Frusher, S. D., Kennedy, R. B., and Gibson, I. D. 1997. Precision of exploitation-rate estimates in the Tasmanian rock-lobster fishery based on change-in-ratio techniques. *Marine and Freshwater Research*, **48**: 1069-1074.

Frusher, S. D., Kennedy, R. B., and Gibson, I. D. 1998. Preliminary estimates of exploitation rates in the Tasmanian rock lobster (*Jasus edwardsii*) fishery using the change-in-ratio and index-removal techniques with tag–recapture data. *In* Jamieson, G. S. and Campbell, A. (Eds.) 'Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management'. *Canadian Special Publication in Fisheries and Aquatic Science*, **125**. pp. 63-71.

Frusher, S. D., Mackinnon, C. J., and Phillips, A. 2003. Assessment of broad scale exploitation rates and biomass estimates for the Tasmanian Southern Rock Lobster fishery. Fisheries Research & Development Corporation, Final Report, FRDC Project No. 1997/101.

Gedamke, T., DuPaul, W. D., and Hoenig, J. M. 2005. Index-removal estimates of dredge efficiency for sea scallops on Georges Bank. *North American Journal of Fisheries Management*, **25**: 1122-1129.

Heimbuch, D. G., and Hoenig, J. M. 1989. Change-in-ratio estimators for habitat usage and relative population size. *Biometrics*, 45: 439-451.

Hoenig, J. M., and Pollock, K. H. 1998. Index-removal methods. In Encyclopedia of Statistical Sciences, Update Volume. Edited by S. Kotz, C. B. Read, and D. L. Banks. John Wiley & Sons, Inc., New York, N.Y. pp. 341-346.

Ihde, T. F., Hoenig, J. M., and Frusher, S. D. 2008a. Evaluation of a multi-year index-removal abundance estimator, with application to a Tasmanian rock lobster fishery. *Fisheries Research*, **89**: 26-36.

Ihde, T. F., Hoenig, J. M., and Frusher, S. D. 2008b. An index-removal abundance estimator that allows for seasonal change in catchability, with application to Southern Rock Lobster *Jasus edwardsii*, *Transactions of the American Fisheries Society*, **137**: 720-735.

Pollock, K. H., and Hoenig, J. M. 1998. Change in ratio estimators. In Encyclopedia of Statistical Sciences, Update Volume. Edited by S. Kotz, C. B. Read, and D. L. Banks. John Wiley & Sons, Inc., New York, N.Y. pp. 109-112.

Wright, I., Caputi, N., and Penn, J. 2006. Depletion-based population estimates for western rock lobster (*Panulirus cygnus*) fishery in Western Australia. *New Zealand Journal of Marine and Freshwater Research,* **40**: 107-122.

13.0 Appendices

13.1 Appendix 1: Intellectual property

The information produced in the study is not suited to commercialisation.

13.2 Appendix 2: Staff list

Staff employed on the project included:

Dr Simon de Lestang

Emeritus Professor Norman Hall

Dr John Hoenig

Dr Stewart Frusher