Building precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through addressing grading and regional anomalies

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Abbreviations/Acronyms

Acronym	**Description**
AILMCGS	Australian Industry Live Mud Crab Grading Scheme
CAC	Commercially Acceptable Crab
CUC	Commercially Unsaleable Crab
CUCs	Commercially Unsuitable Crabs – NT terminology
DAF	Department of Agriculture and Fisheries, Queensland
EIT	Electrical Impedance Tomography
FRDC	Fisheries Research and Development Corporation
GoCCFA	Gulf of Carpentaria Commercial Fishermen Association Inc.
HFSP	Health and Food Science Precinct
JCU	James Cook University
LDA	Linear Discriminant Analysis
NIR	Near Infrared
NMCIRG	National Mud Crab Industry Reference Group
NMRI	Nuclear Magnetic Resonance Imaging
NSW	New South Wales
NT	Northern Territory
PCA	Principal Components Analysis
PFA	Professional Fishermen's Association
PLS	Partial Least Squares
QLD	Queensland
QSIA	Queensland Seafood Industry Association
RI	Refractive Index
SFM	Sydney Fish Market

Executive Summary

What the report is about

The very first Australian Industry Live Mud Crab Grading Scheme (AILMCGS) was rolled out across the entire Australian mud crab industry in November 2012. The scheme was an industry owned and driven initiative to resolve the ambiguity of having various schemes operating around the country. An initial survey on the status of the industry's grading issues identified areas of the scheme that would improve its acceptance and use to both sellers and buyers. From the outset of the project the industry worked in consultation with the research team to modify attributes of the scheme resulting in a better predictive test for crab quality and meat fullness.

The process used to confirm regional and seasonal anomalies was based on the hypothesis that due to recent seasons of high rainfall in parts of New South Wales (NSW), crab shell deposition and subsequent shell hardness had been influenced by water salinity.

Objective methods to grade crabs were scoped and identified to not only provide a science-supported assessment technique to standardise grading under the AILMCGS, but also to identify a cost effective, robust and practical, on-board objective tool to provide consistent and assured grading standards.

Background

Since the introduction of the AILMCGS in November 2012, variability in the application of the thumb pressure grading technique and regional or seasonal anomalies led to some discontent within certain sectors of the industry. With the broader uptake of the scheme, a range of both positive and negative views were expressed from industry sectors. The scheme was market tested at Sydney Fish Market (SFM) prior to its official launch. As the scheme was bedding in around the nation, serious concerns were raised from members of the National Mud Crab Industry Reference Group (NMCIRG) and some sectors, chiefly NSW, that incorrect application of the scheme could be used to manipulate price at various stages of the supply chain. Some misunderstandings in the methodologies of applying the scheme were expressed from specific regional sectors based on what is 'normal' for crabs from those regions. Industry members felt that recent seasons of high rainfall in parts of NSW may be responsible for a reduction in shell deposition resulting in good crab being downgraded at market and crabs from some regions "never reaching full hardness".

There has been a widespread call from industry, including from members that are both satisfied and disgruntled with the current scheme, to have an objective method to determine crab quality and associated grade. Although the use of hand testing is the 'tool' of choice and practicality at this stage, the industry has expressed a strong desire to have an objective method to determine crab quality and associated grade.

Aims/objectives

The project's initial goal was to attain a defined and precise grading technique related to shell hardness using the current AILMCGS. Redefining the procedures and attributes of the scheme to improve the consistency of its application along the supply chain would reduce discontent and downgrades at market.

Seasonal and/or regional grading anomalies need to be substantiated, and if necessary, strategies explored to address them.

Objective technologies and/or methodologies are to be identified to support grading assessment within the AILMCGS. By developing a science-supported assessment technique a standardised grading scheme should address any seasonal and/or regional anomalies if confirmed. Ideally, there will be a cost effective, practical objective tool identified to provide assured grading standards.

Providing all sectors of the industry with equity of grading practices should reduce product downgrades, increase consumer satisfaction and industry profitability.

Methodology

The project engaged directly with industry members through port visits, surveys, forums and workshops. An initial survey on the current status of the industry's grading issues was distributed through peak bodies, industry databases and researchers contact lists. Summarised results were distributed to responders of the survey and key NSW Fishermen's Co-operatives. A subsequent survey on consumer and industry expectation of meat fullness and willingness to pay was conducted and analysed to refine cut-off points between grades.

A series of trials were conducted in recirculated research tanks to test the hypothesis that low salinities may effect shell deposition and hardness. Additionally, the notation that shell hardness decreases whilst crabs are in the supply chain was tested. The full range of parameters used to define crab grades was rigorously analysed to determine the most appropriate attributes that would consistently predict crab quality and the ultimate cooked meat yield.

Objective methods of grading were scrutinised to assist in the refinement of the scheme and identify any non-invasive technologies that may offer a better prediction of meat fullness than the shell hardness thumb pressure test.

Results/key findings

From whole of industry survey results it was clear that there was awareness and support of the concept of having a national live mud crab grading scheme. However, some of the survey responders (24%) were extremely dissatisfied with the initial scheme. It was very evident that their concerns related to the amount of pressure thumb force to apply, effect of repeated pressure tests and application of the scheme along the distribution chain. All responders wanted to see modifications to the initial AILMCGS, but despite a level of dissatisfaction with the scheme since its implementation, most responders said they had changed their grading practices as per the scheme.

Regional anomalies of crabs with high meat fullness and flexible shells were observed most frequently in mud crabs harvested from NSW estuarine waters. Research trials demonstrated that this anomaly is not related to low salinities as hypothesised. From the results of investigation, environmental salinity difference does not appear to affect mud crab shell hardness; nor did exposure to air during transport chains.

The studies of the consistencies between methods for grading crabs (i.e. method based on shell hardness and method based on haemolymph Refractive Index values) revealed that they were fairly consistent for female crabs, but for male crabs they can be considered independent. However, observations of cooked body meat revealed that female crab grades were less predictable by shell grading. The relationship between meat fullness and shell hardness is strong for female crabs, but only if they are rock hard or very soft. Male crabs follow a similar pattern but to a lesser degree.

A range of objective technologies were scoped and investigated with various degrees of success. Two options show promise for future development as useful predictive tools; acoustic velocity (sound waves) and near infrared (light). Overall, the results obtained suggest a stronger linear relationship for the NIR instrument as a good predictor of percentage meat yield and grades.

Implications for relevant stakeholders

The refinement of 'A' grade and 'C' grade parameters in Version 3 of the scheme should alleviate the incongruities in the variations between meat fullness and shell hardness. Analyses of the potential revenue resulting in this refinement of the scheme indicate an increase of \$2.18/kg for male crab and \$2.80/kg for female crab across all grades.

As this is an industry initiated and owned grading scheme, it is imperative that the onus remains on the crabber to grade in accordance with the AILMCGS at harvest point through continued positive reinforcement from industry's peak bodies. It is highly desirable to maintain the NMCIRG for future discussions on industry issues e.g. NT Gulf female crab restrictions, take of 'C' grade crabs in QLD, and export opportunities.

Recommendations

Regional anomalies in mud crab grades assessed in the supply chain have been confirmed and addressed, initially in Version 2 and finally in Version 3 of the AILMCGS. Industry has responded favourably to the scheme's development. The scheme should not require any further development. All efforts should be made to continue to encourage all fisher groups to release newly moulted crabs at the point of harvest.

An extensive array of non-invasive technologies that may offer objective grading opportunities was identified and tested with some of them looking very promising. Industry partners are keen to have these adopted and there has been an overseas investment opportunity to explore the identified options.

Keywords

mud crab, *Scylla serrata*, quality, grading scheme, industry, supply chain, markets, non-invasive, technology

1 Introduction

The Australian Industry Live Mud Crab Grading Scheme (AILMCGS) was initially developed as part of FRDC Project 2011/225 '*Using Industry expertise to develop a National Grading Scheme*' and supported by the National Mud Crab Industry Reference Group (NMCIRG). The scheme was formally released across the entire Australian mud crab industry in November 2012 via a targeted communication strategy, including a suite of information brochures, videos and on-line sources.

With this broader uptake of the scheme, a range of both positive and negative views have been expressed from industry sectors. The scheme was market tested at Sydney Fish Market (SFM) prior to its official launch. This allowed for any obvious problems or perceptions to be addressed prior to launch. As the scheme was bedding in around the nation, serious concerns were raised from members of the NMCIRG and fishers not represented by any peak body that incorrect application of the scheme could be used to manipulate price at various stages of the supply chain. Specifically, the degree, exact location and repeated pressure of the thumb test could not only be exploited at the buyer end but could be misinterpreted. Some misunderstandings in the methodologies of applying the scheme were expressed from specific regional sectors based on what is 'normal' for crabs from those regions. The rollout of the grading scheme coincided with a series of wet seasons in New South Wales (NSW). It was proposed from both fishers and wholesalers that the resultant low salinities from extended periods of high rainfall leads to crabs with thin or weak carapaces whilst having good meat yields similar to higher grade crabs.

The scheme was also introduced about the same time as the SFM changed their auction system for mud crabs. This change has had a number of ramifications. Previously, boxes of crabs were laid across the SFM floor in a single layer, allowing buyers full access for inspection of matching grades and quality prior to auction. Boxes were sold via a traditional increasing price voice auction. Under the new system, boxes from each supplier are stacked, allowing limited pre-inspections and the auction is now on the electronic clock in a modified Dutch auction system. The major implication of this is that buyers now predominately base their bids on the history or reputation of the supplier's crabs in matching grading parameters, hence the importance of a uniform grading application at the harvest source.

In conjunction with the Seafood CRC Project 2012/758 '*Increase sustainable use of crab fisheries resources by recovering revenue from crabs currently rejected at market*', concerns of crab grades changing through transport from packing to market Quality Assurance were expressed from both the harvest and buyer sectors. That project's primary aim was to recover crabs rejected or downgraded at market due to being slow, hence likely not to survive further in the supply chain as reported in FRDC Project 2003/240 '*Maximising Revenue within the NT Mud Crab Fishery by Enhancing Post-Harvest Survival of Mud Crabs'*. However, recently moulted crabs that may fall into the 'C' grade category also show signs of weakness as they have reduced energy stores following the moulting process. This is an excellent example of why it is therefore imperative that crabs are graded accurately at all sectors of the supply chain.

Variability and inconsistency in the application of the thumb pressure grading technique and regional and seasonal anomalies have led to some discontent with the AILMCGS. The grading scheme provides a range of physical attributes, along with a subjective assessment of shell-hardness, to provide consistency in live mud crab grading on a national scale. Consistent grading gives buyers and consumers a product that defines market price expectation to be paid.

Due to variables of lifecycle, seasonality, regionalism, habitat, individual grader and grading techniques, the scheme can never be a 100% guarantee of meat content associated with the given grade. It is implicit to the scheme to apply pressure in a precise and readily reproducible way to minimise variations, damage to, and loss of product.

There has been a widespread call from industry, including from members that are both satisfied and disgruntled with the current scheme, to have an objective method to determine crab quality and associated grade. This relies on clear and precise testing protocols. However, the realities of the operation of this industry are, at this stage, that the use of hand testing is the 'tool' of choice and practicality.

Developing a science-supported assessment technique would standardise grading and allow for any seasonal and/or regional anomalies to be addressed. Ultimately, there is a need for a cost effective, robust and practical, on-board objective tool to provide consistent and assured grading standards.

2 Objectives

1) to attain a defined and precise grading technique related to shell hardness using the current Australian Industry Live Mud Crab Grading Scheme (AILMCGS) across whole of industry

2) substantiate seasonal and/or regional grading anomalies within the AILMCGS and explore strategies to address them

3) identify objective technologies and/or methodologies developed to support grading assessment within the AILMCGS

4) increase profitability across industry through equity of grading practices and reduced product wastage

3 Methods

3.1 Crab grading

Grading was performed as per AILMCGS Version 1 (as reported in FRDC 2011/225) where the crab is held in both hands, with your palms facing upwards and the flat of your thumbs on the test segment and press gently at first. The ease of flex is related to the grade given. Additionally, a shell hardness score was given for each test segment to provide a quantitate value of total shell hardness as measured for all the entire crab (Table 1).

Table 1: Shell hardness score descriptors

Shell hardness score	Description
4	No flex using firm pressure
3	Slight flex with moderate pressure
2	Easily flexed with light pressure
1	Very soft, easily flexed with minimal pressure

The cooked and cleaned body cavities were assigned a visual grade of meat fullness from 'A' representing completely full, 'B' having some free space and 'C' having more free space than meat. Female crab ovaries were removed prior to this evaluation as the variance of sexual maturity was large.

3.2 Sampling of haemolymph

A 22G x ¾" Terumo needle attached to a 3 ml Terumo syringe was inserted at the synapse where the third walking leg (from the front) joins to the carapace. The leg joint must be extended to stretch out the membrane and reveal a white triangular marking. The needle was inserted 5-10 mm into an interstitial cavity beneath the tip of the triangular marking on the membrane of the leg joint (Image 1) and angled to follow an imaginary line to the apex of the belly flap. Haemolymph (0.5 ml) was withdrawn slowly to avoid collapsing the cavity.

Image 1: Extraction of haemolymph sample

3.3 Total protein (Refractive Index, RI)

The RI protein of freshly sampled haemolymph was measured immediately by placing 1-2 drops (enough haemolymph to cover the prism without air bubbles) directly from the sample syringe onto the glass prism of the hand-held refractometer (Atago model SUR-NE calibrated with distilled water). The refractometer lid was then closed before the haemolymph clotted and held towards a fluorescent strip light to assist reading the internal scale accurately. Alternatively, a digital pocket refractometer (Atago model PAL-RI) was used in a similar fashion to the hand-held model (Image 2). Results were manually recorded from the Refractive Index (RI) scale in nD units. Although these units can be converted to mg/ml Total Protein (as per FRDC Project 2003/240), reporting here is presented in nD units as this has become a recognisable reference for industry.

Image 2: Refractometry instruments used for mud crab haemolymph

3.4 Crab quality parameters

Data for 107 mud crabs (54 female and 53 male) were recorded on multiple traits for each crab with the objectives of:

a) Identifying relationships amongst the traits and identifying which traits are more closely related to meat yield.

b) Exploring the feasibility of developing a classification scheme for mud crabs that would predict their meat yield.

Female and male crabs are very different in their internal composition. For this reason, relationships are explored for all crabs together and then separately for crabs of each sex. Firstly, the consistency of the grades assigned to crabs by the three methods in the data is studied using contingency tables and the chi-squared test. Secondly, the matrices of correlations between traits are explored using cluster analysis in order to find groups of traits correlated with each other. Lastly, principal components analysis is used to identify patterns in the data that could reveal associations between traits and grading methods.

Description of the dataset

Multiple traits were recorded on 107 mud crabs. Traits involved physical measurements and several traits related to meat recovery. The trait names (with brief description) are:

- Sex
- MajorClaw (indicates which claw is the major claw: L for left, R for right)
- ResGrade (‘A’, ‘B’, ‘C’ grades assigned by Researcher, John Mayze using the shell hardness test)
- CrabberGrade (‘A’, ‘B, ‘C’ grades assigned by the crabber using the shell hardness test)
- Grade.by.RI (‘A’, ‘B’, ‘C’ grades assigned by arbitrary cut-points of the RI scale)
- ShellScore (shell hardness score)
- Weight (weight of the live crab, in grams)
- Width (width of the crab, in mm)
- Body.Height (height of the crab, in mm)
- Major.Width (width of the major claw, in mm)
- Major.Height (height of the major claw, in mm)
- RIpreCairns (Haemolymph RI, taken shortly after capture)
- RIpostCairns (Haemolymph RI, taken before cooking)
- WholeClaw.CL (weight of the whole cooked left claw, in grams)
- WholeClaw.CR (weight of the whole cooked right claw, in grams)
- WholeClaw.CC (combined weight of the whole cooked left and right claws, in grams)
- ClawMeat.CL (weight of the meat in the cooked left claw, in grams)
- ClawMeat.CR (weight of the meat in the cooked right claw, in grams)
- ClawMeat.CC (combined weight of the meat in the cooked left and right claws, in grams)
- Yield.L (yield percent of the left claw calculated as 100*(ClawMeat.CL/ WholeClaw.CL)
- Yield.R (yield percent of the right claw calculated as 100*(ClawMeat.CR/ WholeClaw.CR)
- Yield.C (yield percent of the combined left and right claws calculated as 100*(ClawMeat.CC/ WholeClaw.CC)
- Yield.Maj (yield percent of the major claw)
- Yield.Min (yield percent of the minor claw)

Statistical methods

The dataset contains three variables with grades for the crabs: ResGrade, CrabberGrade and Grade.by.RI that correspond to three different ways of assigning grades to the crabs. The first two use the shell hardness test and are carried out by two different people, and the last one uses arbitrary cut points on the RI scale. Agreements and disagreements between these ways of assigning grades can be explored to investigate how consistently they grade crabs into the same categories.

Contingency tables are used for studying the consistencies and Pearson’s chi-squared test is applied to test if the grades given to the crabs are independent. The hypothesis it tests is a null hypothesis (H_0); there is no relationship between the two ways of grading the crabs. If this hypothesis is not rejected (i.e. if the p-value for the test is > 0.05) then it means that the ways of grading are not consistent in the grades they assign to the crabs. (For more information on Person's chi-squared test of independence see Moore (1995), for example).

Cluster analysis

Cluster analysis is a multivariate technique that can help with understanding the complex nature of multivariate relationships. Groupings can provide an informal way of assessing dimensionality, identifying outliers, and suggesting hypothesis regarding relationships. Cluster analysis makes no assumptions on the number of groups or the group structure. Grouping is done on the basis of similarities or distances (dissimilarities), therefore similarity measures or data from which similarities can be calculated, must be provided. (For more information on this multivariate technique, see Johnson and Wichern (1992), for example).

In this application, cluster analysis was applied to the matrix of correlations for all numerical traits in order to understand the correlations amongst them. Scatterplots between pairs of traits (not shown) indicated that the relationships between traits were linear. Additionally, the numeric traits are continuous (close enough to continuous in the case of ShellScore). Both of these characteristics of the traits allow the use of the Pearson correlation coefficient as the similarity measure.

Three cluster analyses were performed, namely, on the correlation matrix of all traits for all crabs, on the correlation matrix of all traits for female crabs only and on the correlation matrix of all traits for male crabs only.

Cluster analysis was performed using the agnes agglomerative hierarchical algorithm of the cluster package in R. The clustering algorithm uses average linkage and was applied to the dissimilarity matrix for the traits, which is obtained by subtracting each correlation from 1. Clusters (i.e. groups of traits that are positively correlated) were determined using a cut-off point of around 0.5 on the dissimilarity scale of the dendrogram to ensure that the average correlation between the traits in any given cluster is at least 0.5.

Heatmaps provide graphical representations of the correlation matrices by colour-coding the correlations between pairs of traits in following way: red and orange indicate high, positive correlations; yellow indicates weak, positive correlation; green indicates poor or no correlation; light blue shades indicate weak, negative correlations; and dark blue indicates strong, negative correlation. The ordering of the traits on the heatmaps follows the order defined by the cluster analyses, for ease of visualisation of the groups of traits and their relationships.

Principal components analysis

The general objectives of Principal Components Analysis (PCA) are data reduction and interpretation. PCA explains the variance-covariance structure of the data through a few linear combinations of the original variables. An analysis of principal components can often reveal relationships that were not previously obvious and allow interpretations that would not ordinarily result. PCA based on the variance-covariance matrix is not scale invariant; therefore when variables are measured on different scales the correlation matrix must be used. (For more information on this multivariate technique see Johnson and Wichern (1992), for example).

In the present application, the variables (mud crab traits) were measured on different scales; therefore PCA was performed on the correlation matrix between traits. The minimum number of principal components that explained at least 80% of the total variability was retained for interpretation.

The traits that have the highest influence in the determination of a principal component are those with the highest positive and those with the lowest negative loadings for that principal component. Each individual (crab) has a score on each of the principal components, according to its values on each of the original variables.

The biplot is the combined graph of trait loadings and crab scores. PC1 is always plotted along the horizontal axis and the other components are always plotted along the vertical axes. Therefore, the most influential traits on PC1 have segments that extend further to the left and right of the graph, and the most influential traits on the other PCs have segments that extend further to the top and bottom of the graph.

For the purposes of easily displaying the entry scores and the trait loadings on the same biplot, both scores and loadings were rescaled to vary within ± 1. Individual mud crabs on the biplots are identified according to the three different grading scores available (ResGrade, CrabberGrade and Grade.by.RI) to allow graphical identification of groups of crabs with the same grade.

Separate principal components analyses were performed on the correlation matrices between traits for female and male crabs using the princomp procedure in R.

3.5 Candling

In this study LED visible light sources were used to illuminate a) the mud crab carapace, and b) the dominant claw. Upon illumination, photos were taken of the illuminated carapace and claw (top, side and bottom profile) using a Canon EOS 300D SLR camera and photos subsequently assessed based on percent meat yield of the claws.

The light set up applied to the carapace consisted of a) a round flood light with a diameter of 120 mm with seven individual LED lights producing a total of 3486 Lumens; and b) a 120 mm single row light bar consisting of five individual LED lights producing a total of 2250 Lumens. The round flood light was orientated facing up to illuminate the crab from the underbelly and the light bar was configured to illuminate the mud crab from the front. The lighting was incorporated around a clear acrylic platform enabling the mud crab to be easily placed on the acrylic platform with the lighting fixed in the above mentioned orientation (Image 3).

Image 3: LED lighting platform for candling (left) and mud crab on candling platform (right)

A combination of one or two 1000 Lumen LED head lamps (Ledlensor H14R.2) were used to illuminate the dominate claw depending on size. The LED lamp(s) were orientated to enable illumination for photographing of the top, bottom and side profile of the claw (as per Image 4) to produce the candling affect.

Side Profile:

Top Profile:

Bottom Profile:

Image 4: Placement of LED lamp(s) to provide illumination of claw for top, bottom and side profile

3.6 Acoustic Velocity

In conjunction with the Near Infrared (NIR) and candling trials, the acoustic velocity technology was developed and tested by the expert team of physicists at the joint DAF/JCU Rapid Assessment Unit, Cairns.

Acoustic velocity and attenuation were measured in transmission mode using two 5 MHz transducers (line focussing immersion probes from SIUI International). The transducers were held at a fixed separation distance of 86 mm by 3D printed mounts bolted to a plastic board. The transmitting transducer was driven by an arbitrary function generator (Tektronix AFG3021) that was configured to generate periodic bursts of five sine wave cycles at the resonant frequency of the ultrasound crystal. The transmitting amplitude was 10 V peak-to-peak. The signal at the receiving transducer was measured by a digital storage oscilloscope (Tektronix TBS1102B), and the captured waveforms were saved in real time to a computer. The basic system is shown in Image 5.

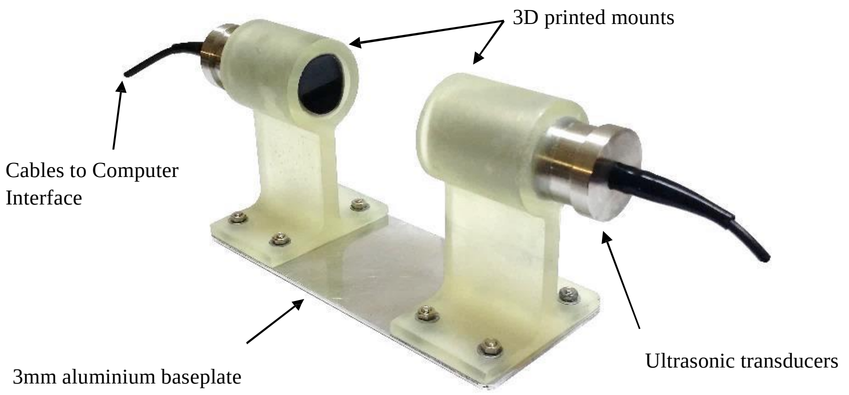


Image 5: Acoustic velocity and attenuation measurement system

All measurements were conducted in a large plastic tub (approximately 600 x 400 x 250 mm) filled with tap water and left at room temperature of approximately 25°C. Before every measurement, the ultrasound probes were first inserted into the water to record the baseline time-of-flight, from which the speed of sound in the water could be calculated. This provided compensation against temperature drift. Next, the dominant claw of the crab was held against the transmitting transducer (Image 6 - left) such that the signal would transverse the thickest part of the claw. Due to the orientation of the tied-up crab claws, measurements were conducted along the semi-major axis of the claw.

Image 6: Dominant crab claw against transducer (left); signal on oscilloscope (left)

During this process, the transmit and receive oscilloscope traces were periodically captured by the computer at a rate of approximately 2 – 3 Hz. The crab was held in place until a clear and consistent time-of-flight signal was observed on the oscilloscope screen (Image 6 - right). However, a signal could not be found for some individuals in the study (13 crabs, approximately 15% of the sample). The explicit reason for this is unknown, but is potentially due to the limited transmit power provided by the function generator. For some crabs, an acoustic measurement could not be found at all, and these have been excluded from the analysis in this section.

The signals were post-processed by manually selecting the oscilloscope traces that corresponded to acoustic transmission through the crab (as opposed to an intermediate step during which the position of the crab was not constant or not yet properly aligned). These were judged based upon annotations made during the experiment, and also by examining the received waveforms in search of consistent measurements indicating that the crab was properly held in place. For each trace, the time-of-flight was calculated as the time delay between the leading edge of the transmit pulse and the leading edge of the receive pulse.

Additionally, for each trace the received signal strength was quantified as the root-mean-square intensity of the beginning of the receive pulse. Specifically,

$$RSS = \sqrt{\sum_{k=k_{LE}}^{k_{LE}+30} \left(v_{receive}(kT)\right)^2},$$

where RSS is the received signal strength, k is the sample index within the oscilloscope trace, k_{LE} is the sample index at which the leading edge of the receive waveform is detected, $v_{receive}(kT)$ is the voltage measured at the receive channel, and T is the sampling period. The units of $v_{receive}$ were the raw oscilloscope analogue-to-digital converter output, so the receive signal strength is proportional to voltage but measured in arbitrary units. A total of 30 samples were summed over, but the result is insensitive to this number because the front of the receive waveforms have a largely rectangular envelope.

The time-of-flight and received signal strength were calculated for every identified measurement, and then the arithmetic mean used to reduce these to a single number for each crab. Finally, acoustic velocity in the crab was calculated as

$$v_{crab} = \frac{d_{claw} v_{water}}{t v_{water} + d_{claw} - d_{transducer}},$$

where d_{claw} is the semi-major thickness of the crab claw, v_{water} is the speed of sound in water (as measured immediately prior to the insertion of the crab to account for any temperature drift), t is the time-of-flight, and $d_{transducer}$ is the distance between the transducers. This equation corrects for varying claw thicknesses, because part of the observed time-of-flight is simply the transmission through the water.

3.7 Near Infrared (NIR)

The spectral characteristics of 103 live mud crabs were measured by two commercially available NIR instruments, these included:

a) A bench top Matrix-F, FT-NIR spectrophotometer (Bruker Optics, Ettlingen, Germany; operating software: OPUS™ version 5.1 - 6.5) in the 830 – 2500 nm range. Spectra were obtained in diffuse reflectance mode, using a standard 4 x 20 watt tungsten light source fibre-coupled emission head fitted to the spectrometer. The external emission head was placed directly above the mud crab (0°configuration). A light reducing box with a 60 mm diameter cut out window was used to hold the crab, so that the area of interest was directly exposed to the focal point of the emission head. A path-length of approximately 170 mm from the external emission head light source to the surface of the crab provided a spectral scan diameter on the area of interest of approximately 50 mm. Spectra were collected from the carapace of each crab and in obtaining each sample spectrum, 8 scans at a resolution of 8 cm^{-1} were collected and averaged.

b) A handheld ultra-compact MicroNIR 1700 NIR spectrometer (JDSU, CA, USA) in the 950 – 1650 nm range with a rubber shroud around the contact surface to reduce stray light interference. The MicroNIR has an internal light source consisting of two integrated vacuum tungsten lamps for diffuse reflectance mode. Spectra were obtained by placing the spectrometer in contact with the area of interest on the live mud crab at a 0° configuration and placed between two external 55 watt halogen light sources orientated at a 45° configuration to the MicroNIR providing an interactance mode (Image 7). Spectra were collected from the carapace and dominant claw for each mud crab. In obtaining each spectrum an integration time of 9.6 ms was used at a resolution of 6 nm.

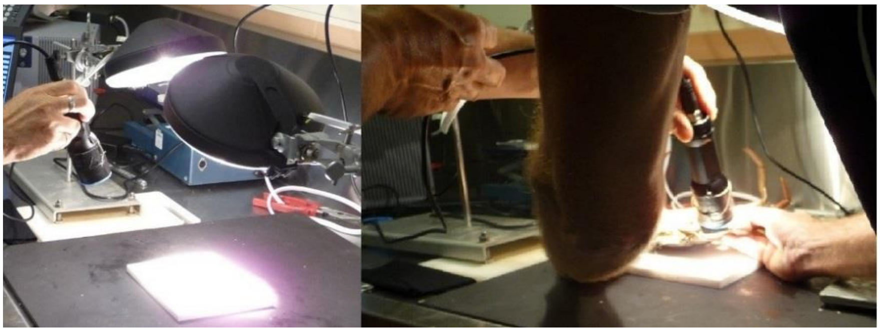


Image 7: Hand held MicroNIR spectrometer with external light sources capturing a spectra from a mud crab

Data analysis

Data analysis was carried out using "The Unscrambler" Software Version 10.3 (Camo, Oslo, Norway). Before the development of a calibration model, the variation of all spectral data was investigated by principal component analysis and obvious atypical spectra were recorded as outliers and removed from further analysis. Partial Least Squares (PLS) regression was used to build the calibration models based on percentage meat yield of the spectral data. PLS regression attempts to establish a correlation between the spectral data and the manual assessment of meat yield (i.e., reference data set) to find the optimal model. Simply, the calibration equation of the NIR and chemical loadings combine mathematically to yield the calibration model which is then used for analysis of future unknown samples. Prior to PLS regression, raw spectral data were mathematically transformed to remove defects observed in the NIR spectra (e.g., noise, base line drift). For the PLS calibration models presented in this study, the spectral data were transformed prior to model development using a combination of a 25-point Savitsky-Golay (SG) spectral smoothing (2^{nd} order polynomial) and a standard normal variate (SNV) transformation.

The objective of smoothing spectral data is the reduction of noise, which can be described as random high-frequency perturbations. The Savitsky-Golay smoothing fits a low-degree polynomial through the data points within the local spectral window and derives the process signal values from the polynomial's function. With higher order polynomials, the individual weights derived from the polynomial coefficients are not the same for all data points within the spectral window to give a weighted moving average. SNV methods are used to remove multiplicative interferences of scatter, particle size, path length effects, source or detector variations, and other general instrument sensitivity effects.

Full cross validation (also known as 'leave-one-out' or 'jacknifing') was used to assess the performance of the model. Cross validation allows for the calculation of calibration statistics such as root mean square error of cross validation (RMSECV) when only a small number of samples are available.

The assessment of model performance and robustness (ability to predict independent samples) from an NIRS perspective was based on the following partial least squares statistics:

(i) the coefficient of determination (R^2)
(ii) the root mean square error of cross validation (RMSECV)
(iii) the bias (average difference between predicted and observed values)
(iv) the slope of the calibration/validation model

The R2 quoted for PLS regression models is the percentage of the total variance accounted for by the explained variance for the given number of latent variables in the model. It is not the square of the correlation coefficient. It is therefore possible to have a low R2 but a high correlation coefficient suggesting a strong linear relationship is still present but the predicted values are not close to the target one-to-one line. This can occur when there is large bias which is consistent across the full meat yield range.

The performance of a classification techniques 'principal components linear discriminant analysis' (PCA-LDA) to discriminate between the three grades of mud crab ('A', 'B' and 'C') based on percentage meat content was also investigated. PCA-LDA is a supervised classification technique where the number of groups and the samples that belong to each group are pre-defined (Naes *et al*. 2002; Otto 1999). This technique produces a number of orthogonal linear discriminant functions that maximise the separation between the classes, yet minimises the variance within categories (Naes *et al*. 2002). To overcome the requirement of LDA that the number of samples in the calibration set is larger than the number of variables, the data dimensionality is reduced using PCA prior to running the LDA.

3.8 Surveys

Surveys on the status of the schemes adoption and attitudes to meat fullness were created and conducted in SurveyMonkey® Gold using (where possible) SurveyMonkey® expert-certified questions and templates. For the '*How full is your mud crab?*' questionnaire a fully random selection design was used to present images of crab claws randomly within each set to responders. The surveys were distributed via a generated web link included in email to industry partners and accessible from Fisheries Queensland Facebook page. Results were collated within SurveyMonkey® and analysed with Microsoft Excel® 2010 and XLSTAT 2013.

4 Results and Discussion

4.1 Grading scheme status survey

In conjunction with co-investigators and the Project Steering Committee (see Appendix 2) an initial survey on the current status of industry's grading issues was developed using SurveyMonkey (see Appendix 5). Asking the right questions is crucial in any survey to gain a valid, unbiased understanding of current issues amongst the various sectors and jurisdictions. To ensure the survey was expert in design, SurveyMonkey Certified questions were utilised in developing the survey wherever possible.

The survey was distributed through representative bodies, industry databases and personal industry contacts to:

- Sydney Fish Market - 93 buyers, 188 suppliers
- Professional Fishermen's Association ~300 members
- East Coast Crabbers Industry Network ~140 members
- The Fishermen's Portal Inc. ~40 members
- Marine Care ~8 crabbers
- Northern Territory Seafood Council - 13 fishers/licensees
- Queensland Seafood Industry Association
- Gulf of Carpentaria Commercial Fishermen Association Inc.
- A Raptis & Sons
- McLaughlin Consolidated Fishermen Ltd
- Macleay River District Fisherman's Co-operative
- Commercial Fishermen's Co-operative Limited
- Mackay Fish Market
- Queensland Seafood Marketing Association Inc.
- Master Fish Merchants' Association of Australia.

The survey reached approximately 800 individuals across key jurisdictions and along the supply chain, and returned a 13% response rate (approximately 100 responses). This is less than the very good response rate achieved in the FRDC Project 2010/310, '*Equipping the mud crab industry with innovative skills through extension of best practice handling',* which achieved a 35% response rate. Typically, surveys of this nature achieve an average 17% response rate (electronic discussion forum, enabling change and innovation 2012).

It is unclear what the views were of those that didn't respond, but for those that did, they identified issues with the scheme in their circumstances, which impacted their operations.

It was clear that industry supported the concept of having a national live mud crab grading scheme with 84% of responders being either extremely or somewhat supportive. Eighty-three percent of responders were either very or slightly aware of the AILMCGS indicating that communication of the scheme was successful since its inception. Survey results confirmed the need for this project with the highest percentage (24%) of responses choosing 'Extremely dissatisfied' as their response to the question '*Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied with the Grading Scheme?*'. Concerns expressed with the scheme and its attributes were highest for the amount of pressure thumb force to apply, effect of repeated pressure tests, application of scheme along the distribution chain and variable interpretation of what is 'lively'. One hundred percent of responders wanted to see modifications to the AILMCGS (Version 1). Since the scheme was implemented in 2012, 59% of responders had changed their grading practices either a great deal or a moderate amount; 24% had no change at all. Seventy percent of responders said they had changed their grading practices since the scheme's inception as per the scheme. Education on grading techniques was seen to be beneficial to 83% of responders. Any change in price/kg for sales since the implementation of the scheme was evenly split between an increase, no change and a decease. Seasonal and regional anomalies in shell hardness were reported by 78% of responders. Thirty-two percent of responders believed that shell hardness softens a little from point of capture to market. Eighty-four percent of responders were likely to use an objective grading tool if it were available.

The survey also asked a series of questions related to fisher practices and benefits of returning newly moulted crabs to the water. Fifty-five percent agreed extremely that all 'C' grade crabs should be returned to the water by both professional and amateur fishers.

See Appendix 5 for all responses.

Survey results were sent to 58 survey responders, the Project Steering Committee and the National Mud Crab Industry Reference Group.

4.2 Shell hardness

The Australian Industry Live Mud Crab Grading Scheme is based on the degree of shell hardness and other specific attributes that endeavor to provide a market grade which provides an indicator of the degree of meat fullness within the crab. Following Industries development of the initial scheme in 2012 we received a number of reports of incongruities occurring with shell hardness grading crabs from different geographical harvest areas with clusters of anomalies in specific areas.

Site visits to NSW Fishermen's Co-operatives that are known by SFM Quality Assurance staff to be problematic with grading issues also confirmed the very strong resentment from some fishers to the National Grading Scheme who reported losses amounting to thousands of dollars due to the scheme, or its application in the supply chain. Evaluation of crab grading anomalies confirmed that many crabs which were being downgraded at markets were in fact good quality crabs as evidenced by high haemolymph protein levels and cooked meat yields.

Findings of the results were distributed to the peak NSW bodies and associated fishermen's co-operative managers. Subsequently, an urgent meeting with industry and some project steering committee representatives was held at SFM.

The results of field trips identified that the top carapace flex for male crabs was responsible for many 'A' grade crabs being downgraded to 'C' grade at markets. The continued ambiguities of shell flex pressure to determine grades was also driving crabbers to market their crabs at lower grades to avoid having them downgraded at market. Most crabbers believe they grade fairly and accurately and to have crabs downgraded undermines their reputation and price offered for future crab sales. Data supplied by SFM showed that for NSW the average 'Ungraded' market price was higher than the 'B' grade market price.

Two immediate interim recommendations were made:

1. **Sydney Fish Market will no longer use the 'top of carapace flex test' for grading male mud crabs.**
2. **If suppliers are unsure if their crab is 'B' or 'C' grade they are recommended to label the box as ungraded.**

Note: As part of this interim measure:

- All male crab grading assessments will be based on flex testing on the underside of the carapace (A grade – no flex on any segment; B grade – some flex on 3rd (middle) segment, others no flex; C grade – all segments flex easily when pressed).
- Boxes marked with no grade or 'Ungraded' will only be assessed for liveliness, shell damage, missing legs or other 'defects' as described in the national grading scheme.

These recommendations were unanimously accepted by the whole project committee and henceforth Sydney Fish Market (one of the project steering committee members) undertook to follow these recommendations when assessing product sold through SFM effective from the 22 January 2015. In conjunction with the co-investigators and select steering committee members, a revised AILMCGS Version 2 was developed and distributed.

4.2.1 Shell softening during emersed transport

Accounts from some harvesters proposed that shell hardness changed from full hardness to slight flex during emersion over the transport time from capture to market assessment. This anecdotal effect caused strong concern from mud crabbers as many regularly ship harvested product long distances. They felt that good quality crab, graded as 'A' grade, was being assessed as lower grade crab by buyers and Quality Control personnel at market, resulting in a lower revenue return for the crabber as well as loss of market reputation.

Information from the staff re-grading crab at market clearly indicated the grade attained post-transport time was correct as determined by shell hardness. There could be several reasons for different grade of shell hardness occurring:

- inappropriate grade assignment initially at harvest
- inappropriate grade assignment later at market
- differences in pressure force applied by different assessors
- number of times thumb pressure has been applied to the same points on the crab shell
- physical damage at test sites from thumb pressure test
- incidence of physical shell softening while crabs out of water.

In an attempt to identify the likely cause, trials were carried out under controlled conditions of emersion, immersion and re-emersion with shell hardness assessed by the one grader throughout the trial. Tables 2 and 3 provide representative results for crabs from Clarence River and Laurieton areas respectively.

There was evidence that some crabs did show a propensity for shell hardness to change between emersion and re-immersion phases. There appeared a trend for shell hardness to lessen in some crabs after storage in bins covered with damp hessian (emersed conditions similar to those used for transporting mud crabs). However, no clear pattern of shell regaining hardness is illustrated for crabs re-immersed as could be expected if the shell hardness change occurs due to simple dehydration effects.

Table 2: Grade changes in Clarence River sourced mud crabs assessed by shell hardness during emersed and immersed storage

Crab #	**Crabber grade**	**Researcher grade**			
	at Co-op	12h after	post 2d immersion	post 4d emersion	post 2d immersion
CR46	A	A	A	C *	A
CR50	C	C	C	C	C
CR55	C/A [α]	C	C	C	C
CR56	C/A	C	A	C	C
CR60	C/A	C	C	C	C
CR64	C-	C	C	C	C
CR68	C+	C	C	C	C

* Coloured font depicts a grade change: up - green or down - red

α C/A means 'C' grade for top carapace; 'A' grade shell underside

Table 3: Grade changes in Laurieton area sourced mud crabs assessed by shell hardness during emersed and immersed storage

Crab #	**Researcher grade**			
	Receival	post 2d immersion	post 4d emersion	post 4d immersion
LC1	A	A	A	A
LC2	A	A	B*	A
LC3	A	B	B	B
LC4	B	B	B	B
LC5	C	C	C	C
LC6	A	A	A	A
LC7	A	A	A	A
LC8	B	B	B	B
LC9	B	B	B	B
LC10	A	B	B	B
LC11	A	A	A	A
LC12	B	C	B	B
LC13	A	B	B	B

* Coloured font depicts a grade change: up - green or down - red

Previous research has shown the crab haemolymph Refractive Index can be correlated to some extent with shell hardness, however, such correlation was not obvious when assessing emersed crabs following transport. From the representative crab data provided in Table 4, all RIs reduced after dry transport but to differing extents. Further data could perhaps evidence that high quality crab ('A' grade) loses quality to a greater extent than lower grade crab.

Table 4: Haemolymph Refractive Index (RI) before and after dry transport

Crab #	Crabber Grading	RI at Co-op	RI post-12h emersed transport	RI decrease %
CR45	A	1.3630	1.3611	14
CR46	A	1.3592	1.3567	2
CR50	C	1.3452	1.3439	1
CR55	C/A *	1.3573	1.3565	0.06
CR56	C/A	1.3629	1.3543	6.5
CR60	C/A	1.3542	1.3545	0.02 increase
CR64	C-	1.3415	1.3410	0.05
CR68	C+	1.3515	1.3506	0.05

* C/A means ‘C’ grade for top carapace; ‘A’ grade shell underside

To observe the effect on shell hardness during re-immersion post capture followed by a emersion period, crabs (n=73) were sourced from Clarence River for trials at the Coopers Plains Health and Food Science Precinct (HFSP) live seafood facilities. Sixty-four ‘C’ grade, two ‘B’ grade and seven ‘A’ grade crabs were graded on arrival, then stored in seawater tanks for four days. They were then regraded and stored in dry bins covered with damp hessian for eight days. Shell hardness scores (Figures 1 and 2) show a decrease for ‘A’ and ‘B’ grade crabs during re-immersion. However, ‘C’ grade crabs increased shell hardness during the immersion period. Shell of all crabs hardened over the eight day emersion period. This is contrary to crabber’s suggestions that crab shells soften when emersed during the transport time from capture to market. It is possible that some borderline grade crabs may be graded differently at market, but in general, shell hardness changes during emersion are only minor and would not cause a complete grade change.

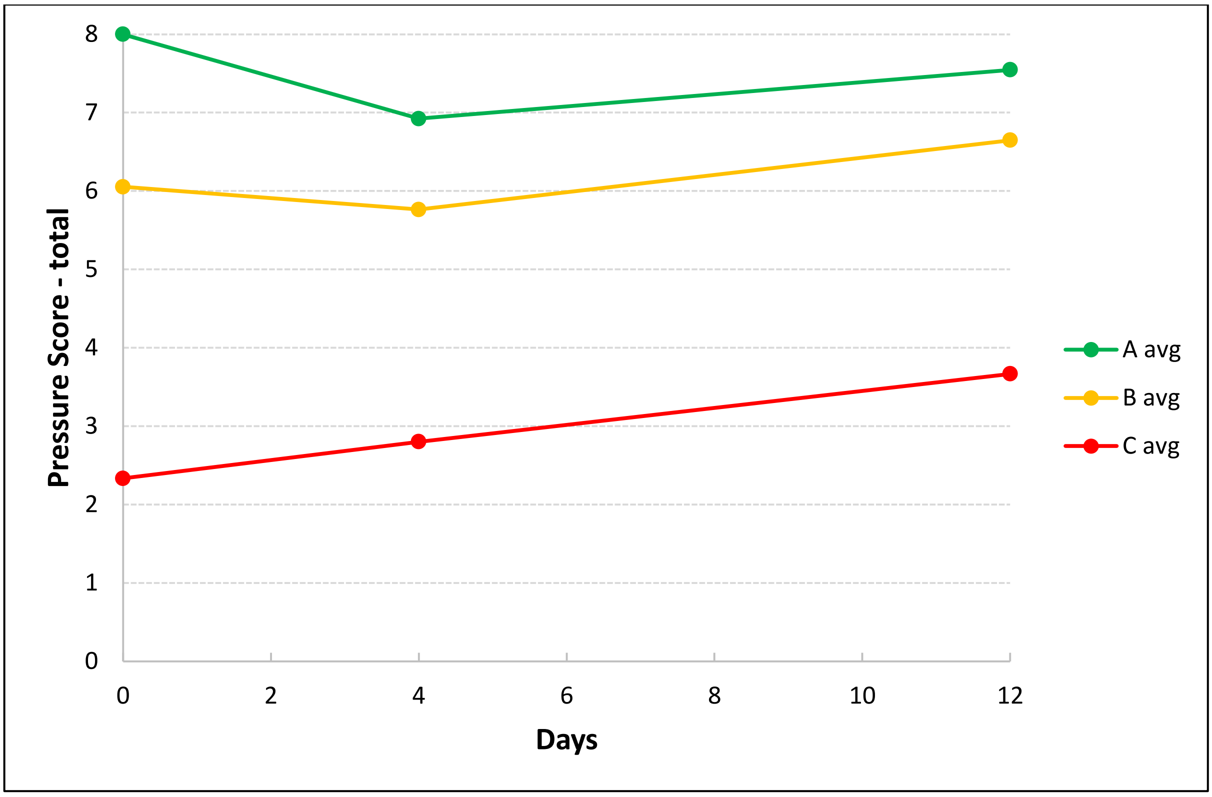


Figure 1: Female crab shell hardness immersed 4 days then emersed 8 days

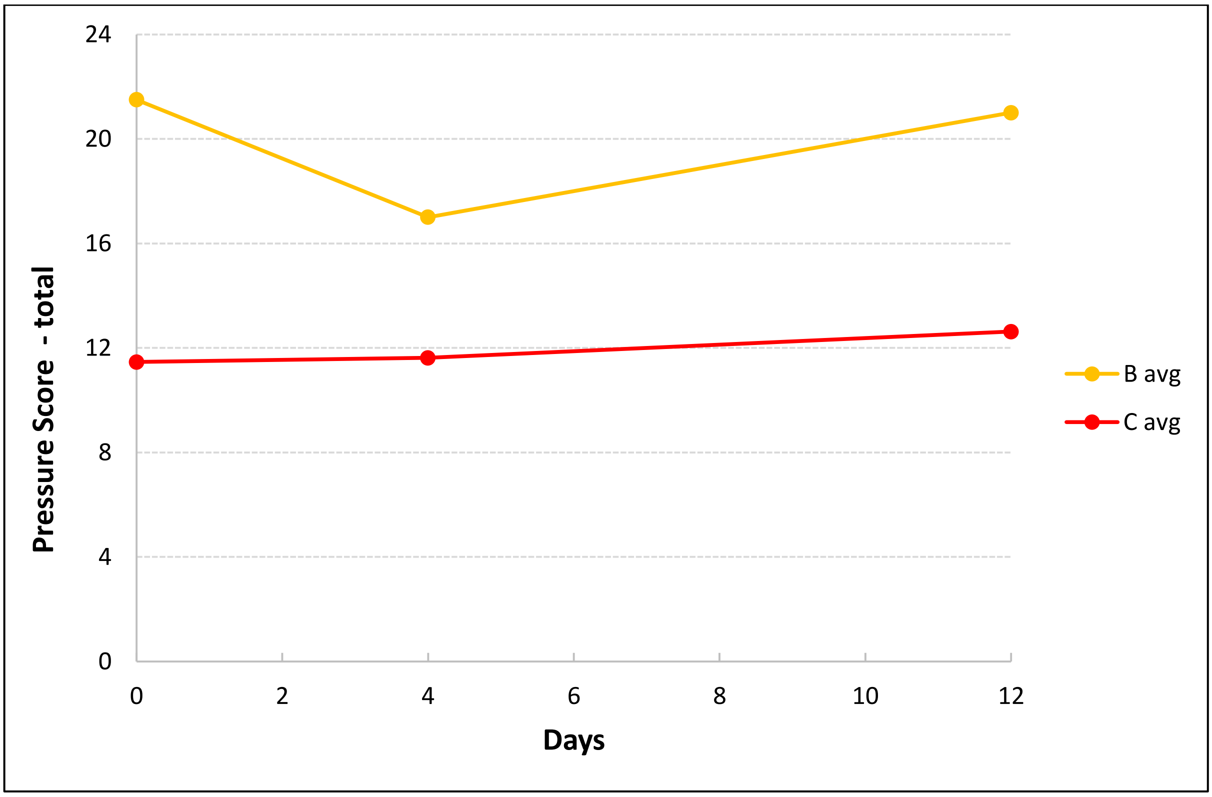


Figure 2: Male crab shell hardness immersed 4 days then emersed 8 days

Despite many studies on the physiological response of crabs to emersion conditions similar to those of mud crab transport, no reports commenting on shell hardness changes occurring during emersion periods were found in published literature.

4.2.2 **Shell not attaining full hardness**

Another anomaly described surrounded incidences of the crab shell not ever hardening fully but retaining slight carapace flex. Such crabs were reported to have full meat volume present. These intelligences were supported by observational evidence during field trips to various New South Wales Fishermen's Co-operatives. During site visits to Ballina, Clarence River, Port Macquarie and Wallis Lake Fishermen's Co-operatives, assessments showed that consignments of male crabs were predominantly crabs with some flex on the top carapace, but were hard shelled on the underside. Under the AILMCGS these crabs would be determined as 'C' grade crabs, yet they corresponded to having high meat fullness as assessed by RI, where RI > 1.350 indicates a full meat crab equivalent to what would be termed 'A' Grade (Table 5).

Table 5: Crab grade with Refractive Index (RI) value

Crab #	Crabber Grading	RI
45	A	1.3630
46	A	1.3592
50	C	1.3452
55	C/A *	1.3573
56	C/A	1.3629
60	C/A	1.3542
62	C/A	1.3515
64	C-	1.3415

* C/A means 'C' grade for top carapace, 'A' grade shell underside

Sampled crabs were typical from all co-operatives and although the sample number reported above is small, the crabs were testified by the crabbers to be typical of crabs from their regions. Purportedly it is "pretty normal" from both the Clarence River and Wallis Lakes areas to have many crabs that demonstrate flex on top carapace with fully hard undersides. Researchers observed a large percentage (~65%) of crabs from one crabber illustrated this phenomenon and crabbers from all Co-operatives were able to show examples of similar crabs.

A random selection of crabs was obtained that had been seized as being commercially unsaleable crab (CUC). These crabs were later analysed for shell hardness and haemolymph RI. Table 6 shows that 63% of the 'C' and CUC grade crabs had RI values equating to crabs of higher quality grade than that determined by shell hardness. Another batch of CUC crabs (n=22) from Wallis Lakes and Macleay River showed similar results, with 64% having higher grades as determined by RI, including 9% that were 'A' grade crab by RI.

Table 6: CUC crab compared to grade by RI range

		Grade by RI range guide		
Researcher grade		**A**	**B**	**C**
A	0			
B	7	2	4	1
C	19	3	9	7
CUC	8	1	4	3

What causes this phenomenon of the crab shell not ever fully hardening?

There could be multiple factors influencing shell hardness, with the most likely being associated with large tidal flows and rain events reducing the water salinity and available feed.

Crab shell is composed of chitin strengthened by the deposition of calcium salts (Rees, 1963) and it could be expected that environment and diet could both strongly influence shell deposition. The importance of dissolved calcium has been demonstrated in crustaceans (Edwards, 2013; Malone and Dodd, 1967; Robertson, 1941) and noted as a vital component for exoskeletal condition and strength, as well as metabolic activity. Marine crustaceans do not store calcium but rather obtain the bulk of their requirement (*ca.* 95%) from the water (Greenaway, 1985).

Environmental salinity affects shell growth by altering biochemical processes, with uptake and conversion of calcium from the water being dependent on temperature for some crustacean species (Waldbusser *et al*, 2010). There is evidence that the laying down of calcium in the shell responds to changing ecological conditions and, in particular, salinity variations have a marked effect (Nagarajan *e*t *al,* 2006). This is especially relevant in estuaries, where salinities range from 0 to 35 ppt, and other water properties such as temperature and nutrient composition also vary widely during transition from fresh river water to saline ocean water. The influence of water salinity on crab shell development was illustrated by an early study on Blue crabs (*Callinectes sapidus*), which showed that the most growth occurred in salt water (>5 ppt) compared to that in 0-1 ppt salinity level (Tagatz, 1968). Additionally, it was found that males and females of this species showed significant difference in growth between fresh and salt water with females growing more rapidly than males. More recent studies on mud crab (*Scylla* spp.) concluded that water salinity of 15-35 ppt was the most favourable for crab survival and growth (Liong, 1994; Anil, 2001). Greenaway (1976) found that *Carcinus maena*s could maintain calcium balance in dilute seawater (>10 ppt) but not in more dilute waters. In further studies, reduced shell hardness was directly related to reduced salinity and temperature of the surrounding water (Nagarajan *e*t *al,* 2006).

It is recognised that the cost of thick shell deposition to the animal is reduced growth rate (Palmer, 1981) and it is postulated that several calcifying species reduce shell production by producing porous shells in order to minimise the significant energetic expense of shell formation (Palmer, 1992). This results in a thinner, and therefore more pliable, shell in crustaceans.

In this current investigation, mud crabs exhibiting the anomaly of not attaining a fully hard shell were harvested from estuarine systems that frequently suffer strong rain and flooding events. The implication of such events is that at many times the water environment of the crabs often was of low or no salinity but rather was fully fresh water.

During the course of the trials two crabs were observed to be in pre-moult stage, so their claws were untied and the crabs were isolated to allow the moult. Post-moult one crab was kept in full strength seawater and the other in half strength with observations of shell hardness taken regularly. The shell of the crab in full salinity hardened to be nearly an ‘A’ grade within two weeks, whilst the low salinity crab’s shell was still just flexible (‘B+’ grade) after five weeks. This crab was then put in full salinity and the shell hardened within two weeks. This is indicative only, but fits with the hypothesis that water salinity affects the rate of shell hardness.

To establish whether low water salinity was causative of mud crab shell retaining slight flex, mud crabs corresponding to ‘C’ grade were sourced from different locations (n=5) from different crab harvesters. On receipt, crabs were graded again using shell-hardness thumb pressure as per the National Grading System. Additionally, each crab was weighed and measured, assessed for liveliness and haemolymph RI recorded. Crabs (n= 48) were then randomly assigned to one of two seawater tanks: high salinity seawater (32 ppt) or low salinity seawater (10 ppt). Water temperature was held the same (27 ^{o}C) and constant in both tanks. Crabs were fed a diet of trash fish and prawns at a rate of 6% body weight per day and monitored for up to 34 d.

Results indicated an overall increase in shell hardness over time in both high and low salinity waters. There were some apparent differences exhibited by male and female crabs. For male crabs (n=32) that shell hardness increased over time (Figure 3) as assessed by thumb pressure grading. The same overall increase trend was shown in both high and low salinity waters despite variable daily increases and decreases.

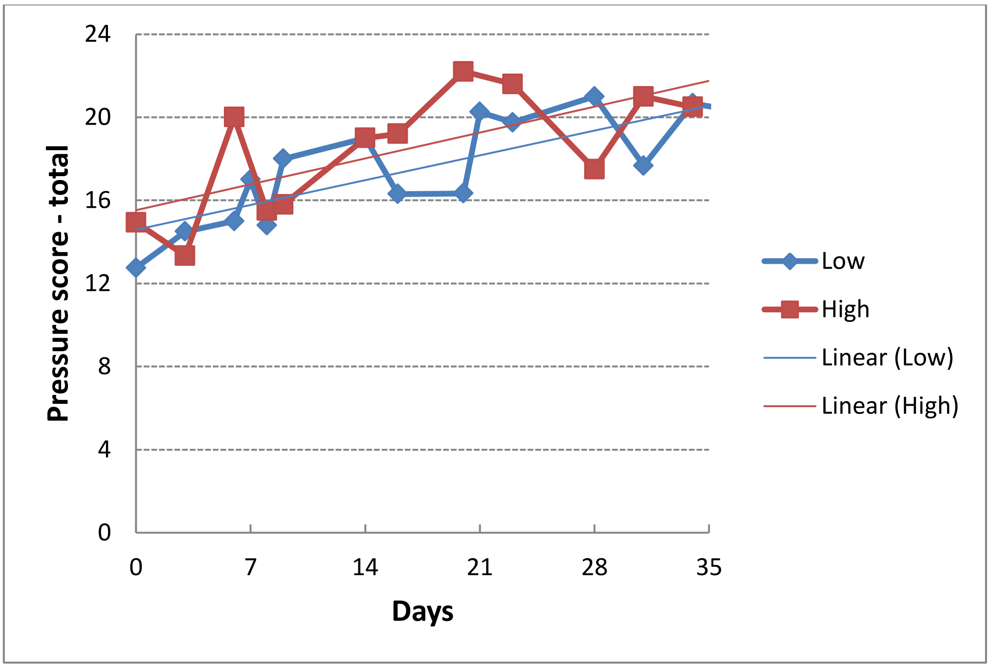


Figure 3: Shell hardness in male crabs in low and high salinity waters over time

For female crabs (Figure 4), shell hardness change was more variable but with a similar general increase in shell hardness over time, more clearly seen in low salinity water.

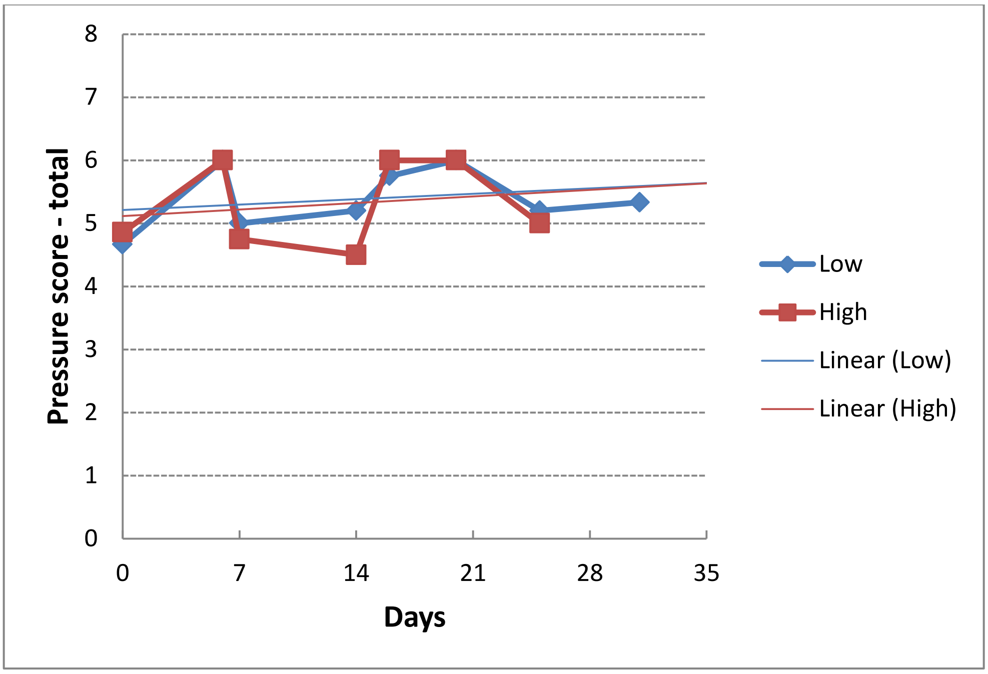


Figure 4: Shell hardness in female crabs in low and high salinity waters over time

However, crab numbers involved in the investigations were lower for females (n=16) due to regulations prohibiting the taking of females from Queensland waters. The trend illustrated should be confirmed with further trials under the same experimental conditions.

From the results of this investigation, environmental salinity differences do not appear to affect mud crab shell hardness.

In all complex biological organisms, it is typical that any one physiological parameter will be influenced by multiple factors, all inter-related and often co-dependent. This is likely to be the case with respect to shell hardness. It is known that the metabolism of edible crabs increases with increasing temperature (Ansell 1973; Uglow, *et al*, 1986). Both feed intake and the build-up of organic reserves are, therefore, assumed to be related to the ambient sea temperature. While investigating environmental effects on marine periwinkle phenotypic variation, Trussell (2000) found that for periwinkles growing in cooler waters the shells weighed less, were thinner and had weaker compression than those growing in warmer waters (a 7^{o}C difference in water temperature). Contrastingly, body size (as measured by soft tissue mass) followed an opposite pattern, where those growing in cooler waters weighed more than those of warmer waters. The researcher concluded that water temperature was a key factor with respect to shell hardness in periwinkles (Trussell, 2000). Similar findings were observed for molluscs growing in Indian and West Pacific Oceans where animals in warmer waters exhibited thicker shells than those in cooler waters (Irie, 2006; Irie and Fischer, 2009). It is possible a similar phenomenon could be influencing shell hardness in mud crabs, particularly during winter months.

Recently, there has been much investigation into the increased acidification of marine waters and whether this imposes a detrimental effect on marine crustacean survival and growth. Increased acidification means the seawater has a lower pH which results from increased presence of dissolved carbon dioxide (CO_2) in the waters. Some investigations have found that acidification of environmental waters does have a negative impact on crustacean growth and vitality. Melatunan and co-workers found that both low pH (pH <8.0) and elevated temperature resulted in periwinkles having weaker shells and disrupted the overall investment in shell deposition (Melatunan *et al*, 2012). Similarly, reduced shell growth in intertidal gastropods was linearly correlated with increasing levels of dissolved CO_2 (Nienhaus *et al*, 2010). However, this observation was paralleled by shell weight loss of empty shells, suggesting the changes in shell weight were due to dissolution of existing shell material rather than caused by metabolic changes causing reduced shell deposition. Additionally, other researchers reported mixed responses to CO_2-induced ocean acidification in 18 species of marine calcifiers (Reis *et al,* 2009), although 10 species exhibited reduced rates of net calcification. Contrary findings have also been reported where researchers observed there was no effect on morphology of Red king crabs or Tanner crabs (Long, *et al*, 2013). Interestingly, calcium content of Red king shell was unaffected after 200 d at low water pH but condition index (vitality) was reduced, suggesting that these crabs could maintain their shell calcium levels but at great energy cost. It was noted that in Tanner crabs, calcium levels were reduced under the same conditions.

To add further complexity, other studies have identified interactive relationships between acidification and other parameters, for example, a report that salinity effects the amount of dissolved CO_2 in marine waters where low salinity allows greater acidification (Dickinson *et al*, 2013). The contrary findings from even this small sample of research investigations depict a currently confused picture and clearly much more research into the effect of acidification on crab shell is required. There is also evidence that increased predation can induce increase in shell strength in marine gastropods (Beadman *et al*, 2003; Cotton *et al*, 2004; Nagarajan *et al* 2006; Trussell and Smith; 2000).

One or many of the discussed factors could be influencing shell hardness changes in mud crabs during different seasons and locations, but at this time there is insufficient information to conclude a specific impact from any of the potential causes.

The phenomenon of some mud crabs exhibiting shell that is not fully hardened while reputedly having full meat content has been shown to be valid from harvest locations that are associated with varying salinity related to tidal flow and seasonal weather events. High rainfall, as frequently experienced in estuarine waters, may cause mud crab feeding behaviour to alter and thereby limit availability of required nutrients for shell deposition.

It could be expected that diet abundance and type would have a strong effect on shell deposition and rate of hardening. However, there are few studies on the effect of feeding regimes on quality of adult crabs and those undertaken (Woll *et al*, 2006; Berge and Woll, 2007) did not assess changes to shell hardness. It has been suggested that plentiful diet and ample feeding opportunity could affect shell deposition and shell growth patterns in molluscs (Lord and Whitlatch, 2012) and Ceccaldi (1997) suggested dietary composition is likely to affect the chemical composition of the hepatopancreas in the crab. As one of the biological functions of the hepatopancreas is to maintain mineral reserves in the crab, a relationship could be postulated between mineral reserves and crab shell deposition. In support of this, investigations with crabs (*Portunus* spp.) fed different diets from a soft-shell state demonstrated significantly different shell hardening rates (Soundarapandian and Raja, 2008; Soundarapandian *et al*, 2010). Studies by Richardson *et al* (1980) showed that shell deposition rate in cockle molluscs was influenced by time of animal immersion and they suggested this was directly related to the length of time the animal had to feed, hence the longer the immersion the greater the feeding rate, the more shell deposition occurs.

However, contrary findings are also reported. Researchers (Anil and Suseelan, 2001) assessing the shell growth of green mud crab (*Scylla* Dana) concluded that shell thickness and strength is independent of diet, although crab vitality, metabolism, meat composition and meat quality were affected by adequate feed intake.

Full feeding trial comparisons were beyond the scope of this current project, however weight gain or loss during the salinity experimental trials described above was recorded. Weight gain attained over 34 days by individual crabs varied greatly, ranging from weight loss of 3% to a maximum weight gain of 13%. There was an average weight gain for all crab of 6.7% and 5.1% respectively in high and low salinity waters. Average weight increases are given in Table 7. All weight gain (and the one instance of weight loss) was progressively directional over time.

Table 7: Percent weight increase in male and female crabs in high and low salinity waters

Male crab		**Female crab**	
High salinity	Low salinity	High salinity	Low salinity
7.7 %	6.7 %	5.1 %	2.4 %

There appears to be a difference in average weight gain between female crabs in high or low salinity water. However, this needs to be confirmed from trials using a greater number of female crabs.

A related parameter to assess crab animal vitality is the Refractive Index of the crab haemolymph. This method has been used by many to gauge the quality of live crustacean. It is a simple non-destructive technique for assessing the serum protein and the total blood protein concentration (Ozbay and Riley, 2002). The method has been showed to be reliable to assess the muscle mass in the American lobster (Leavitt and Bayer, 1977) and western rock lobster (*Panulirus cygnus*) (Paterson *et al*, 1999). The current researchers have also demonstrated the worth of RI as measure of quality for mud crabs.

RI determinations were obtained for the salinity trial work and, interestingly, while haemolymph RI varied enormously in individual animals, between crabs and over experimental timeframe (Figures 5 and 6), trend lines for mud crabs in high and low salinity water both increased with time of immersion and showed an equivalent rate of increase illustrated by the same equation for both water mediums. This suggests that water salinity does not influence free protein levels in crabs.

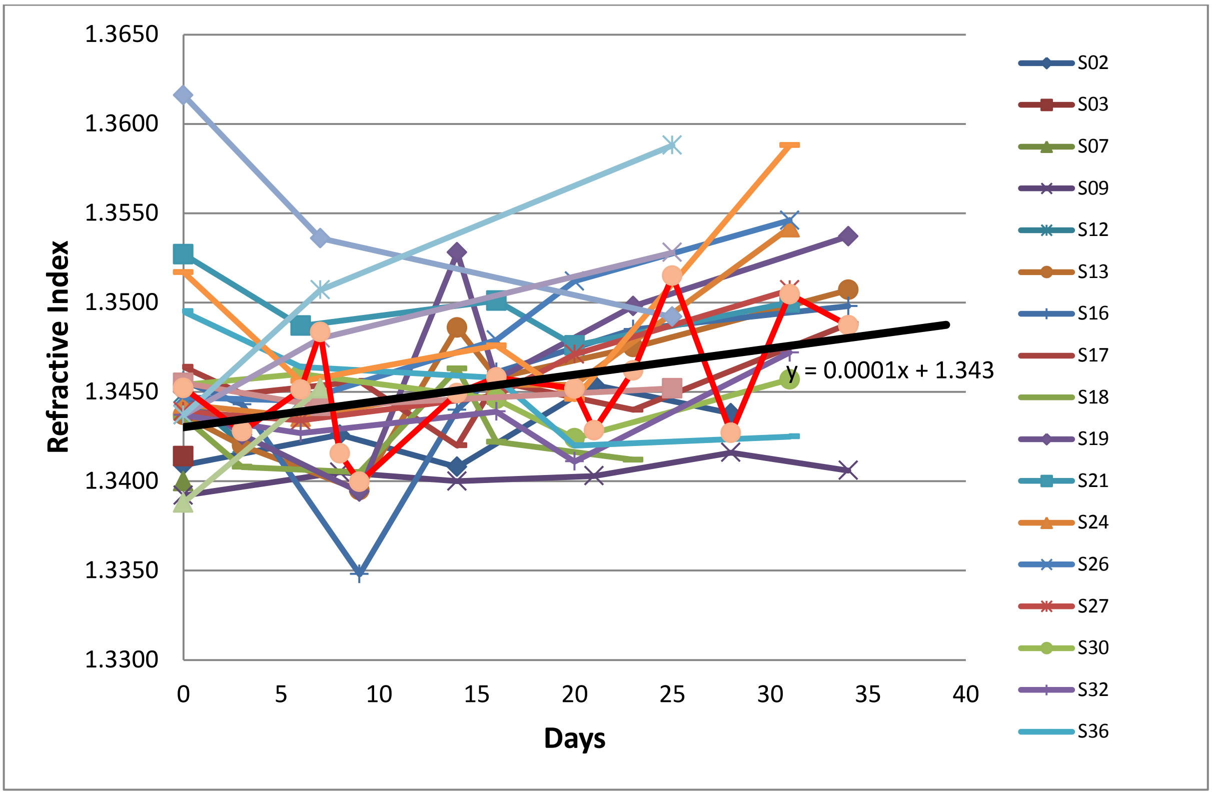


Figure 5: Haemolymph RI of mud crabs in high salinity water

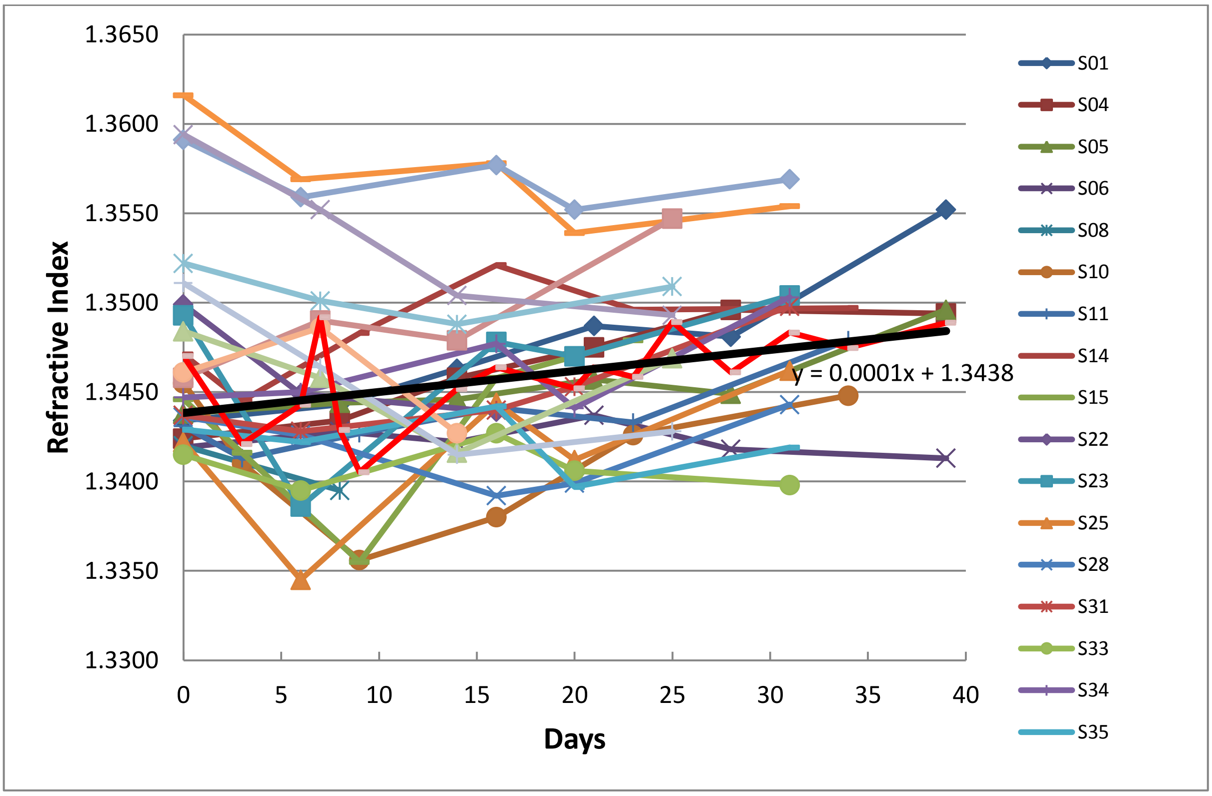


Figure 6: Haemolymph RI of mud crabs in low salinity water

The similar trend in RI increase over time also suggests that crabs were feeding actively and that salinity was not an influence on RI. The diet of trash fish and prawns provided is typical of that available for mud crabs in their usual habitats and observation of feeding behavior through the trial phase showed that the diet was highly acceptable to the crabs.

Anecdotal feedback from industry stated that crabs with slight carapace flex and fully hardened shell sections on the underside were typically “full of meat”. It is seen that the RI values (Table 5 above) for the ‘C/A’ graded crabs correspond to crab commonly graded as ‘A’ and also indicative of full meat content (Figure 7).

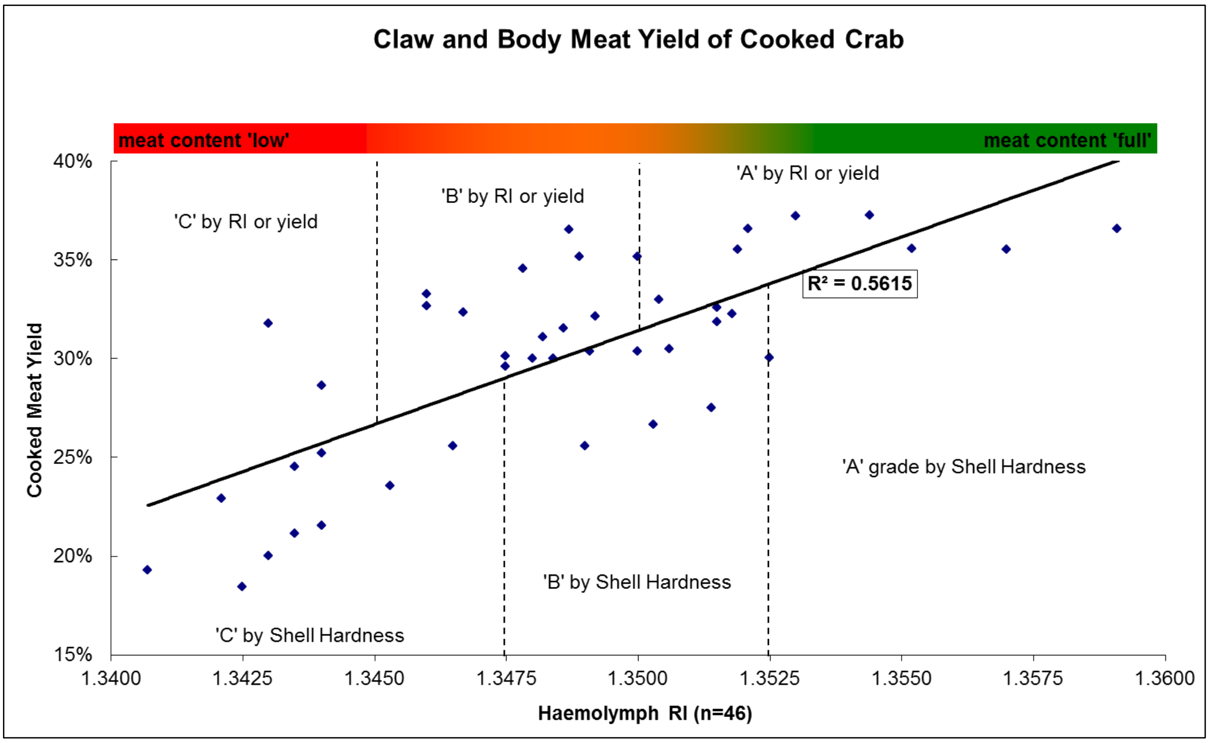


Figure 7: Relationship between total (body and claw) meat yield and RI, showing associated grades determined by shell hardness

The angst within the mud crab industry caused by this apparent anomaly in the grading system arises from the significant loss in revenue when a good quality crab with full meat content is down-graded. Therefore it was considered important to evaluate meat content yields for the crabs.

These findings strongly suggest that the top carapace flex test on male crabs is inappropriate as a stand- alone evaluation method for determining the quality (grade) of crabs within the market.

4.3 Meat fullness

One of the major anomalies extensively described with respect to the National Grading System was that of the occurrence of mud crabs retaining slight carapace flex and reportedly never attaining full shell hardness. Under the Grading System, such crabs are defined as ‘B’ Grade, yet crabs exhibiting this phenomenon were often noted as full of meat by industry and the researcher. Purchasers of mud crabs ultimately base satisfaction on the meat content of the crab, with purchase price paid equating to level of satisfaction. Therefore, most buyers would be completely happy to pay ‘A’ grade crab-price for those crabs exhibiting slight carapace flex but having full meat content. Hence the disappointment within industry that such crabs are graded as ‘B’ grade or less, when they reportedly have full meat content present.

It was clearly important to establish whether this phenomenon was widespread in occurrence and to gain a picture of the significance to the industry.

4.3.1 **Survey - buyer satisfaction**

Analysis of the grading systems to date has been about the available parameters, mainly shell hardness, used to provide a grade for live mud crabs. The grade is then used to attribute a likely meat fullness quality indicator to buyers and consumers with an associated price. An electronic survey was conducted to gather data based on responses to a series of photos of cooked claws showing an exposed section of meat. The aims of the survey were to:

- Confirm the grading scheme’s categories of ‘A’, ‘B’ and ‘C’ grade.
- See if the individual RI values relate to survey responses and can be used to support and define the cut off points between ‘C’ – ‘B’ and ‘B’ – ‘A’.
- Gain an insight into buyer and consumer’s perception of quality.
- Measure willingness to pay based on claw meat fullness.

Survey methodology

A series of crab claw images showing an exposed section of cooked meat were selected that represented a range of meat fullness and RI values across the three grades (Table 8). The survey was created in Survey Monkey® using a fully random selection design to equally distribute three images representing each grade (Image 8) to the individual survey respondent. Six images were available to be selected at random within the survey design for each grade. Each grade question was also presented in random order. The full survey questionnaire is presented in Appendix 6.

Table 8: Average values of six claws for each grade

Grade	Average RI	Average meat yield (%)
A	1.3576	54.5
B	1.3490	39.9
C	1.3452	33.2

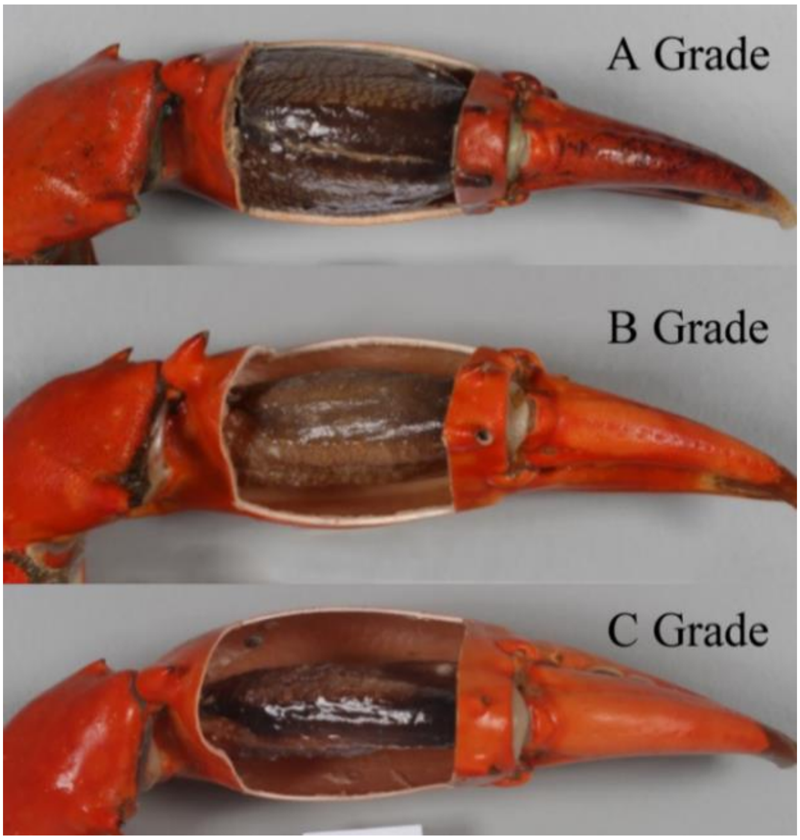


Image 8: Examples of 'A', 'B' and 'C' grade crabs presented in survey

The survey questionnaire (Image 9) was sent via a SurveyMonkey® generated email link to:

- industry bodies for distribution
- researcher's mud crab industry client contact list
- Queensland Fisheries Facebook page and website

Two hundred and thirty-one responses were gathered across industry sectors including crabbers, traders, recreational fishers and consumers.

How full is your mud crab?

Welcome to My Survey

Thank you for participating in our survey. Your feedback is important to a joint Queensland Government DAF and Fisheries Research and Development Corporation project to improve mud crab grading.

You will be shown 3 photographs of mud crab claws that have had a section of shell removed as shown by the shaded section in the diagram below. The photographs are taken from above to show the exposed meat within the shell cavity.

Please answer the two questions with each photograph. The final page will ask a little background about yourself and your mud crab eating experience.

Scroll down and click in the Next box to proceed to the next page.
On the last page click in the Done box.

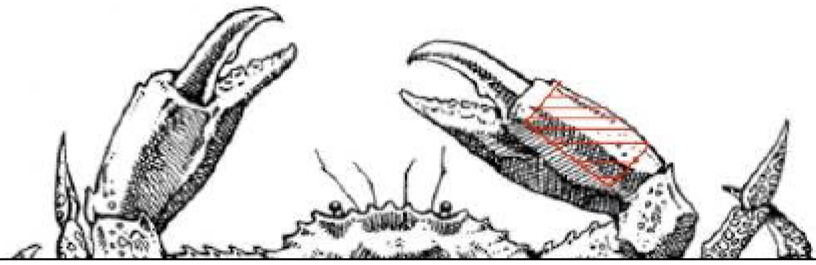


Image 9: Survey introduction and instructions

Variables obtained from the survey

1) Respondent satisfaction with the meat content of the claws observed.

Question: How does this meet your expectation of a full mud crab?
1= Extremely satisfied
2= Quite satisfied
3= Somewhat satisfied
4= Neither satisfied nor dissatisfied
5= Somewhat dissatisfied
6= Quite dissatisfied
7= Extremely dissatisfied

2) Respondent willingness to pay for the crab they observe.

Question: If a full mud crab cost $35/kg how much are you willing to pay for this?
1= Less than $10/kg
2=$10-$14/kg
3=$15-$19/kg

4=$20-$24/kg
5=$25-$29/kg
6=$30-$34/kg
7=$35-$40/kg or more

3) Respondent involvement with mud crabs.

Question: What is your involvement with mud crabs? (One or many answers can be chosen by the respondent.)
- Professional mud crab fisher
- Amateur mud crab fisher
- Consumer of mud crabs
- Trader e.g. retailer, wholesaler, restaurateur
- None of the above

4) Respondent mud crab eating frequency.

Question: How regularly do you eat mud crabs?
Weekly
Monthly
Every three months
Rarely
Never

5) Respondent eating background.

Question: What is your ethnic eating background?
Asian
Australian
European
Other

Survey responses

See Appendix 6 for all responses.

Survey question: If a full mud crab cost $35/kg how much are you willing to pay for this?

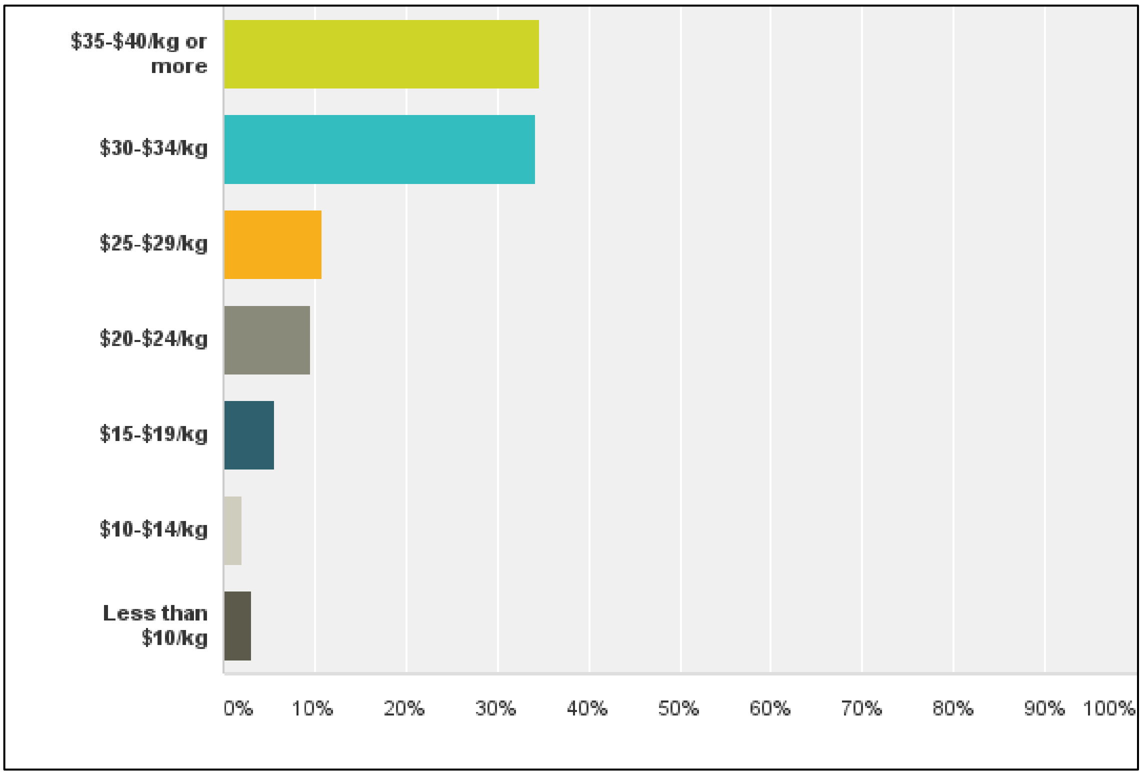


Figure 8: Willingness to pay response to 'A' grade claw pictures

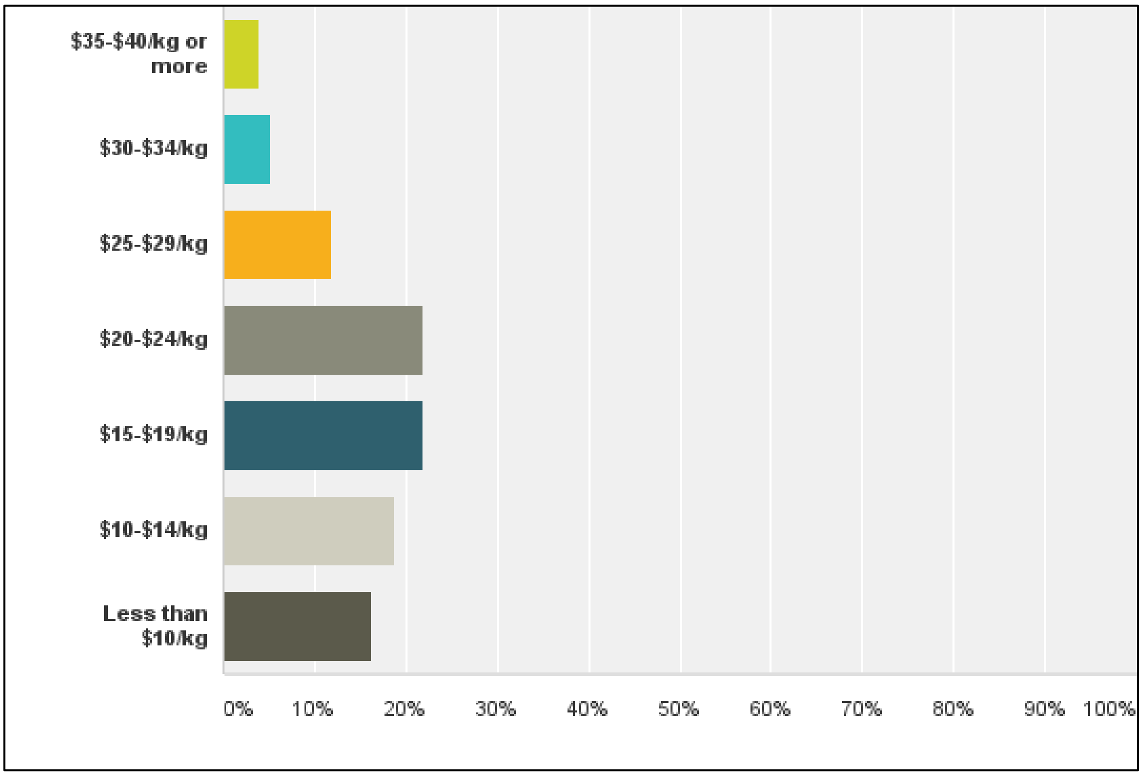


Figure 9: Willingness to pay response to 'B' grade claw pictures

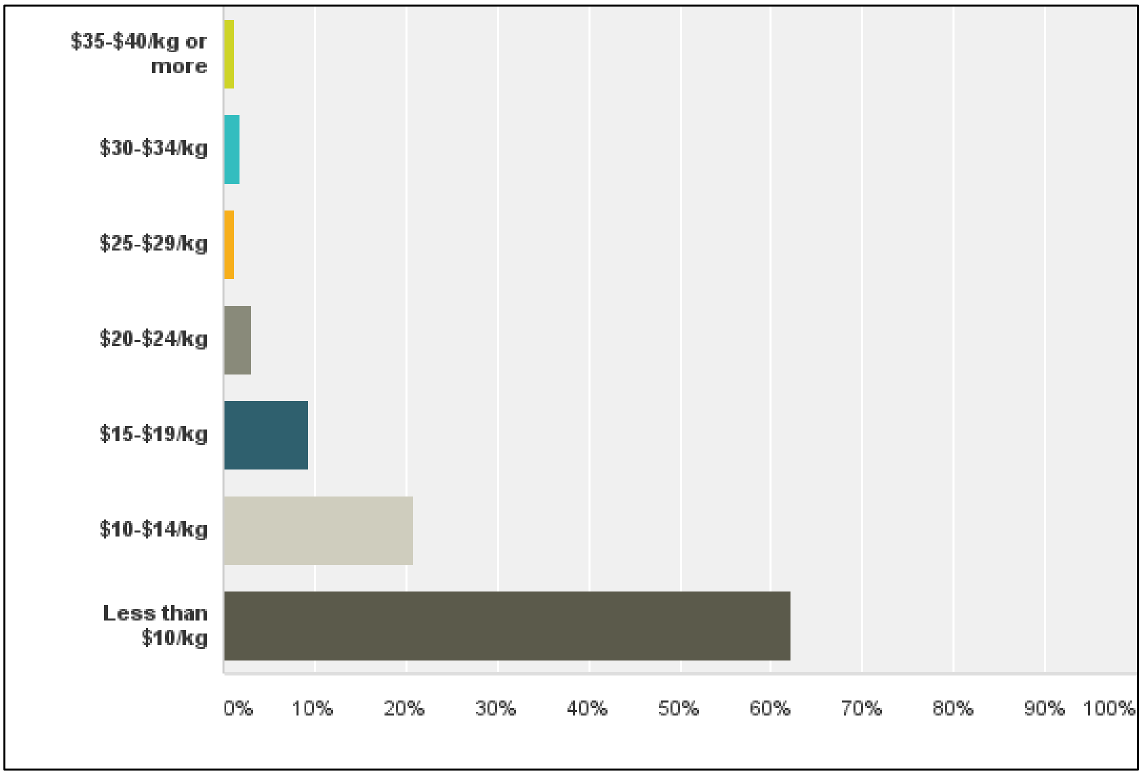


Figure 10: Willingness to pay response to 'C' grade claw pictures

Figures 8, 9 and 10 show the willingness to pay for each grade is well defined. Figure 11 shows the satisfaction score for each sector for each crab photo represented in order of six 'A' 'B' and 'C' grade claws. There is a clear separation of satisfaction between the grades. Further descriptive analysis of the data follows.

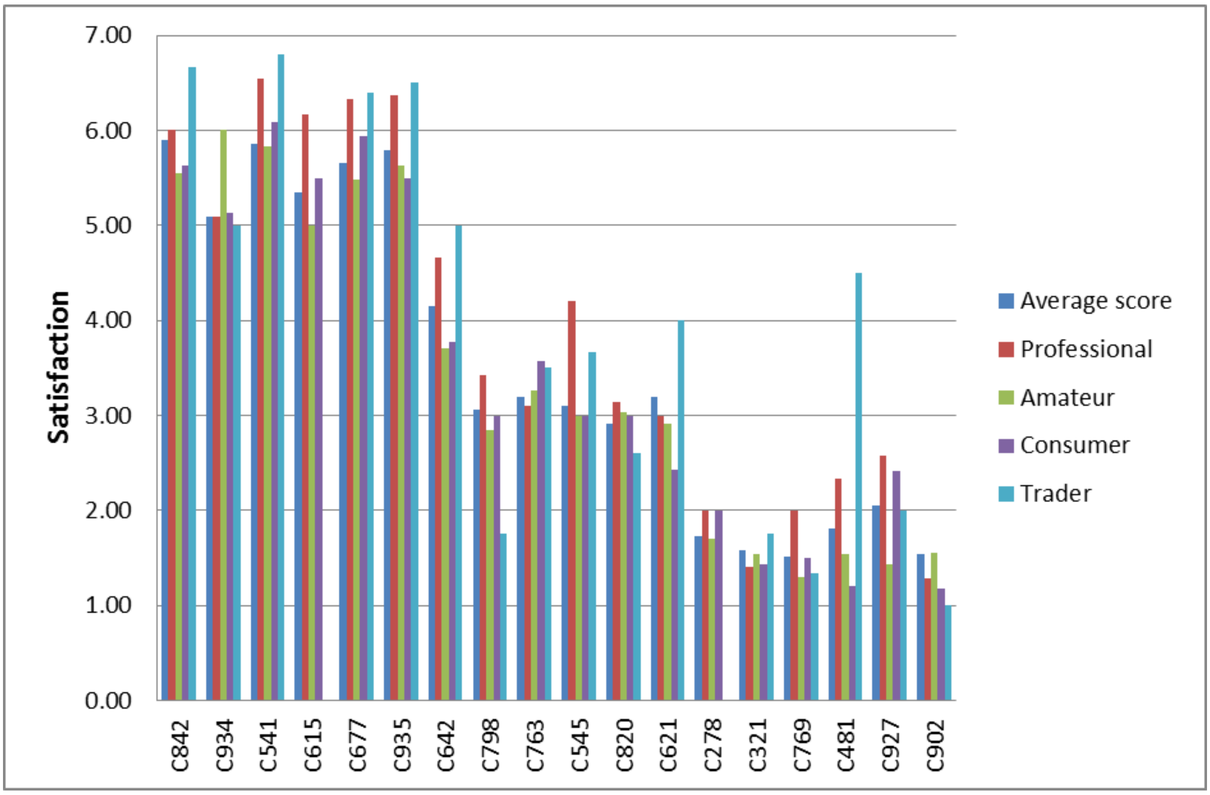


Figure 11: Satisfaction on meeting expectation of a full $35/kg mud crab against sector

Comparative values to Sydney Fish Market (SFM) auction prices (Table 9) show that responders were willing to pay more than SFM low season prices for 'A' grade, about the same for 'B' grade and much less for 'C' grade crabs.

Table 9: Comparative values to Sydney Fish Market auction prices

Grade	Survey range ($)	SFM Low season ($)	SFM High season ($)
A	35-40	26	65
B	15-19	20	44
C	<10	17	26

Descriptive analysis

All the descriptive analyses that follow must be interpreted in the context of the survey only. Results cannot be extrapolated to the whole consuming population because the sample of respondents is not representative of the population. Note: Respondent mud crab eating frequency and eating background are not taken into account in the descriptive analysis that follows.

Crabs used in the survey

Most of the crabs used in the survey were male crabs. The three female crabs available were 'B' grade (Table 10).

Table 10: Sex and grade of crabs used in the survey

	Sex		
Grade	f	m	Total
A		6	6
B	3	5	8
C		4	4
Total	3	15	18

Graphs of the RI values of the crabs versus their meat yield percent help visualise the structure of the crabs included in the survey. Respondents were looking at photographs of a cooked claw of these crabs when providing their answers. Each of the 18 points on Figures 12, 13 and 14 corresponds to one of the crabs used in the survey. These points are in the same position in these three figures while they are identified by the grading they received according to the shell hardness test (Figure 12), the question in the survey they were assigned to (Figure 13), and sex (Figure 14).

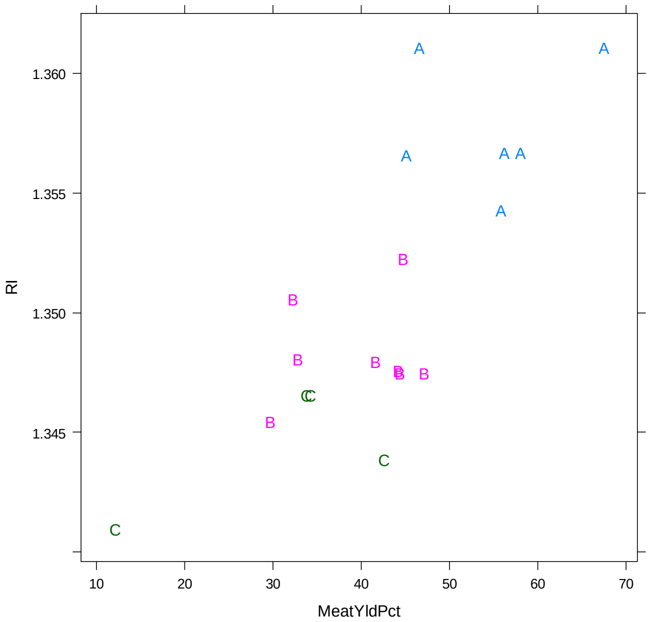


Figure 12: Refractive Index (RI) values vs meat yield percent for crabs in the survey. Letters indicate the grades they had received according to the shell hardness test, which tend to align with their RI values.

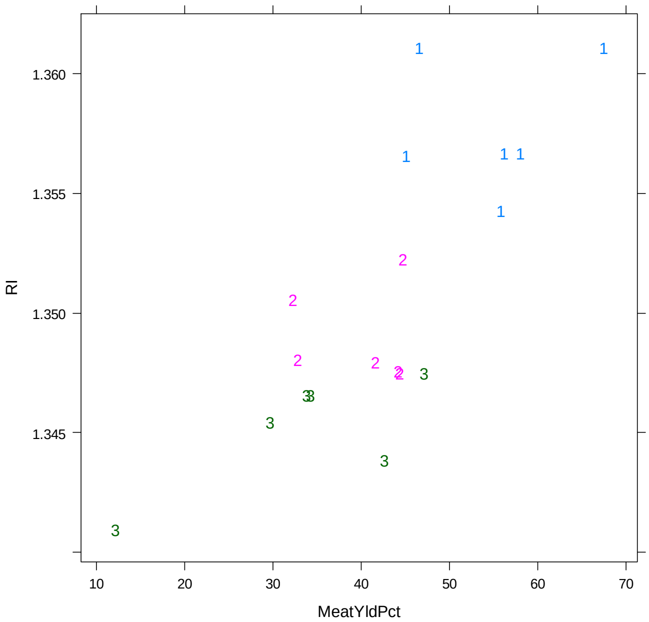


Figure 13: RI values vs meat yield percent for crabs in the survey. Numbers indicate the question in the survey they were assigned to.

Mud crabs with the highest RI values (those ones that had received ‘A’ grade) were assigned to Question 1 in the survey, those ones with the lowest RI values (most of them had received ‘C’ grade) were assigned to Question 3 in the survey, and crabs with intermediate RI values (all had been classified ‘B’ grade) were assigned to Question 2 in the survey.

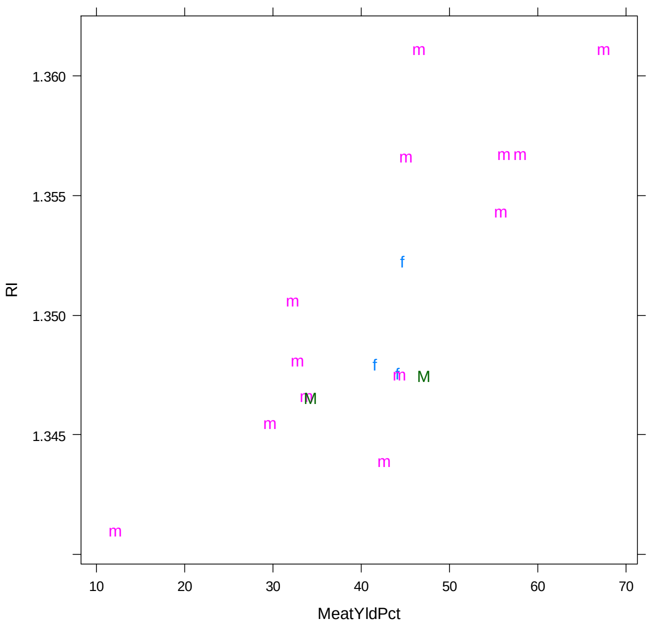


Figure 14: RI values vs meat yield percent for crabs in the survey. Letters indicate the sex of the crab (“f” for female; “m” and “M” for male).

The three female crabs used in the survey had been given ‘B’ grades, had intermediate RI values, and were assigned to Question 2.

Satisfaction with meat fullness and price respondents are willing to pay

Boxplots for individual crabs for satisfaction level and price respondents are willing to pay helped identify outliers (or extreme observations). These graphs have been done for each survey question in order to facilitate the identification of these extreme values. Given that this was a voluntary survey (i.e. respondents participate by their own will), there is always a small percentage of responses that lack meaning. Removing these few responses facilitates understanding of the general trends in the data. Figures 15a and 15b display boxplots for individual crabs in each survey question for satisfaction with meat fullness (with and without the outliers, respectively).

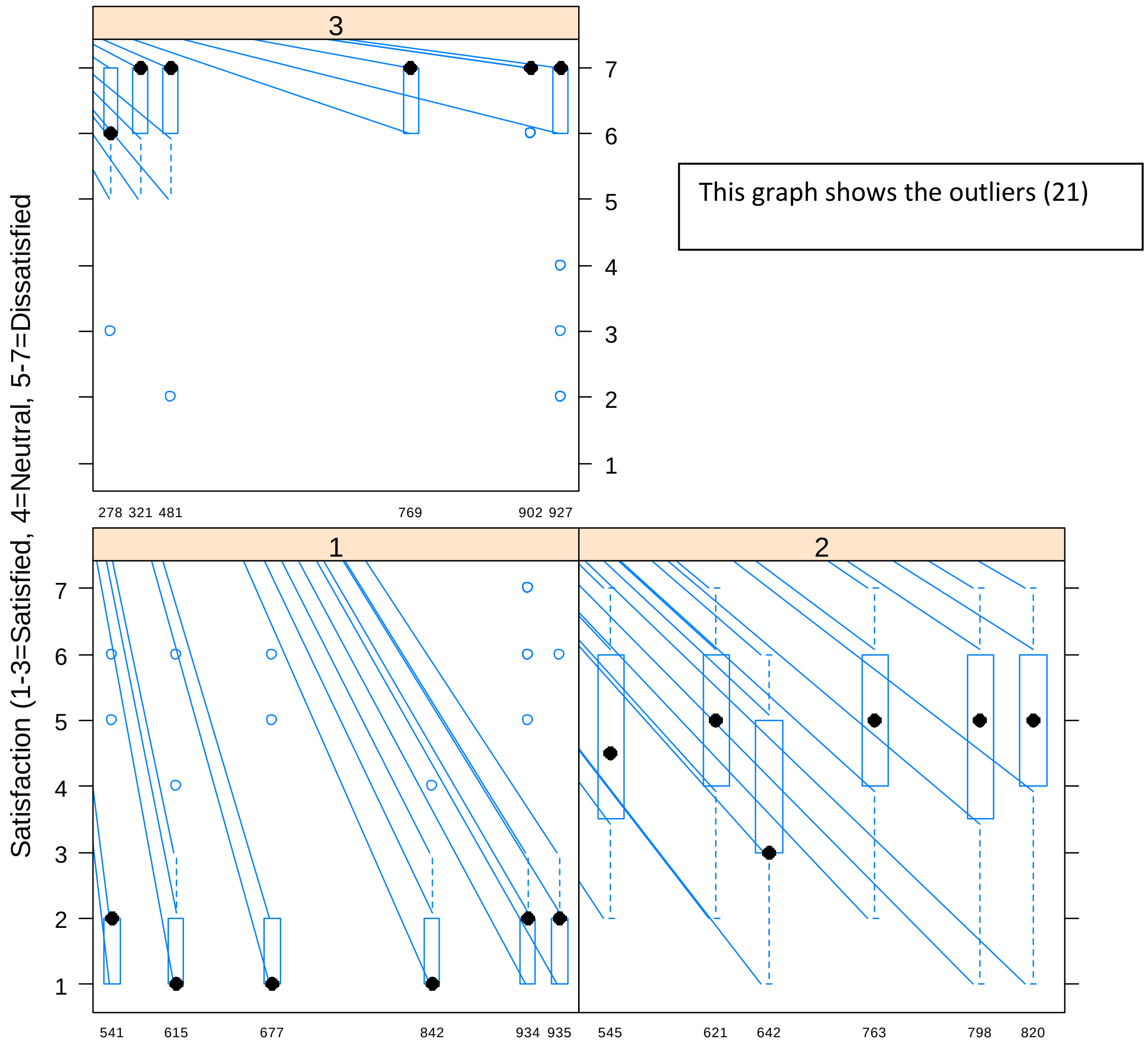


Figure 15a: Boxplots for individual crabs in each question (panels) for satisfaction with meat fullness

The general trend shown is that there is more satisfaction with crabs in Question 1 (low values) and more dissatisfaction with crabs in Question 3 (high values). Satisfaction levels for crabs in Question 2 are, on average, somewhere in between and the variability in the responses is much higher than for Questions 1 and 3 (i.e. responses span across the entire satisfaction scale).

Several outliers can be observed that correspond to high dissatisfaction with crabs that were clearly full of meat in the photographs (Question 1) and others that correspond to high satisfaction with crabs that clearly had extremely low meat content in the photographs (Question 3).

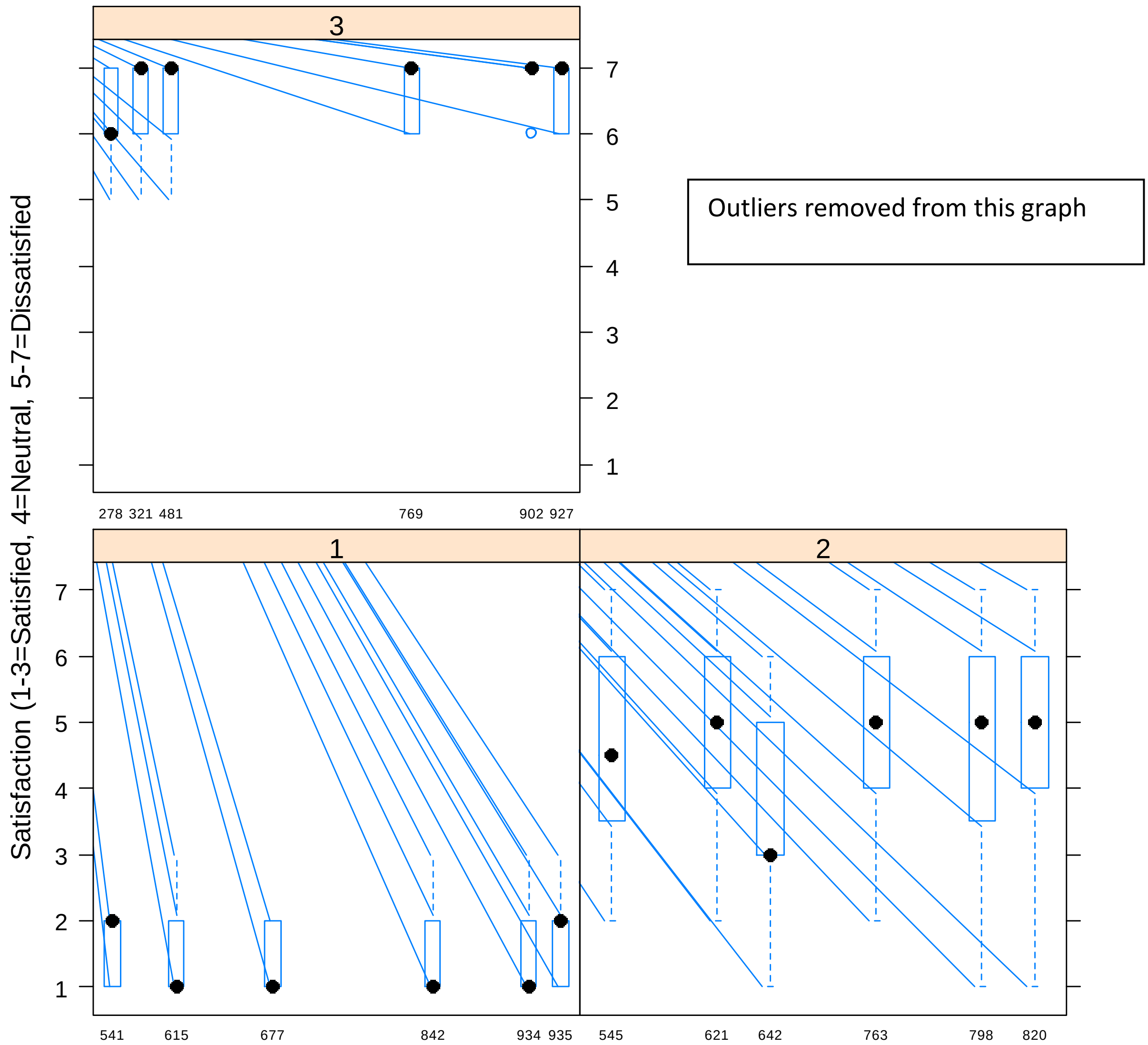


Figure 15b: Boxplots for individual crabs in each question (panels) for satisfaction with meat fullness

With the outliers removed, the general trend is easier to appreciate: overall more satisfaction with crabs in Question 1 (low values) and overall more dissatisfaction with crabs in Question 3 (high values). Crabs in Question 2 are on average somewhere in between and the variability in the responses is much higher than for Questions 1 and 3 (i.e. responses span across the entire satisfaction scale).

Figure 16 displays boxplots for individual crabs in each survey question for price willing to pay.

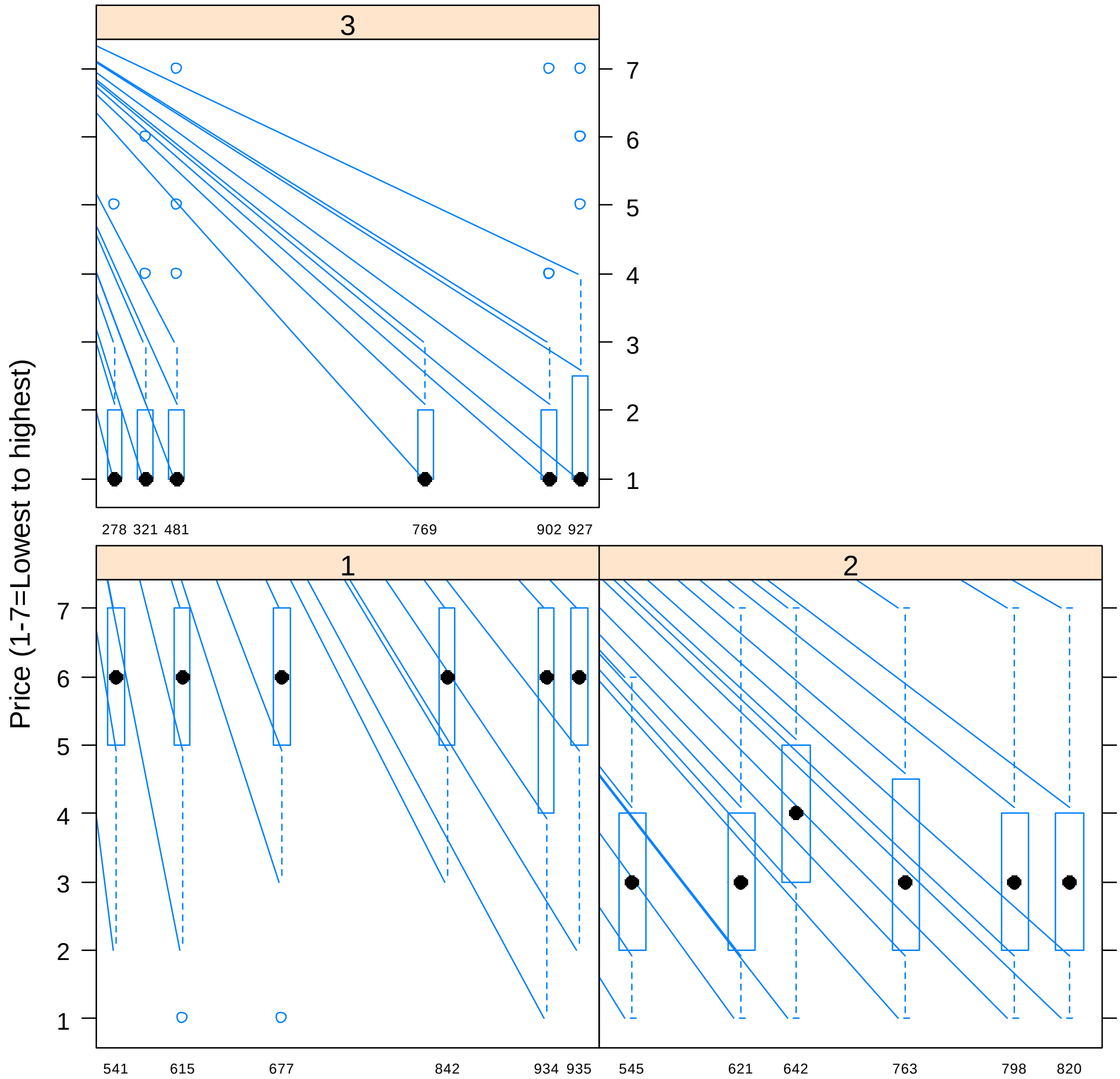


Figure 16: Boxplots for individual crabs in each question (panels) for price willing to pay

The general trend shown is that, on average, respondents would pay higher prices for crabs in Question 1 (high values) and lower prices for crabs in Question 3 (low values). Respondents would pay (on average), a price in between for crabs in Question 2.

There were less outliers in general than for satisfaction. These extreme values cannot be removed as it is possible that people are/are not willing to pay what is expected for a specific mud crab.

Relationship between RI and satisfaction

The relationship between RI and satisfaction with meat fullness can be explored via three graphs (Figures 17, 18 and 19). These graphs show the relationship between RI and satisfaction for all respondents (Figure 17), the relationship between RI and satisfaction by Question in the survey (Figure 18) and the relationship between RI and satisfaction by involvement of the respondent with mud crabs (Figure 19).

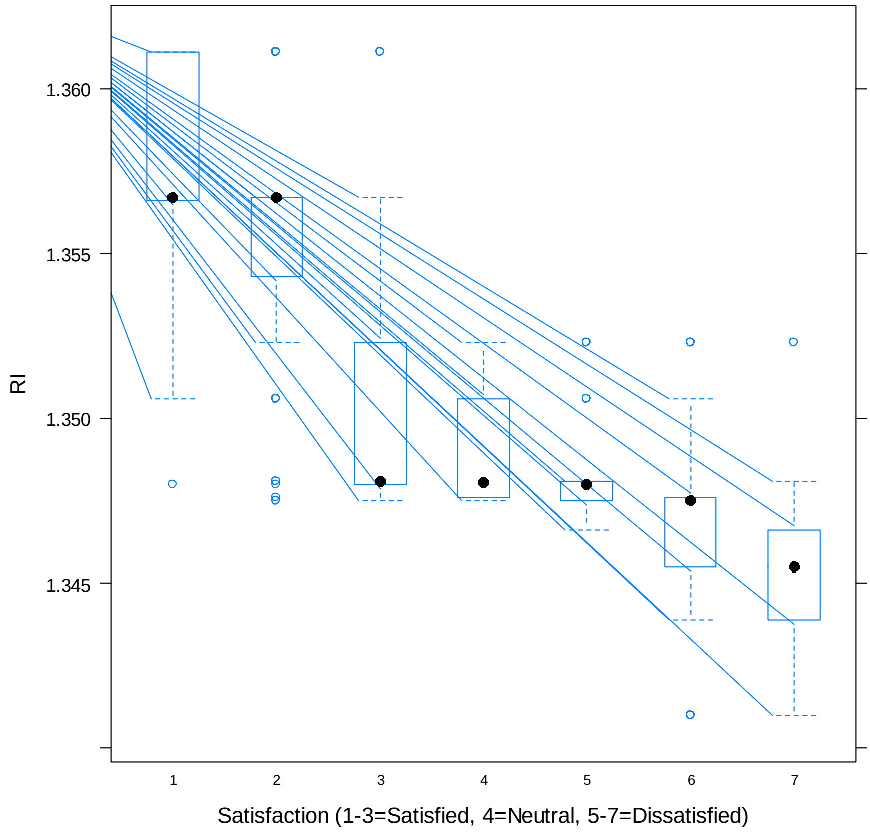


Figure 17: Boxplots of RI values for each level of the satisfaction scale, based on all responses

The general trend observed indicates that, on average, there is a relationship between satisfaction with meat fullness and RI of the crab where the higher the RI values the higher the satisfaction. This supports the arbitrary RI thresholds established for ‘A’ grade >1. 3500 and ‘C’ grade <1.3450.

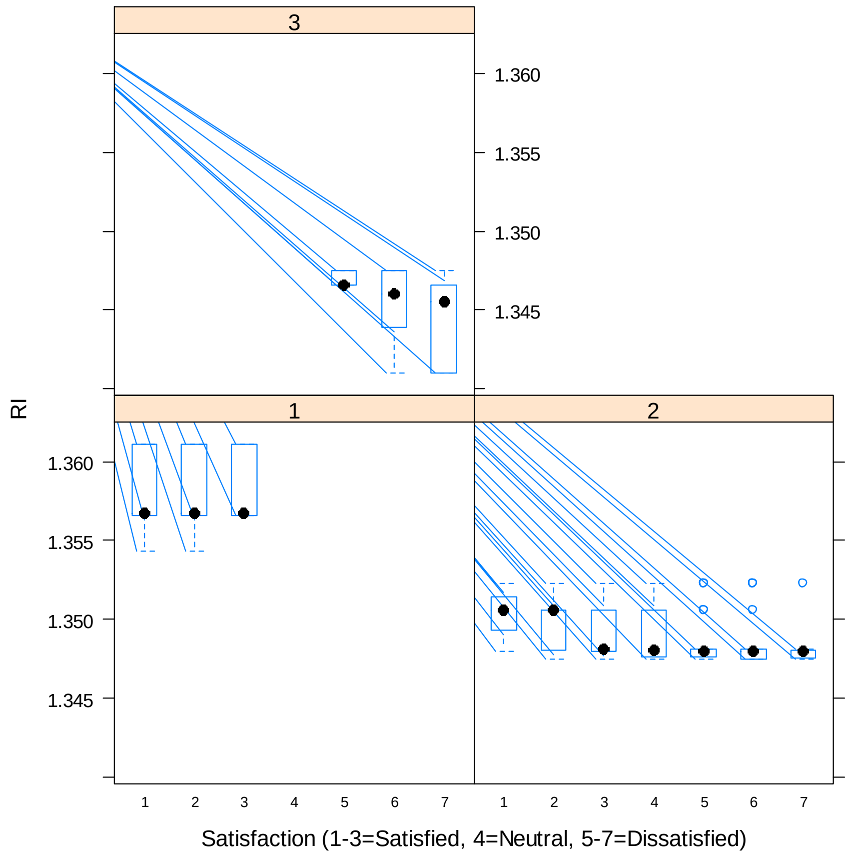


Figure 18: Boxplots of RI values for each level of the satisfaction scale, separated by Question in the survey

There is general satisfaction (low end of the scale used 1-3) for crabs in Question 1 (these crabs have high RI values) and general dissatisfaction (high end of the scale used 5-7) for crabs in Question 3 (these crabs have low RI values). All levels of the satisfaction scale were used for crabs in Question 2 (these crabs have intermediate RI values).

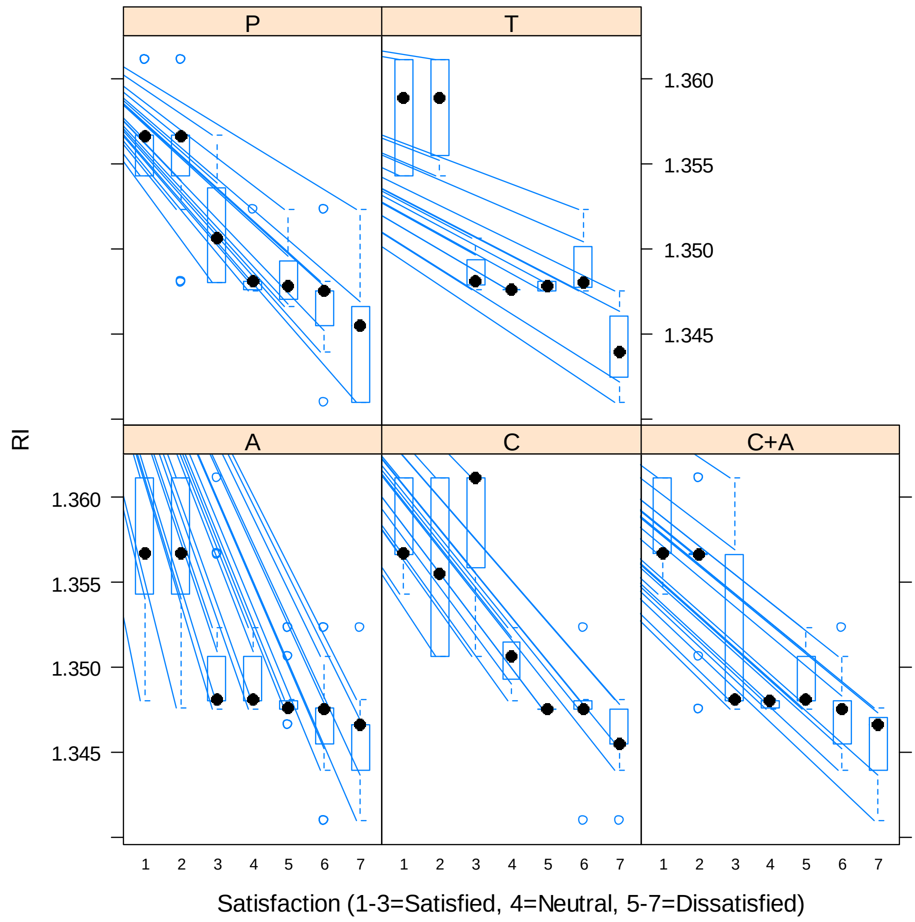


Figure 19: Boxplots of RI values for each level of the satisfaction scale, separated by involvement of the respondent with mud crabs (A = amateur mud crab fisher, C = consumer of mud crabs, C+A = amateur mud crab fisher and consumer, P = professional mud crab fisher, T = trader)

The trends observed align with the general average trend observed in Figure 17 where the higher the RI values the higher the satisfaction. (Note: the panel for traders is based on a low number of responses because there were only about 12 traders that took the survey).

Relationship between RI and price that respondents are willing to pay

The relationship between RI and price respondents are willing to pay can be explored via three graphs (Figures 20, 21 and 22). These graphs show the relationship between RI and price willing to pay for all respondents (Figure 20), the relationship between RI and price willing to pay by question in the survey (Figure 21) and the relationship between RI and price willing to pay by involvement of the respondent with mud crabs (Figure 22).

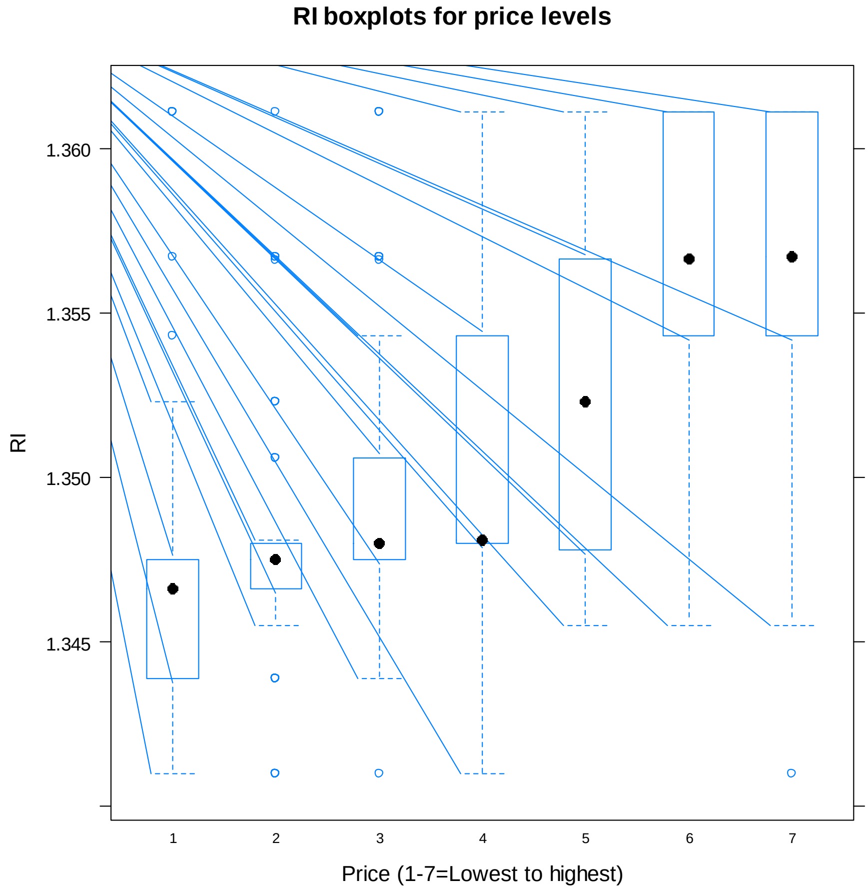


Figure 20: Boxplots of RI values for each level of price respondents are willing to pay based on all responses

The general trend observed indicates that, on average, the higher the RI values the higher the price that respondents are willing to pay. The highest variability in the prices that respondents are willing to pay corresponds to crabs with intermediate to high RI values. This trait has more variability than satisfaction.

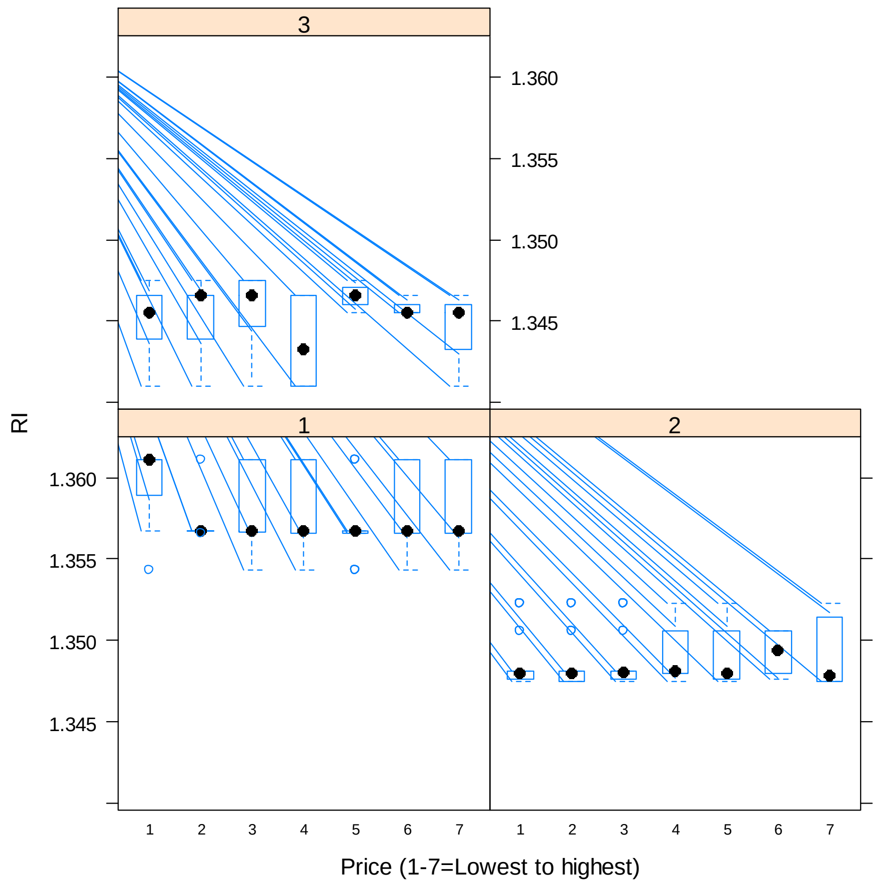


Figure 21: Boxplots of RI values for each level of the price respondents are willing to pay, separated by Question in the survey

This graph reflects the high variability for prices observed in Figure 20, and there are no obvious trends in the average price respondents are willing to pay that can be associated with specific crabs included in each of the questions.

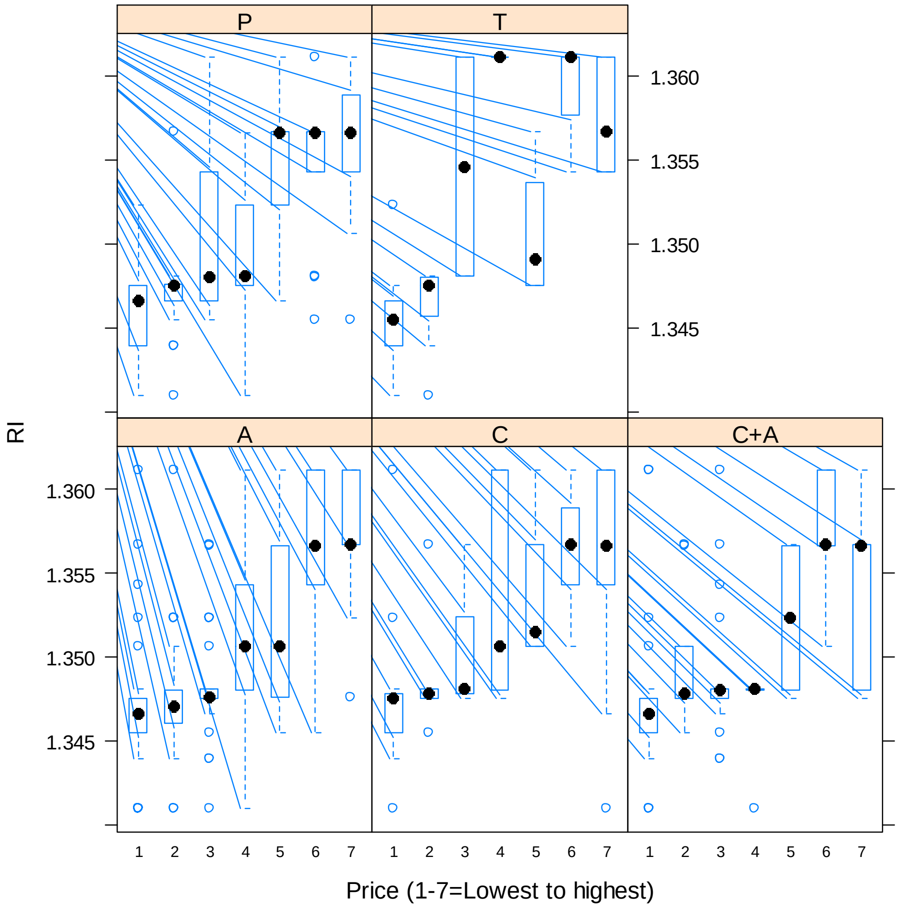


Figure 22: Boxplots of RI values for each level of price that respondents are willing to pay, separated by involvement of the respondent with mud crabs (A = amateur mud crab fisher, C = consumer of mud crabs, C+A = amateur mud crab fisher and consumer, P = professional mud crab fisher, T = trader)

The trends reflect the general trend observed in Figure 20 as well as the high variability of this trait. (Note: the panel for traders is based on a low number of responses because there were only about 12 traders that took the survey.)

4.3.2 Meat yield method development

Mud crabs are most commonly cooked by boiling in water for a set period related to the weight of animal. This cooking method countenances exchange of moisture between the crab muscle structures and the water cooking medium. Uptake or loss of water content from crab meat will therefore vary according to both external and intrinsic crab condition factors. This can result in erroneous meat yield weights being attained. This has been previously demonstrated by the current researchers using the water boiling method for cooking mud crab in early trials (FRDC 2003-240).

During this work the vagaries of determining meat yields in mud crabs, particularly female crabs, became evident. Initial whole weight of crab can be affected by many factors such as sexual maturity (ovaries [Image 10] are not included in meat content), gut content, fat content, abdominal flap water retention (particularly in females), limb damage, time and condition kept out of water pre-death, kill method (e.g. ice, ice slurry, refrigerated), cooking method etc. A consistent process was developed in pre- and post-cook treatments that allowed for some degree of certainty in determining cooked meat yields. However, it became evident that the body component of the crab was always prone to giving misleading whole weights and was very time consuming.

Image 10: Female crab showing ovaries - mature (left), undeveloped (right)

The difficulty in obtaining accurate meat yields from crabs has been noted by other researchers (Carpo and Crawford, 1991; Woll *et al*, 2006). One of the greatest contributors to variation in any meat yield assessment is the meat extraction technique post-cooking and cooling of the crab. Manual meat extraction or hand-picking is the traditional method and is by far the commonest method still used today. This method permits large error in total extraction of crab meat due to factors of: difficulty of removing meat from shell and appendages of some crab species; great variation in operator skill and experience and includes human attitude difference on the day. Cooking protocol is also important. Reports throughout the last 40 years have indicated that meat yield loss through cooking is common and loss varies according to precision of cooking method. The most critical parameters of cooking are temperature and time, exemplified by meat yield from crabs cooked at 100^{o}C for 8 min illustrating a 10% yield loss increasing to 21% when cooked at 121^{o}C for 10 min (Hanover *et al*, 1973).

Carpo and Crawford (1991) conducted trials with both water (boiling) and steam cooking and found no significant difference in meat yield between cooking methods, but reported cooking time was critical, with longer cooking periods resulting in reduced meat yield. However, Ninlanon (2011) describes meat yield losses through different pre-cooling of live mud crab treatments and up to 30% reduction in meat yield after 7 days storage post-cooking.

To avoid interference from uptake or loss of water during the killing process, crabs were emersed for a standard period of 20 minutes prior to being encased in ice only and kept in a refrigerator overnight in a draining bin. To avoid interference from uptake or loss of water during the cooking process, it was considered likely that cooking by steam would provide more consistent and directly comparative results across individual animals. The steaming method developed using a commercial steamer oven (Unox® model XF135, Image 11) where crabs are placed in a Pyrex dish and steamed for 20 min per kg at 120°C in 100% humidity. Up to six large crabs can be cooked in one session.

Image 11: Crabs cooking in a commercial steamer oven

From multiple investigations determining meat yields for male and female crabs of all grades it was illustrated that just recording meat yield from claws was most indicative of crab quality and range of grades. Claws were removed from the body at the natural autotomy point using a Dremel cutting tool (Image 12). The tool creates a small score which then allows the claw to be snapped cleanly off at a consistent point for all limbs.

Image 12: Removal of limbs with cutting tool at autotomy point

Free liquid was drained briefly for a standard period of time from the cut end as it often flowed freely during the separation from the body, particularly from 'C' grade crabs. The cooked claws were weighed individually. Meat was then hand-picked from the entire claw and weighed. Any excess fat or remaining free liquid was not included in weights. Yield percentage is calculated as: total claw weight / picked meat weight *100. The body cavities were cleaned and any female ovaries removed and a visual grading assigned as mentioned in the Methods section.

4.3.3 **Results**

Investigation of the meat content of mud crabs showing slight shell flex demonstrated that the occurrence of crab with high meat yield and flexible shell was a physical reality and a common occurrence observed most frequently in mud crabs harvested from NSW estuarine waters. Site visits to Ballina, Clarence River, Port Macquarie and Wallis Lake Fishermen's Co-operatives, as well as at Sydney Fish Market, illustrated that consignments of male mud crabs were predominantly crabs with some flex on the top carapace while being hard-shelled on all the underside segments. Graded under the AILMCGS, these crabs were not equivalent to 'A' grade crab, but would be determined as 'B' grade and suffer the lower price return for that grade crab.

In order to have a confident basis on which to amend the AILMCGS, this phenomenon needed to be fully explored.

The main edible portion of mud crabs is contained in the claws and the body area, with swimming pereiopods ('legs') frequently eaten, but contributing little to total meat yield. In mud crabs, meat content of an animal shows seasonal variation (Figure 23) and is also correlated directly to moulting phase and breeding cycle (Chiou and Huang, 2003). Harlioğlu and Holdich (2001) found that maturity, size, condition and location, as well as the way the meat was prepared for analysis, influenced meat yield from lobsters. Crab gender was also shown to be a factor, with observation that meat yield from claws of males is greater than that for females (Barrento *et al*, 2010) and harvest location (Naczk *et al*, 2004). There are only a few reports of studies focused on crab meat content or yield and these investigations appeared to have been triggered by observation of similar phenomenon to that exhibited by mud crabs. It was observed that the quality of hard-shelled crabs may vary between and within regions (Oshira *et al*, 1999; Woll *et al*, 2006; Yomar-Hattori, 2006). Feeding studies showed a positive effect of meat yield increasing for all fed groups of Norwegian Brown crab (*Cancer pagurus* Linnaeus) and the effect seemed greater with increasing water temperature (Woll and Berge, 2007). The improvement of quality traits was a continuous process correlated with time of feeding or cumulative feed intake. From their studies, the researchers concluded that feeding at an appropriate temperature and acceptable diet has proved to increase the quality of female edible crab during a three to four week period (Berge and Woll, 2006; Woll *et al*., 2006).

Previous research work on mud crab quality by the Department of Agriculture and Fisheries, FRDC project 2003-240, has illustrated a good correlation between crab haemolymph RI and cooked meat yield obtained.

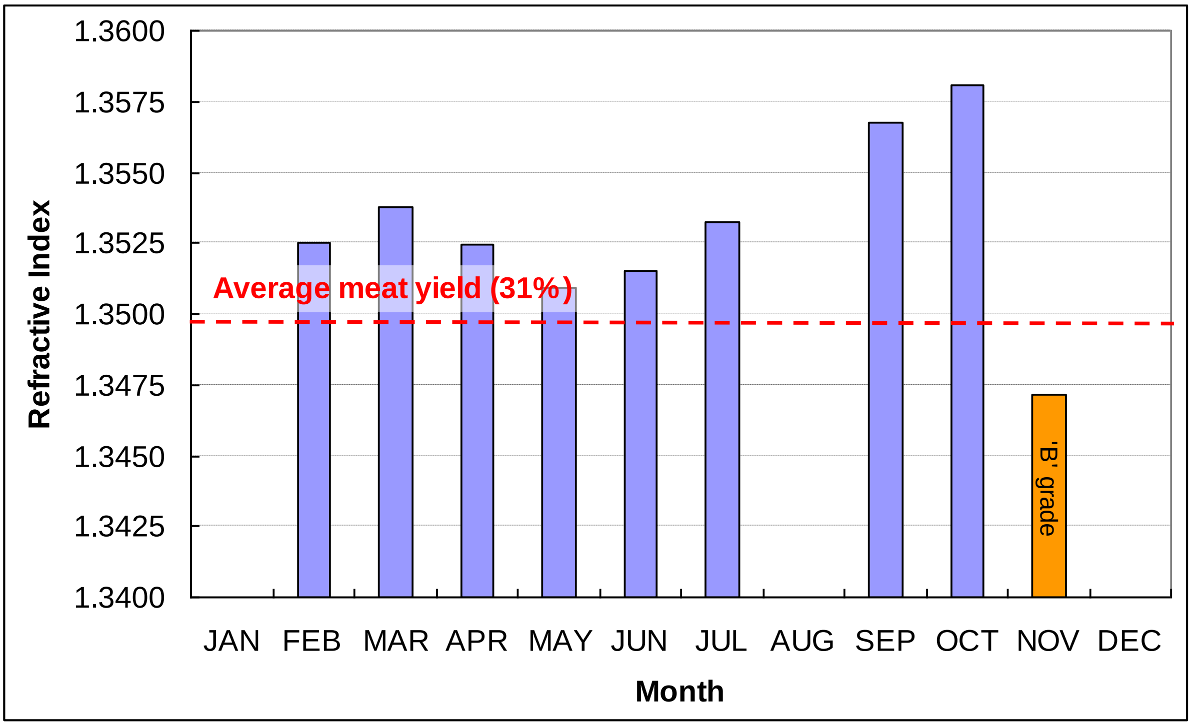


Figure 23: Seasonal variation of 'A' grade crab

As the average meat yield for 'A' grade crabs (claw and body meat combined) was 31%, the conservative threshold RI value of 1.3500 was adopted. Woll *et al* (2006) used a threshold of 30% meat yield as a measure of good quality crab. However, it was considered beneficial to attain futher cooked meat data on a wide range of crabs that exhibited the slight-flex characteristic on the carapace from descrete regions and continue to refine the meat yield methodology. As illustrated in Figure 24, the best correlation was from claw yields. The drain period for the claws was later increased to improve this correlation.

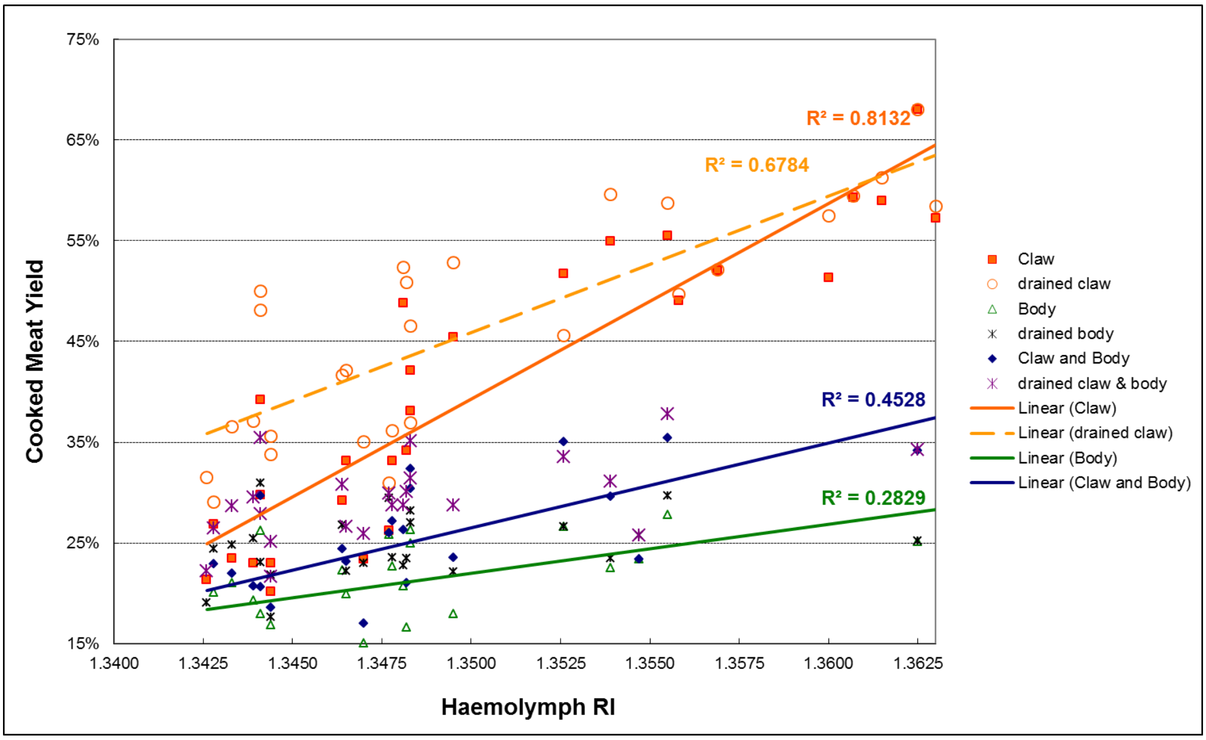


Figure 24: Relationship between (body, claw and both) meat yields and RI for male and female crabs

The increased range of drained claw meat yields of crabs with lower RI values was predominately due to female claws, as depicted in Figure 25.

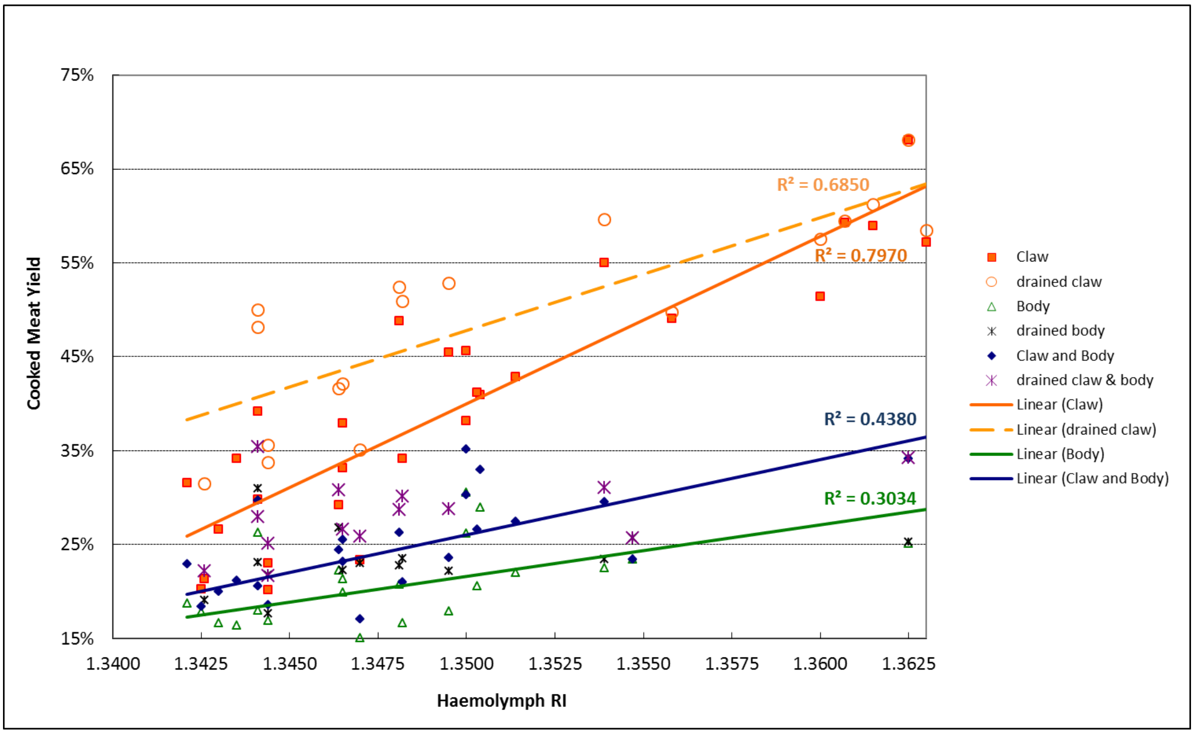


Figure 25: Relationship between (body, claw and both) meat yields and RI for female crabs

Further sampling of claw yields (Figures 26 and 27) has shown a similar trend that crabs with low haemolymph protein can have a wide range of meat yields. A factor contributing to this may be that the protein has only recently entered the crab's system and not yet converted to muscle mass in newer moulted crabs and that claw shell density and mass varies between individuals and sexes in the rate in which it develops post-moult.

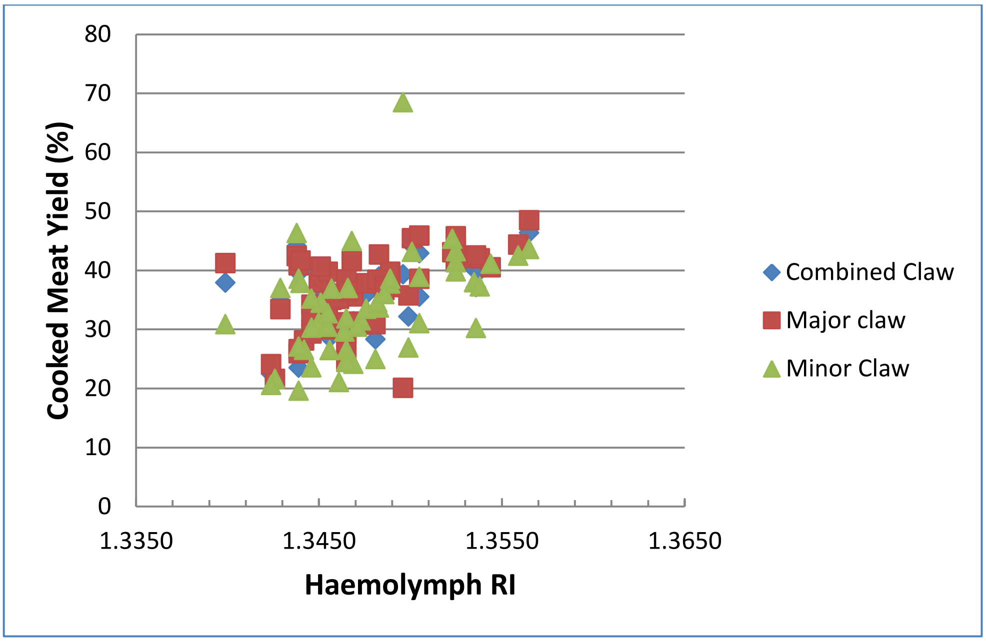


Figure 26: Relationship between meat yields and RI for male crabs

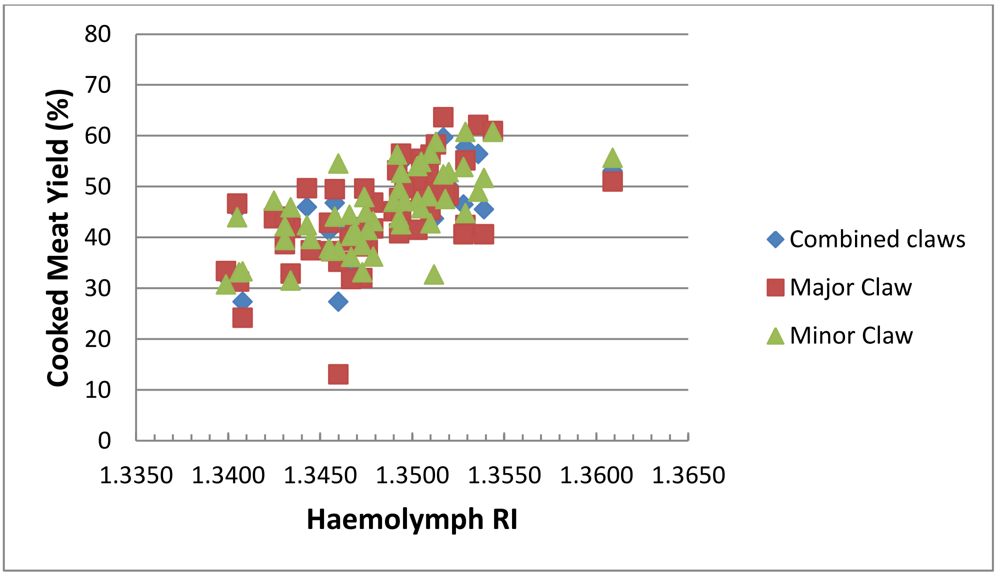


Figure 27: Relationship between meat yields and RI for female crabs

Pooling data from all trials (Table 11) from this project shows the average RI is the nearly same for both sexes for each grade. 'A' grade female crabs have an average minimum RI value used as a guide for grading marginally higher than males. However, the large overlaps in ranges between grades make the use of total protein as a measure for determining the thresholds between grades somewhat ineffective. Some of the low RI values for ‘A’ grade crab are attributed to being terminal moult crabs or ‘crusties’.

Table 11: RI average range against grades (n=155)

Sex	Grade	RI range	RI average	Range guide for grading
Female	A	1.3439 - 1.3631	1.3523	>1.3490
	B	1.3460 - 1.3588	1.3502	1.3480 - 1.3520
	C	1.3362 - 1.3556	1.3476	<1.3500
Male	A	1.3439 - 1.3630	1.3524	>1.3470
	B	1.3454 - 1.3602	1.3508	1.3475 - 1.3520
	C	1.3415 - 1.3517	1.3474	<1.3500

Visual grades assigned to the exposed body cavity meat were compared to the shell hardness grade and average RI values of the body meat grade categories (Table 12).

Table 12. Body meat and shell grade comparison (n=104)

	Grade	Body Meat Grade	Shell Grade	Average RI of body meat grades
Female	A	25	28	1.3507
	B	25	9	1.3466
	C	3	16	1.3404
Male	A	21	22	1.3508
	B	22	21	1.3461
	C	8	8	1.3445

For male crabs the body meat grade matched the shell grade. However, female crabs differed greatly for ‘B’ and ‘C’ grade. This is likely to be attributed to the stage of sexual maturity of the female crabs. The average RI values of the body meat grades are typical of previous observations.

The meat yields attained for mud crabs in this current research were higher than those reported for other crab species (Table 13). However, it is difficult to directly compare meat yields from different studies as experimental protocols differ. For example, Hattori *et al* (2006) gave meat yields that included pereiopod meat and Cherif *et al* (2008) only stated the yield from both claws. Additionally, several researchers picked raw meat from the crab, which is far more laborious than extracting cooked meat and retains natural moisture without the gains or losses involved in cooking.

Table 13: Meat yields from different crab species

Crab species	Reference	Cooking method	Cooked meat yield (%) *		
			Total	Males	Females
Scylla serrata	**Current research**	**steamed**	**18 - 41**	**32.2**	**28.5**
Scylla serrata	Brown, 1986	boiled	29.0	-	-
Scylla serrata	Chiou and Huang 2003	not cooked	10.6 - 17.6	15.1	14.6
Portunus pelagicus	Brown 1986	not cooked	39.0	-	-
Portunus pelagicus	Wu 2010		32	-	-
Charybdis natator	Sumpton, 1990	not cooked	35.0	-	-
Ucides cordatus	Pinheiro *et al* 2015	steamed	15.0 - 30.8	25.4	21.1
Callinectes bocourti	Hattori *et al* 2006	boiled	23.4	28.5	22.1
Carcinus maenas	Naczk 2004	not cooked	23.5 - 27.8	-	-
Carcinus mediterraneus	Cherif *et al* 2008	not cooked	24.9 – 26.1#	-	-
Eriocheir sinensis	Chen *et al* 207	steamed	24.2	-	-

* meat yield calculated as meat weight/crab wet weight x 100

\# claw meat only

From the meat yield data reported separately for male and female crabs in Table 10 above, females provide higher meat yield than males. Wu *et al* (2010) also found that female blue swimmer crabs (*Portunus pelagicus*) yielded significantly more meat (44.3%) than the males (35.9%).

For mangrove crab (*Ucides cordatus*) meat yield was similar between right and left claws irrespective of claw dominance in behaviour (Table 14). Meat yield was also independent of crab gender and biological period analysed (Pinheiro *et al*, 2015).

Table 14: Meat yields of mangrove crab

	Meat yield (%)		
	Combined	**Major**	**Minor**
Female	44.9	44.6	45.2
Male	35.3	36.2	33.9

In mud crab, the claws are normally not of even size, particularly in males. There is no regular pattern as to whether the major claw is a left or a right claw in either sex. In the sample set depicted in Table 15 there is preference for the right claw to be the major claw in both sexes, but this does not always hold true across sample sets. Furthermore, the major claw does not always have the higher meat yield for both sexes. This data set shows a preference for males to have a higher meat yield in the major claw and the opposite for females.

Table 15: Claw dominance distribution and yields

	Major claw		Higher meat yield (%)	
	Left	**Right**	**Major**	**Minor**
Female	10	44	22	31
Male	17	36	36	16

The significance of this finding is that both claws need to be included in any assessment by a non-invasive grading tool.

4.4 Objective methods for grading

The industry has been calling for an objective method for much time. Within the current project, a broad range of objective technologies were explored to determine their potential usefulness for grading mud crab.

4.4.1 **Introduction**

Traditionally, the decision of whether a mud crab should be retained at harvest is based on shell hardness. Shell condition is most commonly assessed by thumb pressure applied to the carapace of the crab. When a crab has recently moulted, the carapace will flex considerably and such a crab, regarded as a “water-bag” within the industry, is returned to the water. From this water-bag state, the crab shell increases in hardness until fully hard, considered a premium quality crab. In general this assessment system is effective, however there will always be disagreement if this measure is used to divide crabs into different quality grades. The issues arise from the subjective nature of the test:

- different force applied by individual operators
- different areas of the carapace tested
- multiple assessment at same points on shell along the supply chain
- crab animal morphological differences and males/females different
- different values between crabbers along the supply chain

Therefore, where degree of shell flex is the measure for assigning crabs into different grades, the majority of crabs may fall into a grade neatly but there will always be dispute at boundaries of the grade.

4.4.2 **Haemolymph protein**

As outlined in the previous section haemolymph protein and the total blood protein concentration has been shown to be reliable to assess the muscle mass of crustacean.

The RI range guide (Table 16) has been developed over many years of meat yield and RI analysis. As a simple test to provide a grade in relation to meat yield rather than shell hardness it may be limited in its application as a definitive grade definer and best used as a predictive test or used in combination with other quality parameters to predict crab grades. However, without actually cooking the crab and determining the meat yield, it provides a better prediction for research analysis than the shell hardness test.

Table 16: Grade by RI range guide relative to meat yield

Grade by RI	**RI range**
A	>= 1.3500
B	1.3451 - 1.3499
C	<= 1.3450

The Shell score for female crabs (Figure 28) seems to correlate with RI values.

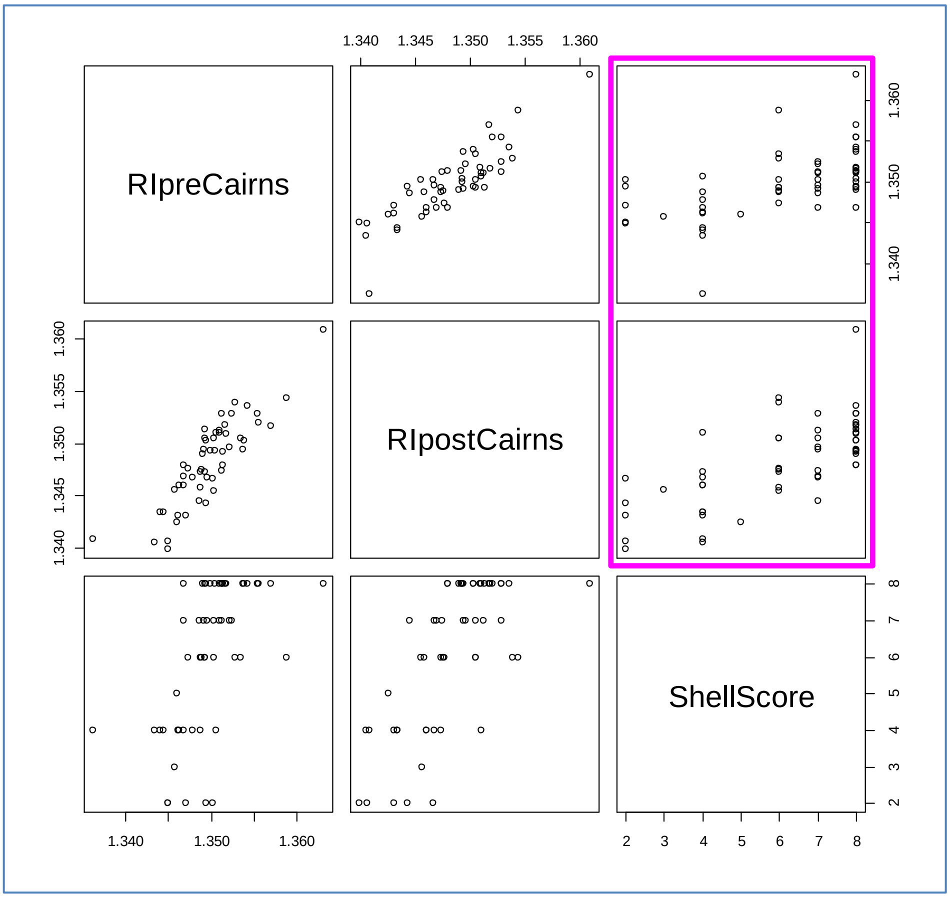


Figure 28: Female crabs – RI and shell hardness

The Shell score for male crabs (Figure 29) reaches a maximum of 24. This value of 24 corresponds to the whole range of RI values. The lower scores (< 15) aren't necessarily associated with the lowest RI values. Shell scores between 15 and 23 seem to correlate more with RI values. Further analysis of quality parameters was clearly required and has been since carried out as reported in a Section 4.5 of this report.

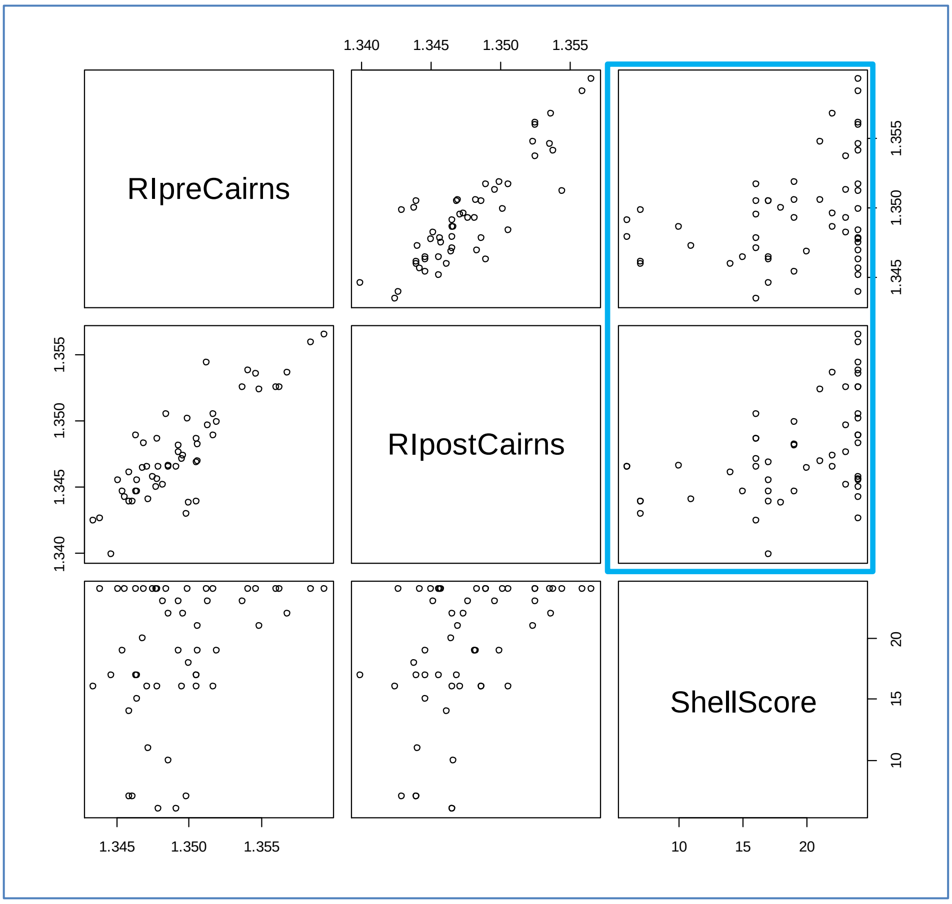


Figure 29: Male crabs – RI and shell hardness

Total protein can be easily and accurately measured using a variety of techniques. The techniques have been verified against commercial laboratory protein determination test kits.

Refractometry

This method is a measure of total free protein in the haemolymph of an animal and, of course varies according to many factors, including diet abundance, physiological state and moulting cycle phase. Many researchers have used refractometry to gauge physiological state of crustaceans (Lorenzon *et al*, 2011; Ozbay and Riley, 2002; Paterson *et al*, 1999) and it is demonstrated to be an accurate and reproducible method. Refractometry has been well applied to mud crab haemolymph throughout studies over the last 13 years. However, while the method is simple, it does demand removal of the haemolymph sample by use of a syringe from the sinus at the base of the third pereiopod. This requirement is not appropriate in all circumstances occurring within the mud crab industry.

Reagent test strips

It was considered worthwhile to see whether simple reagent test strips would be effective for dividing mud crabs into established grades. Seimens Multistix® 10 SG Reagent Strips for Urinalysis (Image 13 - highest values from the top strip down) were compared to RI values of haemolymph samples across the range total protein found in mud crabs. The strips are typically for *in vitro* diagnostic use and include a test pad to detect protein with a sensitivity of 15-30 mg/dL albumin. Although the strips measure within range of total protein found in crabs, interpreting the discrete colour change from the products Colour Chart tended to be somewhat objective.

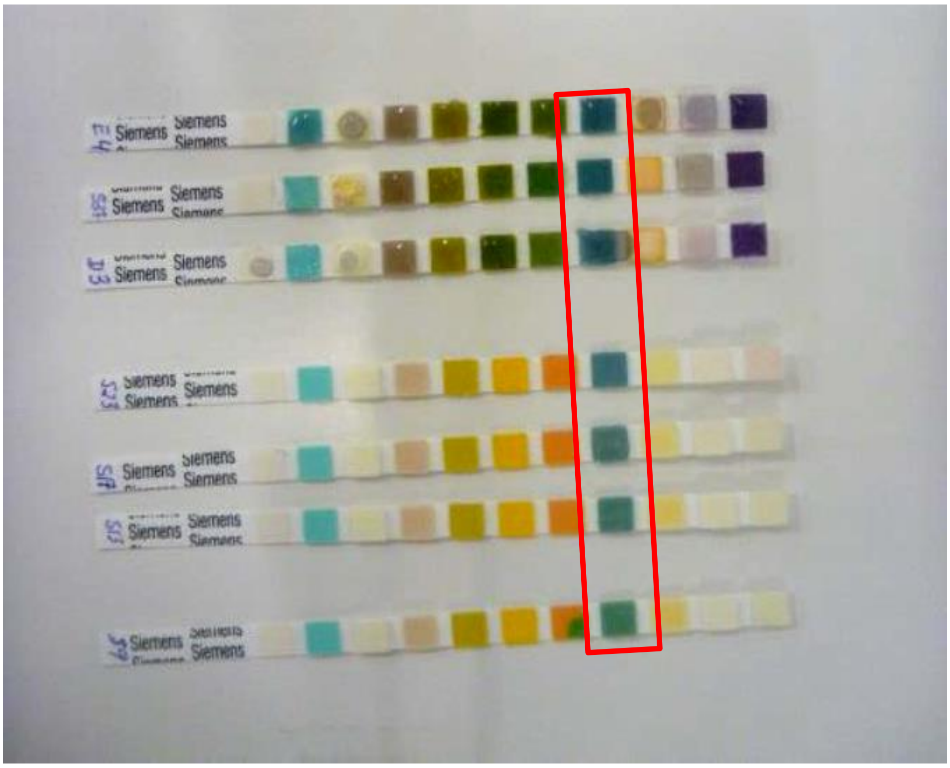


Image 13: Siemens Reagent Strips from a range haemolymph protein samples

This method still requires a syringe to remove the haemolymph sample from the animal, hence does not resolve that issue with the refractometer. More fundamentally, these test strips were not sensitive enough to differentiate levels of protein in mud crab haemolymph. The deduction is that this is not an effective tool for quantifying mud crab grades.

4.4.3 **Force sensing**

The traditional thumb pressure test for shell hardness is highly subjective, particularly with different forces applied by individuals and each operator's decision about degree of flex. To avoid this subjectivity, several 'pressure tools' were assessed for effectiveness in measuring crab shell hardness.

Durometer

Investigations by Grubert *et al* (2012) assessing Northern Territory mud crab for shell hardness focused on the use of the durometer. The Northern Territory prohibits the retention of Commercially Unsuitable Crabs (CUCs or “soft” crab) and the industry seeks consistency with the interpretation of the mandatory shell hardness test. As such, extensive research was undertaken in the feasibility of the durometer as an objective tool to distinguish between Commercially Acceptable Crab (CAC) and CUCs.

Several issues were highlighted within this body of research in the suitability of the durometer as a tool to be used within the industry:

- variability between instrument models
- location point on carapace
- unevenness of carapace surface at location point
- carapace already damaged
- the application of the tools indenter causing softening or damage to the shell
- the risk of classifying some CACs as CUCs and vice versa
- cost and durability of the tool

In the opinion of the author, the tool is not suitable for field use, but possibly useful as a research tool if care was taken to keep assessments very standard across animals.

Tekscan® flexiforce

Pressure and force-touch can be readily assessed by force-sensing resistors; one of these is the Tekscan® force sensitive resistance tool (Image 14). Force sensing resistors are thin isometric force sensors whose resistance decreases with the force applied in a nonlinear way. Typically these types of force sensors are qualitative and used on a maximum–minimum measuring basis (Hollinger and Wanderley, 2006) although they can be semi-quantitative to specific set thresholds (Almassri *et al*, 2013).

Image 14: The Tekscan® force sensor with adapter

The Tekscan® sensor was used to quantify the force required to flex mud crab carapaces of various hardness. As with the durometer, the pressure pad requires a level surface and consistent application. Pressure readings could be affected by applying pressure with the point (Image 15) or side of the thumb to the acetate sensor pad.

Image 15: The Tekscan® force sensor tool

To eliminate this problem, a touch tag holder was secured to the pad (Image 14). This adapter aided for an even pressure to be applied from different size thumbs at the correct angle in a consistent manner. The Tekscan® sensor was then calibrated against a penetrometer (Instron Model 5543). Readings against a range of crab shell harnesses demonstrated that a threshold could be assigned to each grade as in Table 17.

Table 17: Force required creating flex for each grade

Grade	Pressure applied
A	6kg
B	4kg
C	2kg

Despite efforts to describe how much pressure to apply during the thumb test in the AILMCGS, wide variations remain in the amount of pressure and the technique applied between individuals across the industry. "How much pressure do I apply to create flex?" is one of the most common questions asked. This kilogram pressure guide enable crabbers the ability to 'self- calibrate' their thumbs. By simply pressing down on the centre of a weighing scale with the same technique as per grading a crab, crabbers can 'feel' what the minimum pressure is required to create flex for each grade.

However, there are a few downsides of this application. The judgement is still subjective as to what is described as flex; just a minuscule amount after several squeezes or a noticeable movement with one squeeze of moderate pressure. Also, and most importantly, the minimum size of the sensor is larger than underside carapace segments of small crabs, particularly from New South Wales where a smaller legal minimal carapace size exists. This makes those readings invalid. A dual sensor system that measures both discrete movement and pressure would be required to remove this subjectivity. Further technological developments in this field may offer opportunities for an objective mud crab grading sensor tool.

Pressure glove

Force sensors of a similar nature as described above can be incorporated into a hand glove (Aroca *et al*, 2013). One such sensor glove (Image 16) has been developed by Darryl Joyce, DAF, for the avocado industry. In this research consumer behaviour on the way avocados were squeezed in retail outlets was studied. Avocados have a similar problem to mud crabs in that multiple pressure tests damage the product.

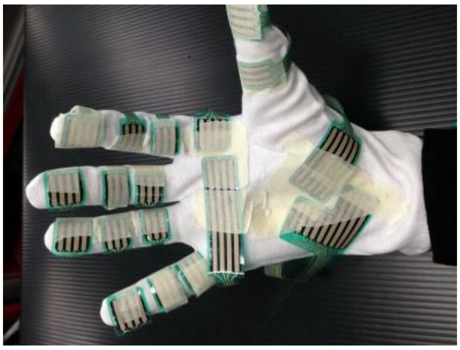


Image 16: Pressure sensitive glove developed for avocado research

The findings provided useful information to the industry but this tool would not be suitable in its current form for the industry.

4.4.4 X-ray

Custom designed machine vision technology using x-ray images is used in many industries world-wide to separate animals into different grade categories. Non-destructive soft x-ray similar to that used in airport baggage scanning has the ability to identify meat content and/or shell thickness of crustaceans based on the density found.

Contact was made with the Canadian Lizotte Machine Vision group to supply information and pricing on the suitability of such technology for the Australian mud crab industry. The information provided appears to have a theoretical potential. However, there were too many negatives to further the investigation:

- the proposal required:
  - the algorithm to developed by Lizotte engineers, including travel and living expenses
  - 40% payment before technology developed
  - price (excluding data acquisition, installations and commissioning): $200,000 US
  - an additional cost, on invoice (estimate): $1,250 per day US
- several staff are required to operate the machine
- ongoing maintenance costs are likely to be significant
- industry is likely to be suspicious of grading defined by a system they cannot match their traditional grading to
- only three grade categories defined; currently SFM have 31 categories!
- the logistics of unpacking, measuring re-packing measuring every crab and distributing individual consignment returns

The conclusion is that this system would only be suitable for a very large throughput of product at major market facilities and not suitable at all for the wider and geographically dispersed Australian industry.

4.4.5 Nuclear Magnetic Resonance Imaging

In an effort to explore the physiology the mud crabs in relation to their moult stage, carapace dynamics and body content, an opportunity was taken to utilise the mortuary at the John Tonge Centre, Queensland Health Forensic and Scientific Services on-site at the Coopers Plains facilities. Obviously, this was purely an investigative look into crab physiology to quantify parameters and not something applicable to the industry.

The morgue agreed to the use of their Nuclear Magnetic Resonance Imaging (NMRI) scanner in an attempt to measure the components of a live mud crab that may be related to meat fullness. The process required the crab to remain motionless during scanning, something that is not a problem for their normal subjects. Fortunately, crabs placed on their back do go into a motionless state for a period of time long enough for the scanning process. Pre-chilling the crab assisted in the length of time it remained motionless.

The instrument used had some issues in assisting to quantify quality parameters:

- It was not able to give images of shell width accurate enough to measure.
- The internal water movement of the crab blurred images of muscle structure.
- The crab was deemed potentially unsafe to eat after exposure.

Further studies using the University of Queensland's School of Veterinary Science advanced NMRI were said to be more likely to provide higher resolution images.

4.4.6 **Candling**

The art of 'candling' is a very old one and the term originally referred to holding an egg before a candle flame to inspect for freshness. Candling is also commonly used in embryology to study the development of an embryo inside an egg. The method uses a bright light source behind the egg to illuminate the contents and show details through the shell. The method is simple but has developed into highly technical applications. It has been applied in many seafood processing applications for quality inspection, assessment for presence of fish nematodes and as a means to detect foreign matter presence in final product (Brattey, 1988; Bublitz and Choudhury, 1992; Lunestad, 2003). It has been noted that candling is used in some Bangladesh mud crab businesses to determine sexual maturity and moult phase in female crabs (Image 17).

Image 17: Carapace exposed to torch – early moult (left) and late moult (right) stage

Results and discussion

Photographs were collected of the illuminated carapace of each individual mud crab and the dominate claw for the top, bottom and side profile. The photographs were plotted into histograms to determine if there was a relationship between the percentage meat yield of the claws (cooked) versus the amount of illumination for each crab and sample point. The photographs for all female and male mud crabs for carapace and dominant claw (top, side and bottom profiles) are depicted in Image 18 and 19. The histograms indicate there is no obvious correlation between the percentage meat yield of the cooked claws versus the illumination of both the carapace and the dominant claw.

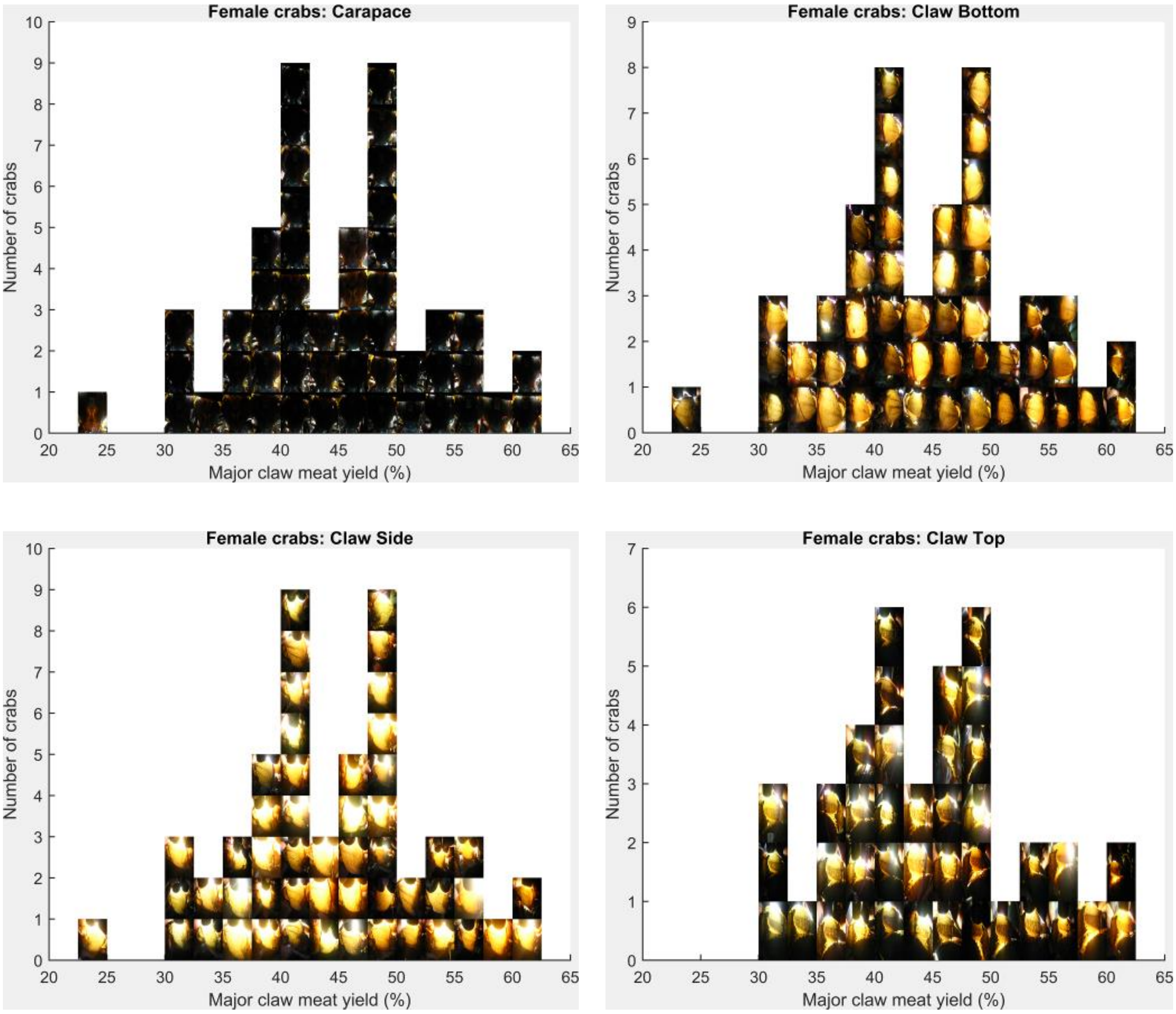


Image 18: Candling histograms for Female crabs for carapace and dominant claw (top, bottom and side profile)

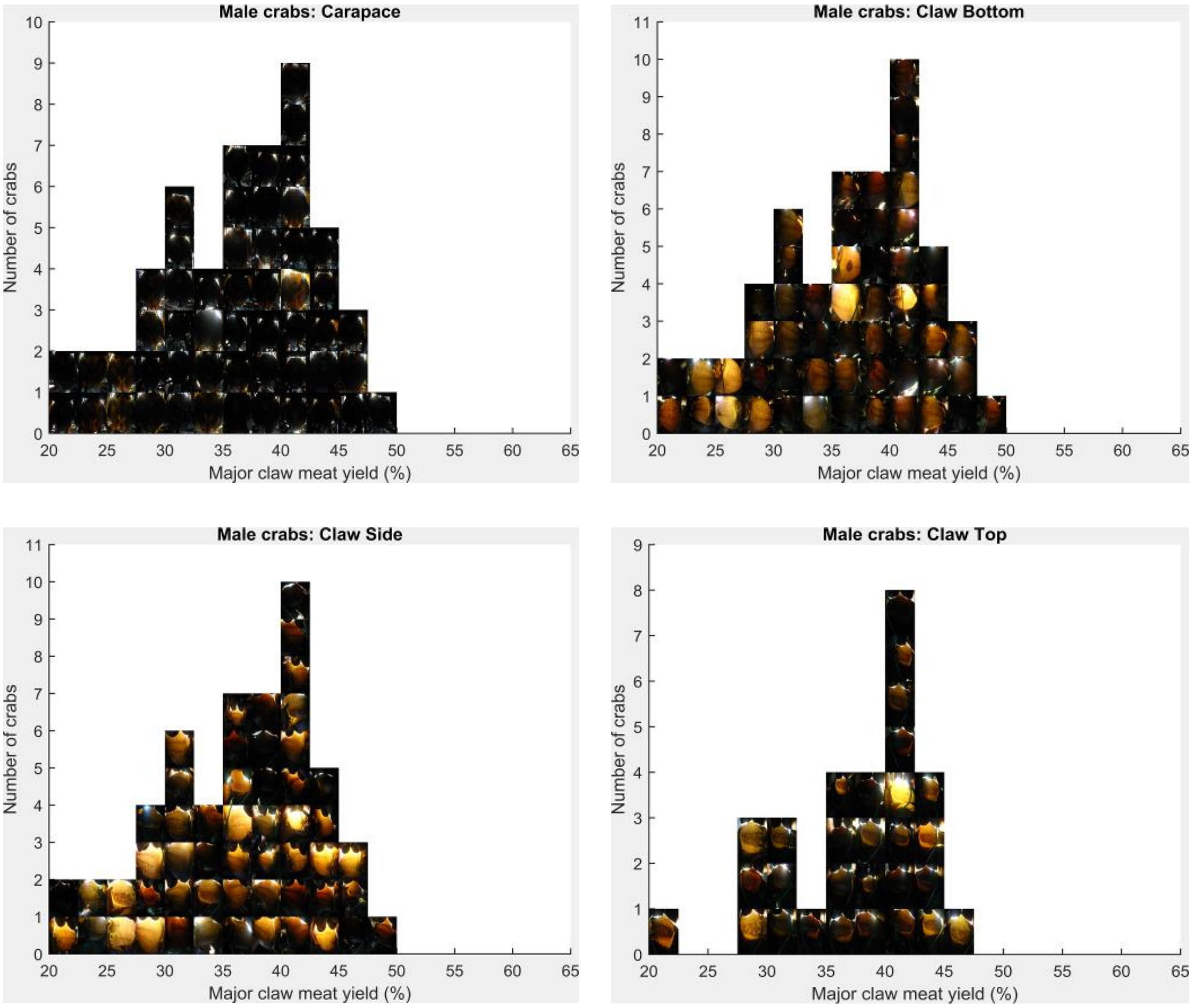


Image 19: Candling histograms for Male crabs for carapace and dominant claw (top, bottom and side profile)

Conclusion

Results from the preliminary investigation indicate that there was no obvious correlation between the percentage meat yield of the cooked claws versus the illumination of both the carapace and the dominant claw. The candling method could be further investigated using other techniques of image capturing to see if enhancing the image will improve the correlation performance.

4.4.7 Acoustic Velocity

Scoping Study Thesis

This project was very fortunate to have a thesis on non-invasive technologies submitted to the College of Science, Technology and Engineering, James Cook University. The thesis, titled 'Investigation of Technology to Accurately and Non-Invasively Assess the Meat Content of Mud Crabs' was submitted by Stuart Fordyce in partial fulfilment of the requirements for the degree of Bachelor of Engineering (Electrical and Electronic).

Thesis Objectives

This thesis thoroughly analysed the feasibility and accuracy of several techniques of estimating the meat content of mud crabs. The objectives of this research were to:

- Identify and investigate possible methods of estimating the meat content of mud crabs.
- Test and analyse the effectiveness and accuracy of each of the methods.
- Demonstrate a proof of concept for the technique on mud crabs.
- Identify the most accurate grading method and test its accuracy.
- Time permitting, design and build and commercial product.

The study was undertaken in full collaboration with this FRDC grading project Principal Investigator.

To investigate the problems of grading, several different technologies were thoroughly investigated, applied and tested in order to identify and/or develop a method which is more accurate and less invasive than existing techniques. Such techniques considered are:

- near-infrared spectroscopy
- ultrasonic/acoustic analysis
- magnetic resonance imaging (MRI)
- electrical impedance tomography (EIT)
- and x-ray

The scope of this research was limited to only the application of different technologies to male mud crabs (bucks).

This preliminary investigation identified that the existing methods of estimating the meat fullness of mud crabs are no longer suitable in the current industry. It was also established that there exists a large knowledge gap in literature with regards to non-invasive techniques for these measurements. Acoustic/ultrasonic analysis and near-infrared spectroscopy appear to have the least limitations of all technologies investigated and also offer the most useful information. On the other hand, MRI and EIT were shown to have factors limiting their practicality of implementation into the industry. MRI appeared to be a feasible technique; however, the size, complexity of hardware and cost of this technology renders it an impractical solution to the problem. Similarly, the application of electrodes in EIT technology was concluded to be either impractical or highly invasive.

The complete thesis is included as Appendix 4. The work is invaluable as a precursor to future refinement of the technologies outlined in the next sections. It highlighted restrictions in both software and hardware that were addressed in the next stages of the research.

Stage 2 - Development of Technology

In conjunction with the NIR and candling trials, the acoustic velocity technology was developed and tested by the expert team of physicists at the joint DAF/JCU Rapid Assessment Unit, Cairns.

Results

An example measurement sequence is shown in Figure 30a. The sequence from left to right begins with only water between the transducers, then noise as the crab is inserted into the tub and positioned near the transducer. The measurements highlighted in red were averaged over to obtain the acoustic time-of-flight for this individual. Figure 30b displays the raw data for one of the measurements, showing how the time-of-flight is calculated.

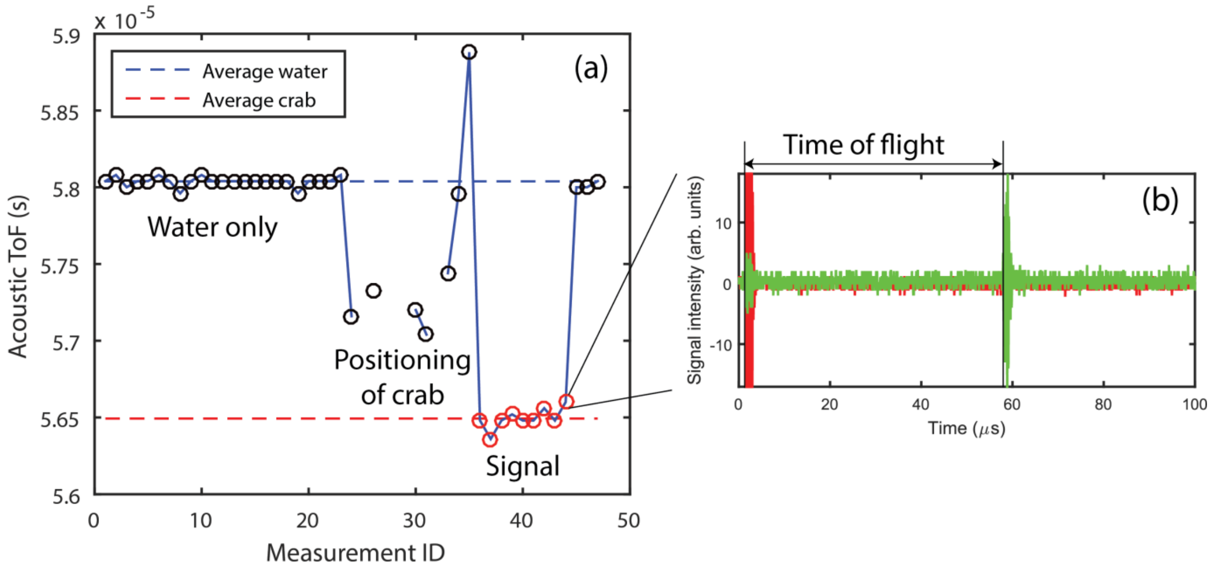


Figure 30: (a) Time-of-flight signals recorded on a crab claw; (b) raw data for a single measurement. The time-of-flight is calculated as the time delay between leading edges of the transmit (red) and receive (green) waveforms.

Not all crabs displayed a clear acoustic signal with an unambiguous time-of-flight, for example, the sequence in Figure 31. In this case, the raw data for each of the measurements were inspected, and it was judged that the measurements highlighted by the red circles are the most probable (based upon the received signal strength and the shape of the waveforms). This is a subjective assessment, and these particular crabs have been classified as having an unclear signal in order to distinguish them from the clear cases such as Figure 30. Unclear signals may have arisen due to movement of the crabs/experimentalist or those where the signal was too weak to be clearly received. The linear regression models show the two classes of measurement.

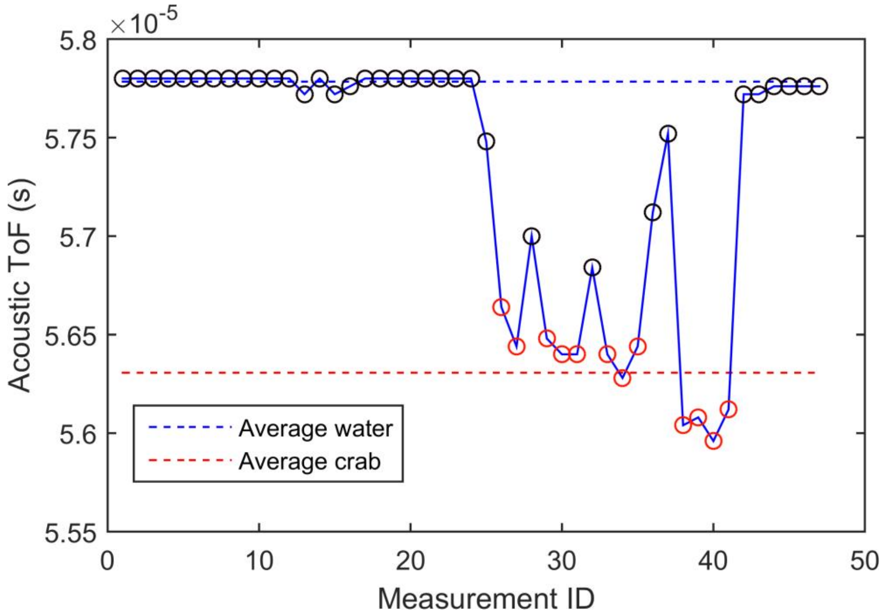


Figure 31: Example of an individual with an unclear/ambiguous measurement sequence, where there is no single value that obviously corresponds to the acoustic time-of-flight through the crab claw. The red circles were averaged to produce the value shown by the red dotted line.

Figure 32 plots claw meat yield against the two predictors (acoustic velocity and received signal strength). There is a weak correlation between yield and acoustic velocity. Figure 32b shows a substantial clustering of signal strength measurements at the lower end, near the instrument sensitivity limit, showing that a higher transmit power may have been beneficial and may have led to improved results.

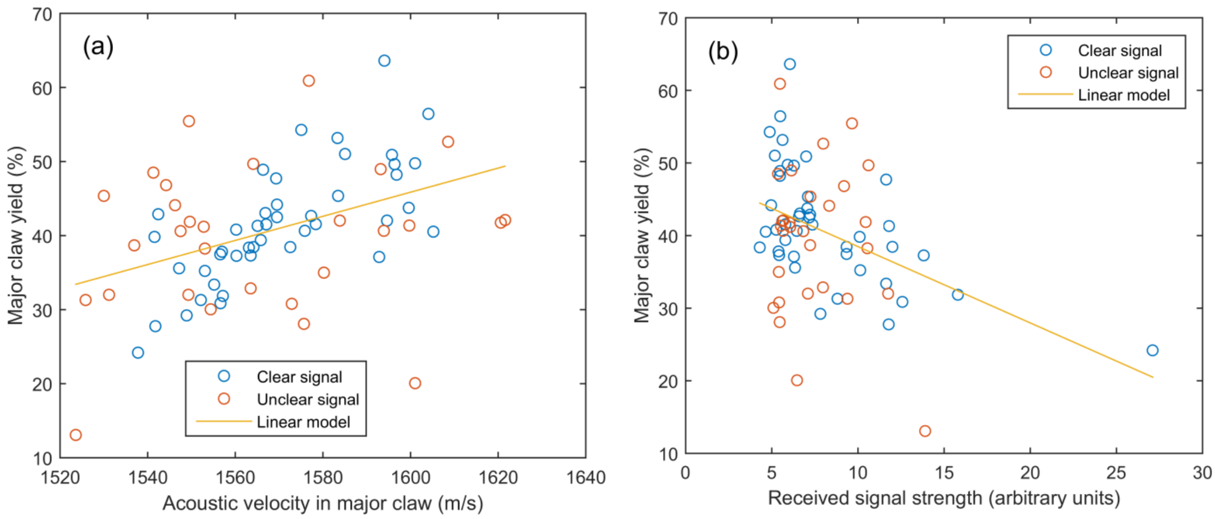


Figure 32: Across the whole dataset, acoustic velocity is weakly correlated with claw yield. For panel (a) R^2 = 0.177; whereas for panel (b) R^2 = 0.167.

If the measurements with unclear signals are excluded from the analysis, then the model performance improves substantially, as shown in Figure 33. The acoustic velocity is the most useful predictor (Figure 33a), but the received signal strength also provides information. The received signal strength is a measure of the acoustic attenuation in the crab, in other words, how much the sound is absorbed. A higher attenuation corresponds to a greater meat yield.

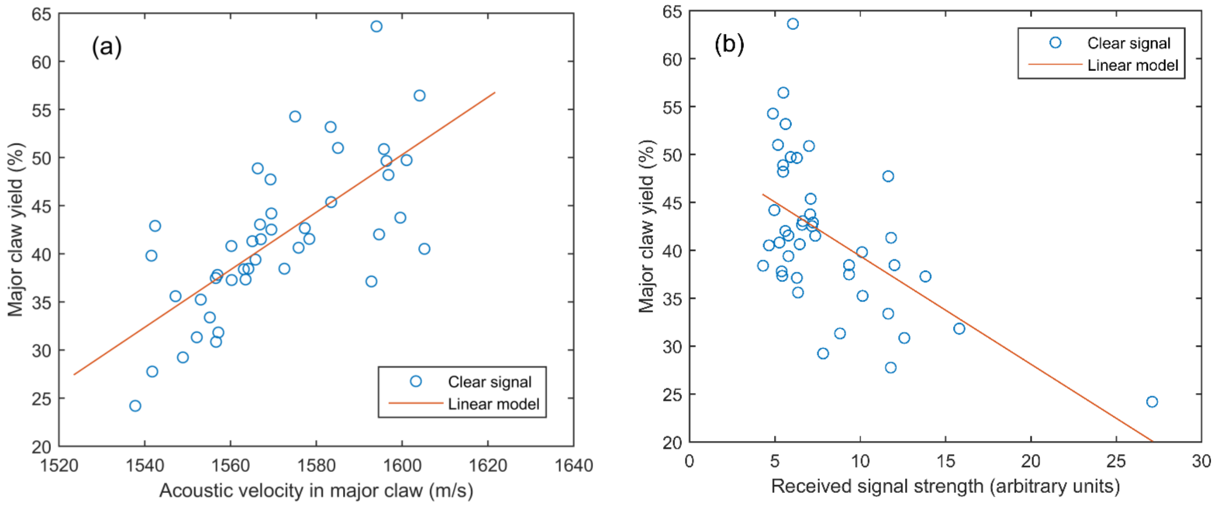


Figure 33: Considering only the measurements with clear acoustic signals, effectiveness in predicting meat yield is greatly increased. (a) Claw yield vs acoustic velocity (R^2 = 0.496). (b) Claw yield vs received signal strength (R^2 = 0.331).

Discussion

Our results show that acoustic information can provide a useful predictive tool if a clear measurement signal can be obtained. A combined linear model using both predictors achieves R^2 = 0.556 (considering only those individuals with clear acoustic signals). Unfortunately, obtaining a clear signal using the preliminary apparatus was challenging. Ultrasound transducers are small and inexpensive, so this is a technology potentially suited to practical deployment within the industry. If the signal clarity issues can be resolved then the evidence collected here shows that acoustic measurements can effectively predict meat yield, at least in terms of broad grade categories.

There are a number of different experimental parameters and configurations that were not sampled in this investigation and require further investigation/sampling in order to optimise this technology. These include:

Frequency mode: Sound at 5 MHz was strongly attenuated in the crab claw. A lower frequency may provide additional penetration and allow for a clearer signal to be obtained. Changing the frequency would require the purchase of additional transducers with new resonant frequencies.

Transmission power: The function generator driving the transmitter was limited in its output power. It is recommended that any future experiments utilise an amplification circuit to boost the power supplied to the transmitter to ensure there is significant signal.

Operational mode: All measurements reported here were conducted in transmission mode. A reflectance mode might be useful and it should be explored as an alternative measurement type. A handheld instrument with reflectance mode ultrasound would be portable and very convenient for practical use. To implement reflectance mode, a modified circuit would need to be built to disconnect the transmit source quickly, in time for the receive pulse to be detected. There are off-the-shelf integrated circuits designed for this purpose.

Analysis of the signal attenuation: In the current study we have only extracted two quantities from the raw transients – (i) the acoustic velocity measured using the difference in the received start pulse signal time, and (ii) the "received signal strength" measured as the change in the RMS amplitude of the received signal. Within the received signal however, there is a wealth of information that reflects the path of the sound waves through the crab claw. For example, the temporal attenuation coefficient (i.e. the reduction in amplitude of the received signal with time) may be more representative of distinguishing flesh-based paths from shell-based paths of the sound waves.

4.4.8 **Near Infrared (NIR)**

Introduction

All organic matter is composed of molecules which consist of atoms; groups of which are linked together in various combinations mainly by covalent bonds. All molecules continually vibrate at specific frequencies. Irradiation of molecules by an energy source such as NIR light causes some molecules to change their vibrations from one energy level to another. When these transitions occur, energy is absorbed at a certain frequency coinciding with those of the molecular grouping in the scanned material. This absorption of energy is detected by NIRS instruments. Certain groups of small atoms, such as carbon-hydrogen (C-H), oxygen-hydrogen (O-H) and nitrogen-hydrogen (N-H), absorb at characteristic wavelengths. NIR spectroscopic measurements obtain information about the relative proportions of these fundamental absorbers which are also repeated throughout the NIR region as overtones or ripples of the fundamental absorber. Therefore, the chemistry of the mud crab (shell and flesh) provides the spectral information that is assumed to be related to meat fullness.

NIRS requires reference techniques (i.e., percentage meat yield) to build up calibration routines and to guarantee the proper maintenance of an established calibration with reference to outlier detection and troubleshooting. As a secondary method of determination, the major limitation of NIRS analysis remains its dependence on the accuracy of the reference method. Errors in manual estimation of percentage meat yield will perpetuate through NIRS calibration and predictive models. In short, the more accurate and precise the manual estimation of meat yield per crab, the more accurate and precise the NIR calibration and prediction models.

The general NIR calibration process involves:

(i) Reference or calibration sample selection of the property of interest (in this case meat fullness based on percentage meat yield recovery from cooked mud crab claws).
(ii) Evaluation of sample preparation and presentation for NIR analysis.
(iii) NIR spectrum measurement of reference mud crabs.
(iv) Analysis of the mud crab against the appropriate reference method, in this case meat fullness;
(v) Chemometric model development (i.e., the calibration equation of the NIR spectra and chemical loadings combine mathematically to yield the calibration for analysis of unknown mud crab samples).
(vi) Validation of the calibration model to ensure that the model accurately predicts the property of interest (i.e., meat fullness per class: A, B and C) in mud crab samples not subjected to the calibration process.
(vii) If the calibration model is found to be robust and accurate, the model (i.e., the relationship between percentage meat yield per claw and spectral data) can then be used to predict the percentage meat fullness based (percent yield recovery) of new mud crab samples.

Two instruments tested

The NIR calibration process, as outlined in the 'Introduction' section, was used to develop NIRS-based models for predicting percentage meat fullness. Developing an appropriate calibration model requires reference or 'training sets' that cover not only the entire spectrum of quantities of interest (i.e., meat fullness), but also compositional space, instrument space and measurement condition space (e.g., sample handling and presentation). This avoids the need to extrapolate beyond the boundaries of the calibration set and makes the calibration robust and extensive. Temporal and spatial effects have major impacts on the robustness of the NIRS calibration models and must be incorporated into the development of the calibration model.

The spectral characteristics of live mud crabs were measured by two commercially available NIR instruments as outlined in the Methods section.

Results and discussion

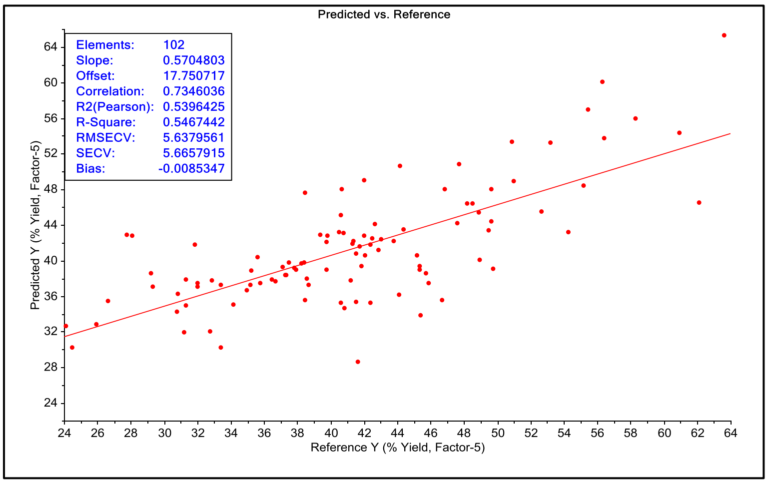
The PLS calibration model statistics for male and female mud crabs combined population for each NIR instrument and collection site are presented in Table 18 and Figure 34. The calibration statistics for the high resolution Matrix-F FT-NIR instrument based on a wavelength selection of specific wavelengths within 845 - 1,321 nm for spectra from the mud crab carapace were R^2 = 0.55, RMSECV = 5.64 using 5 factors (latent variables). The MicroNIR instrument applied to the mud crab carapace produced PLS calibration models with comparable predictive performance to the Matrix-F instrument, with an R^2 = 0.54, RMSECV = 5.68. The calibration statistics for the MicroNIR with spectra collected from the dominant claw produced the highest predict performance with an R^2 = 0.65, RMSECV = 5.00 using 5 factors. This is not surprising as the manual percentage meat yield (reference data) was undertaken on the claws, which was then related to the NIR spectra. Overall, the results obtained suggest a strong linear relationship between the NIR predicted percentage meat yield.

As this was a preliminary assessment trial the light source configuration and presentation platform was not optimal. The MicroNIR setup used for this preliminary assessment study, using both the integrated light source within the unit in reflectance mode and the external lighting system in interactance mode could be greatly improved to provide a more controlled lighting configuration for collection of chemical sensitive spectral data. Similarly, the positioning of the MicroNIR onto the sample site in conjunction with the lighting source could be improved as a platform to achieve greater calibration model predictive performance for future prediction. This requires further investigation and refinement.

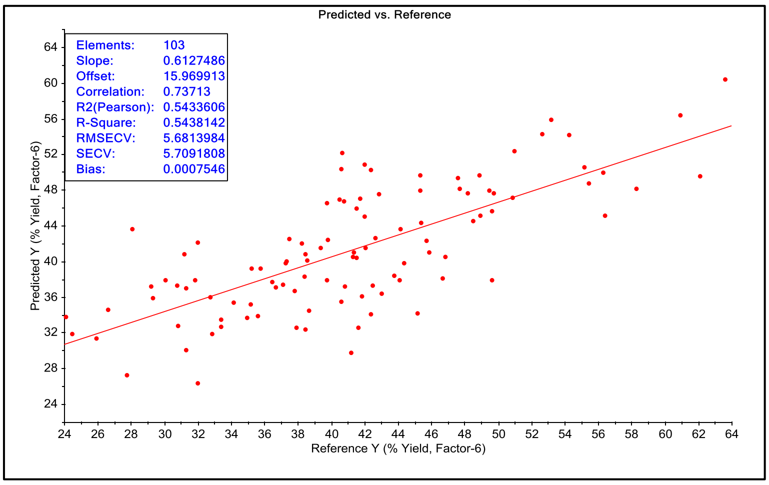
Table 18: PLS Calibration statistics for the prediction of percentage meat yield for male and female mud crabs combined population on two Near Infrared systems

System	Spectra collection site	Spectra n (outliers removed)	Meat yield Ref. site	Meat yield range %	Mean	SD	R^2	RMSECV	LV
Matrix-F	Carapace	103 (1)	Claw	24-64	41.2	8.4	0.55	5.64	5
MicroNIR	Carapace	103	Claw	24-64	41.2	8.4	0.54	5.68	6
MicroNIR	Claw	103	Claw	24-64	41.2	8.4	0.65	5.00	5

A) Matrix F - Carapace



B) MicroNIR – Carapace



C) MicroNIR – Dominant Claw

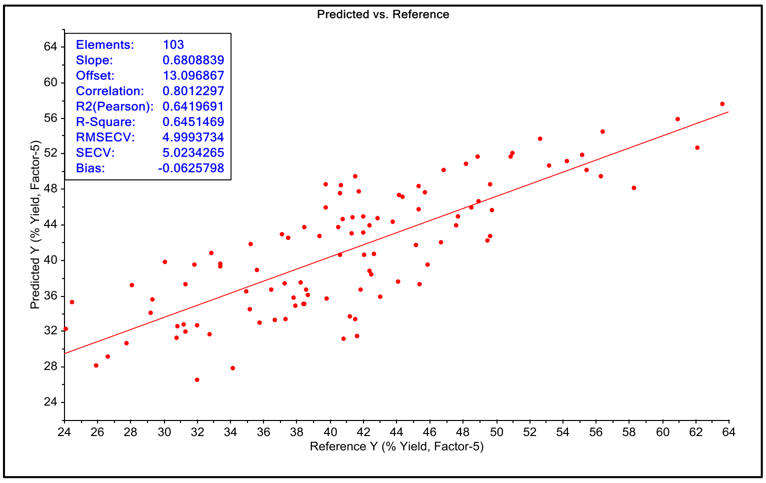


Figure 34: PLS calibration statistics of the manual percent meat yield (reference method) verses NIRS predicted meat fullness of both male and female mud crabs combined population for: A) Matrix –F on the carapace, B) MicroNIR on the carapace, and C) MicroNIR on the dominant claw

For the PCA-LDA the percentage meat yield recovery for male and female mud crab population combined was split into three categories (Table 19). Table 20 summarises the classification matrices from a PCA-LDA, for both raw data and the data transformed. Columns are known grades, and rows predicted grades. The transformed data has a higher correct classification of grade ‘A’ but at the expense of grade ‘C’. The key point is that no grade ‘A’ were classified as ‘C’ and no ‘C’ crabs classed as ‘A’. This combined model having 103 samples in the population, utilised wavelengths in the region below 1,100 nm with seven principal components.

Table 19: Grades based on percentage meat yield for males and females combined

Grade	Meat Yield %
A	>45
B	35 – 45
C	<35

Table 20: PCA-LDA for raw and transformed data for male and female mud crabs combined based on percentage meat yield

Raw Data			
	Known Grade		
	A	**B**	**C**
Predicted as A	25	3	0
Predicted as B	6	36	5
Predicted as C	0	10	18
Correct %	81	73	78
Transformed data (second derivative transformation)			
	Known Grade		
	A	**B**	**C**
Predicted as A	28	8	0
Predicted as B	3	39	10
Predicted as C	0	2	13
Correct %	90	80	57

The potential of differences between male and female mud crabs for the prediction of meat yield were investigated. Several multivariate statistical techniques, including PCA and discriminant analysis, were used to look for groupings of percentage meat yield within each sex. Table 21 summarises potential groupings of percentage meat yield for males and females. Using these meat yield grades, the best discrimination for female mud crabs is summarised in Table 22. Columns represent known grades, and rows are predicted grades. Thus, 12 out of 13 ‘A’ grade females were correctly classified.

The findings from the multivariate analyses on the male mud crabs suggested there was not a well-defined separation of the percentage meat yield into groups. Therefore in comparison, male mud crabs did not achieve as good classification results as the female mud crabs as depicted in Table 23. These separate gender models are based on raw data with transformed data producing equivalent results. Wavelength range utilised in the discriminative model was below 1,100 nm with only 4 principal components used. With only small numbers of 51-52 samples in each gender population any more than 4 principal components could lead to over fitting of the model and prediction problems on future samples.

Table 21: Grades based on percentage meat yield for males and females

Sex	**Grade**	**Meat Yield %**
Male	A	>42
	B	34 – 42
	C	<34
Female	A	>50
	B	38 - 50
	C	<38

Table 22: PCA-LDA classification matrix for female mud crabs based on percentage meat yield from claws

PCA-LDA – raw data			
	Known Grade		
	A	**B**	**C**
Predicted as A	12	7	0
Predicted as B	1	20	2
Predicted as C	0	4	6
Correct %	92	65	75

Table 23: PCA-LDA classification matrix for male mud crabs based on percentage meat yield from claws

PCA-LDA – raw data			
	Known Grade		
	A	**B**	**C**
Predicted as A	8	5	0
Predicted as B	4	16	8
Predicted as C	0	2	8
Correct %	67	70	50

Conclusion

The potential of NIR in diffuse reflectance mode as a rapid and non-invasive technique for assessing mud crab fullness based on percentage yield recovery of cooked meat from individual mud crab claws has been investigated through a scoping study. Preliminary PLS calibration models were developed that could predict percent meat yield to ±4.99 – 5.68% with and R^2 of 0.54 – 0.65 depending on NIR spectra collection site and NIR system used for collection.

Preliminary PCA-LDA models separating mud crabs into three classes: A, B, and C based on meat yield showed positive results. The current study showed that no grade 'A' mud crabs were classified as 'C' and no 'C' crabs were classed as 'A'. The best PCA-LDA model developed on a small number of crabs performed best when both male and female mud crabs were combined into one population to increase the sample size and biological variation of the data set. The NIR methods require further research in refining both the method and the spectra collection platform, plus assessment of sufficient mud crab numbers to enable construction of robust calibration models to predict mud crab samples.

4.5 Crab quality parameters

4.5.1 **Summary**

Data for 107 mud crabs (54 female and 53 male) were recorded on 19 numeric and 5 categorical traits for each crab with the objectives of identifying relationships amongst the traits and identifying which traits are more closely related to meat yield, and exploring the feasibility of developing a classification scheme for mud crabs that would predict their meat yield.

Studies of the consistencies between methods for grading the crabs (i.e. method based on shell hardness and method based on RI values) revealed that they were fairly consistent for female crabs, but for male crabs they can be considered independent (i.e. they have no correlation).

Results from cluster analyses on the matrices of correlations between numerical traits revealed that the patterns of correlations amongst traits differ for male and female crabs. One finding was that shell hardness was correlated to RI values for females but not for males. For female and male crabs RI values are correlated to yield percentage traits but are not correlated to physical characteristics of the crabs.

Principal components analyses on the numerical traits applied to female and male crab data separately revealed that although several correlation patterns can be identified and several groups of crabs can be formed, the grading that these crabs receive based on shell hardness scores or RI values are not consistent.

Exploring the possibility of developing a model for classification of crabs that permits classification of crabs in a way that would reflect the yield percent is the next step and will explore further the correlations between RI values and yield percent.

4.5.2 **Introduction**

Commercial fishery of mud crabs in Australia relies on the Live Mud Crab Grading Scheme, developed to provide a consistent grading process across Australia. According to this scheme, mud crabs receive an 'A', 'B' or 'C' grade based on the hardness of the shell. These grades aim at estimating the likely meat content of the crabs. The shell hardness test is performed using thumb pressure on specific points of the crab's carapace. However, the hardness of the carapace is still somehow subjective depending on factors such as, for example, size of the hands and strength of the person performing the test, and also may not reflect meat content as accurately as expected.

Exploratory analyses and summary statistics of the data indicated that three crabs presented abnormal values. Further investigations revealed that two of them (crab codes T8-6 and T8-12) were in fact atypical crabs from Wallis Lake, and the third (crab code CNS 74) had been mislabelled when it lost its tag, so the values for some traits had been estimated. These three crabs were removed from the dataset, with the final dataset comprising 104 crabs (51 female and 53 male). A small number of crabs had some missing data for a few traits.

Except for the first five, all traits are numeric. Sex was only used for splitting the dataset into two (male and female crabs) when performing the different analyses. All numeric traits except for ShellScore were measured on a continuous scale. ShellScore is the sum of several scores measured on different points on the crabs' carapaces and has seven values for female crabs and 15 values for male crabs.

4.5.3 **Results**

Comparison of the grading variables

Female crabs

Comparisons of grading variables are based on the 50 female crabs with complete observations for all traits that entered the principal components analysis. There is a general agreement between ResGrade and CrabberGrade (Table 24) for female crabs, with CrabberGrade being stricter.

The grade provided by choosing arbitrarily cut-points on the RI scale (Grade.by.RI) has a tendency to grade the crabs higher than using the shell hardness test, ending up with only 4 out of 50 crabs classified into the 'C' grade, compared to 14 and 17 with the shell hardness test (Tables 25 and 26). Additionally, most crabs classified as 'C' grade with the shell hardness test have moved into the 'B' grade and about half of the 'B' grade crabs have moved into the 'A' grade category, while only six and three crabs were down-graded from 'A' to 'B', compared to ResGrade and CrabberGrade, respectively (Tables 25 and 26).

Table 24: Number of female crabs classified into 'A', 'B' or 'C' grades by ResGrade and CrabberGrade. Agreements in bold (main diagonal) and disagreements in shaded cells.

	CrabberGrade			
ResGrade	A	B	C	Total
A	**16**	3	0	19
B	1	**12**	4	17
C	0	1	**13**	14
Total	17	16	17	50

Pearson's Chi-squared test statistic = 56.248, df = 4, p-value < 0.0001

The grades assigned to female crabs by ResGrade and CrabberGrade are not independent, i.e. they can be considered consistent.

Table 25: Number of female crabs classified into 'A', 'B' or 'C' grades by ResGrade and by Grade.by.RI. Agreements in bold (main diagonal) and disagreements in shaded cells.

	Grade.by.RI			
ResGrade	A	B	C	Total
A	**13**	6	0	19
B	9	**8**	0	17
C	2	8	**4**	14
Total	24	22	4	50

Pearson's Chi-squared test statistic = 16.59, df = 4, p-value = 0.0023

The grades assigned to female crabs by ResGrade and CrabberGrade are not independent, i.e. they can be considered fairly consistent.

Table 26: Number of female crabs classified into 'A', 'B' or 'C' grades by CrabberGrade and by Grade.by.RI. Agreements in bold (main diagonal) and disagreements in shaded cells.

	Grade.by.RI			
CrabberGrade	A	B	C	Total
A	**14**	3	0	17
B	9	**7**	0	16
C	1	12	**4**	17
Total	24	22	4	50

Pearson's Chi-squared test statistic = 23.869, df = 4, p-value < 0.001

The grades assigned to female crabs by ResGrade and CrabberGrade are not independent, i.e. they can be considered fairly consistent.

Male crabs

Comparisons of grading variables are based on the 50 male crabs with complete observations for all traits that entered the principal components analysis.

There is nearly a perfect agreement between ResGrade and CrabberGrade for male crabs (Table 27).

The grade provided by choosing arbitrarily cut-points on the RI scale (Grade.by.RI) shows the same tendency as with female crabs to grade the crabs higher than using the shell hardness test, ending up with only 3 out of 50 crabs classified into the 'C' grade, compared to 18 and 19 with the shell hardness test (Tables 28 and 29).

Additionally, most crabs classified as 'C' grade with the shell hardness test have moved into the 'B' grade and a few into the 'A' grade categories. About half of the 'B' grade crabs have moved into the 'A' grade category, while about half of the 'A' grade crabs were down-graded from 'A' to 'B' (and even 'C') categories, compared to ResGrade and CrabberGrade (Tables 28 and 29). In comparison to female crabs, a larger number of crabs were down-graded by the Grade.by.RI (10 and 8 crabs compared to ResGrade and CrabberGrade, respectively, Tables 28 and 29).

Table 27: Number of male crabs classified as 'A', 'B' or 'C' grades by ResGrade and CrabberGrade. Agreements in bold (main diagonal) and disagreements in shaded cells.

	CrabberGrade			
ResGrade	A	B	C	Total
A	**16**	2	0	18
B	0	**13**	0	13
C	0	1	**18**	19
Total	16	16	18	50

Pearson's Chi-squared test statistic = 83.297, df = 4, p-value < 0.0001

The grades assigned to male crabs by ResGrade and CrabberGrade are not independent, i.e. they can be considered consistent.

Table 28: Number of male crabs classified as 'A', 'B' or 'C' grades by ResGrade and Grade.by.RI. Agreements in bold (main diagonal) and disagreements in shaded cells.

	Grade.by.RI			
ResGrade	A	B	C	Total
A	**8**	9	1	18
B	6	**7**	0	13
C	3	14	**2**	19
Total	17	30	3	50

Pearson's Chi-squared test statistic = 5.4052, df = 4, p-value = 0.2482

The grades assigned to male crabs by ResGrade and Grade.by.RI are not consistent, i.e. it can be considered that both methods grade the crabs independently.

Table 29: Number of male crabs classified as 'A', 'B' or 'C' grades by CrabberGrade and Grade.by.RI. Agreements in bold (main diagonal) and disagreements in shaded cells.

	Grade.by.RI			
CrabberGrade	A	B	C	Total
A	**8**	7	1	16
B	7	**9**	0	16
C	2	14	**2**	18
Total	17	30	3	50

Pearson's Chi-squared test statistic = 7.8608, df = 4, p-value = 0.09681

The grades assigned to male crabs by CrabberGrade and Grade.by.RI are not consistent, i.e. it can be considered that both methods grade the crabs independently.

Cluster analysis

All crabs

Traits appear positively correlated in three main groups for the combined data for all crabs. These groups can be visualised in the dendrogram (Figure 35), and are formed by the traits below the cut-off point of 0.5. These groups correspond to the three squares in red/orange tones on the heatmap (Figure 36).

The first group (top left) comprises all yield percent related traits and RI traits. Within this first group, the correlation is very strong between the two RI traits and between all yield percent related traits, and weaker between the RI and yield percent related traits.

The second group (middle and the largest one) includes ShellScore, weight of the crab, and traits related to the size of the major claw, whole claw cooked weight and meat weight. All these traits are highly correlated with each other.

The third group (bottom right) contains two traits: crab width and height. These two traits are highly correlated with each other but generally uncorrelated with all other traits (green shades at the intersections of groups 1 and 2 with group 3), except for crab weight (orange strip at the intersection of width and height with weight).

Negative correlations between traits in the first and second groups can be observed on the heatmap, where blue shades are present at the intersection of both groups. These mainly relate to negative correlations between yield percent related traits and weight of the crab, weight of the whole claws cooked and height and width of the major claw. This indicates that heavier crabs with larger, wider and heavier cooked claws have lower yield percentages. The ShellScore and meat weight related traits are either very weakly correlated or uncorrelated with yield percent related traits or RI measurements.

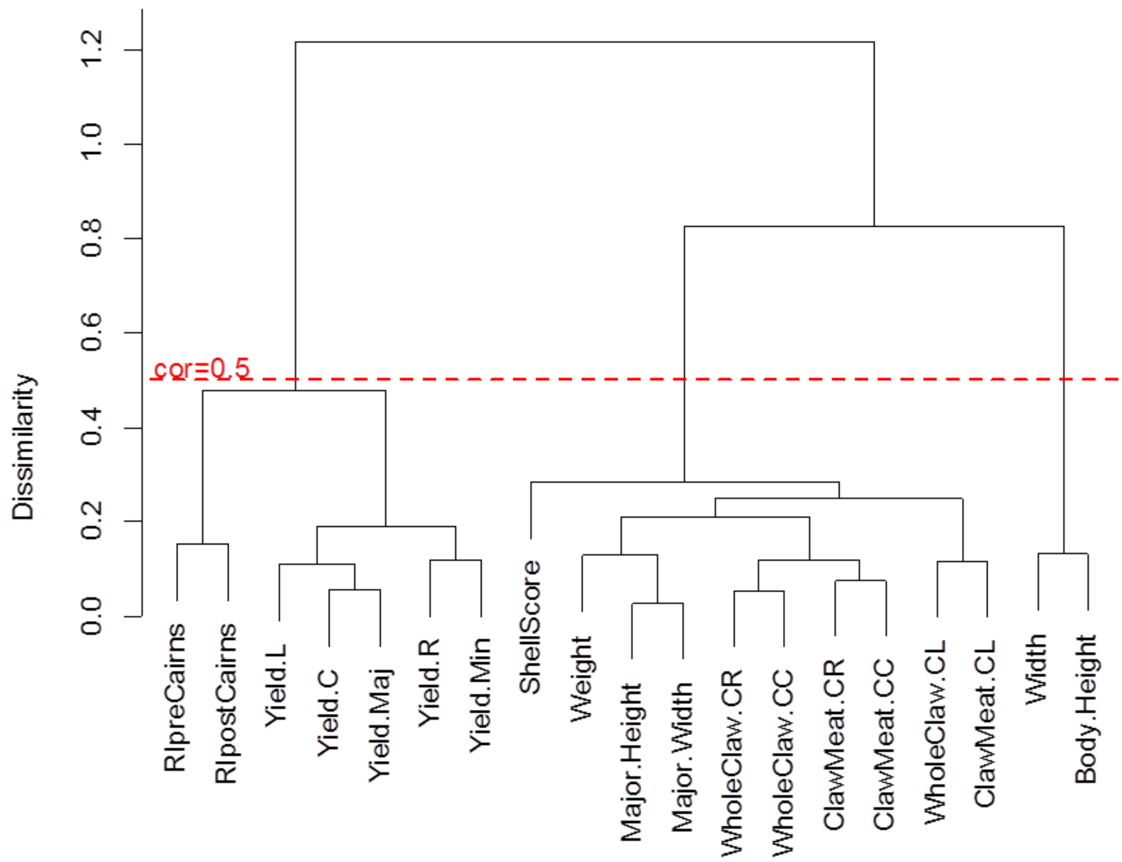


Figure 35: All crabs. Dendrogram from cluster analysis applied to the correlation matrix for all traits. Groups of traits that are positively correlated are those formed below the cut-off line of 0.5.

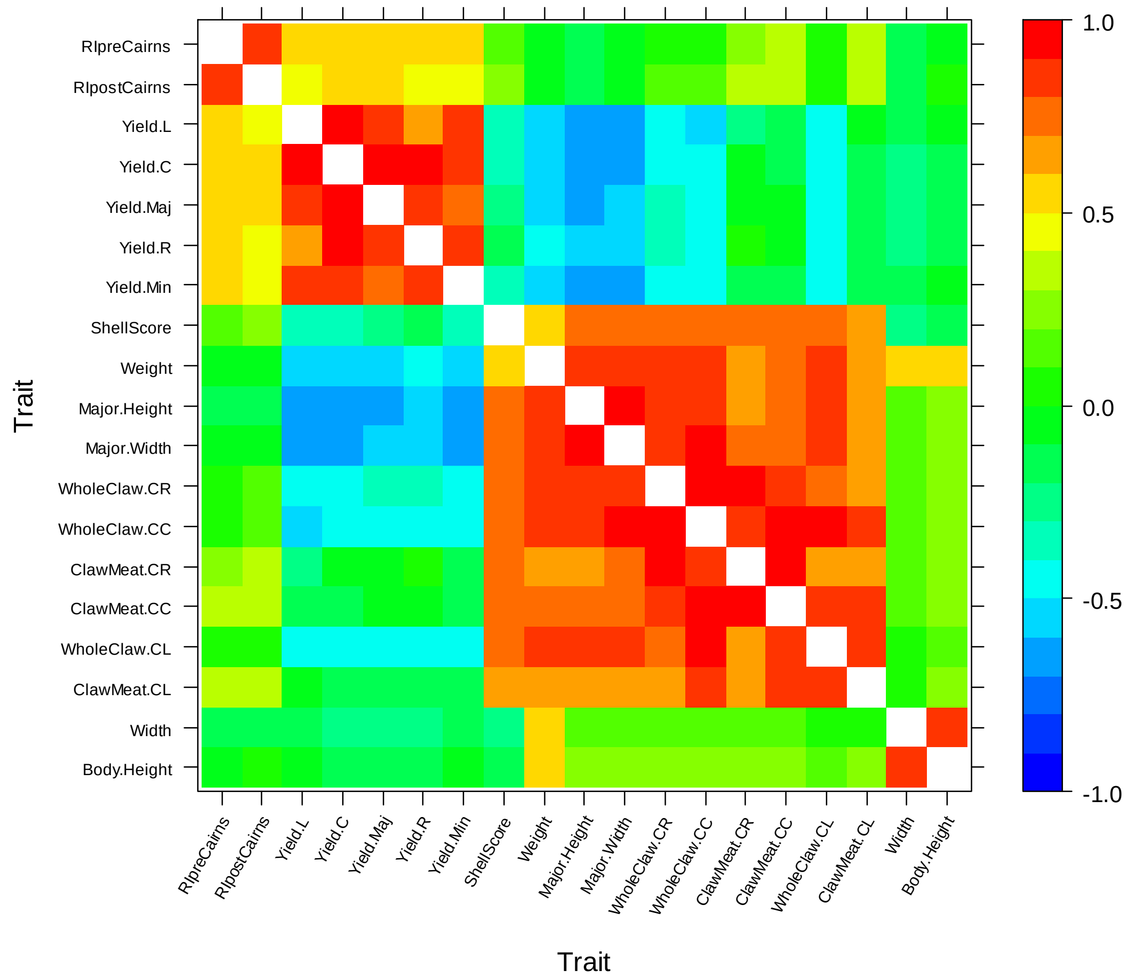


Figure 36: All crabs. Graphical representation of the correlation matrix for all traits. Legend on the right indicates the magnitude and direction of the correlations between pairs of traits.

Female crabs

Traits appear positively correlated in two main groups for the female crabs' data. These groups can be visualised in the dendrogram (Figure 37), and are formed by the traits below the cut-off point of 0.5. These groups correspond to the two squares in red/orange tones on the heatmap (Figure 38).

The first group (top left) comprises all yield percent related traits, both RI traits and ShellScore. Within this first group, all traits are strongly and positively correlated, in general.

The second group (bottom right) includes all the remaining traits, which are also generally strongly and positively correlated.

Correlations between both groups are moderate to weak. Crab weight, width and height and width and height of the major claw are negatively correlated with yield percent of the right claw (which is the major claw for most female crabs – 43 out of 51), yield percent of the major claw and yield percent of the combined claws. This indicates that lighter, smaller crabs with smaller major claws tend to have higher yield percentages. RIpostCairns has moderate and positive correlations with weight of the meat in the cooked claws (mainly right and combined claws).

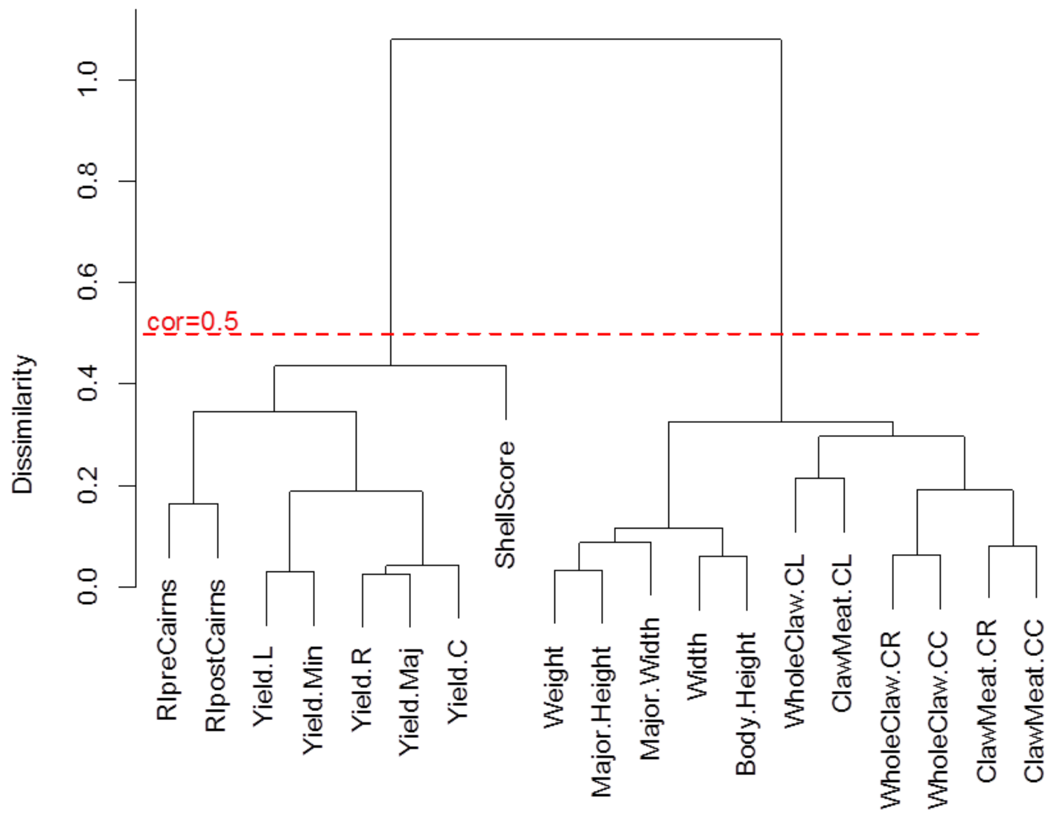


Figure 37: Female crabs. Dendrogram from cluster analysis applied to the correlation matrix for all traits. Groups of traits that are positively correlated are those formed below the cut-off line of 0.5.

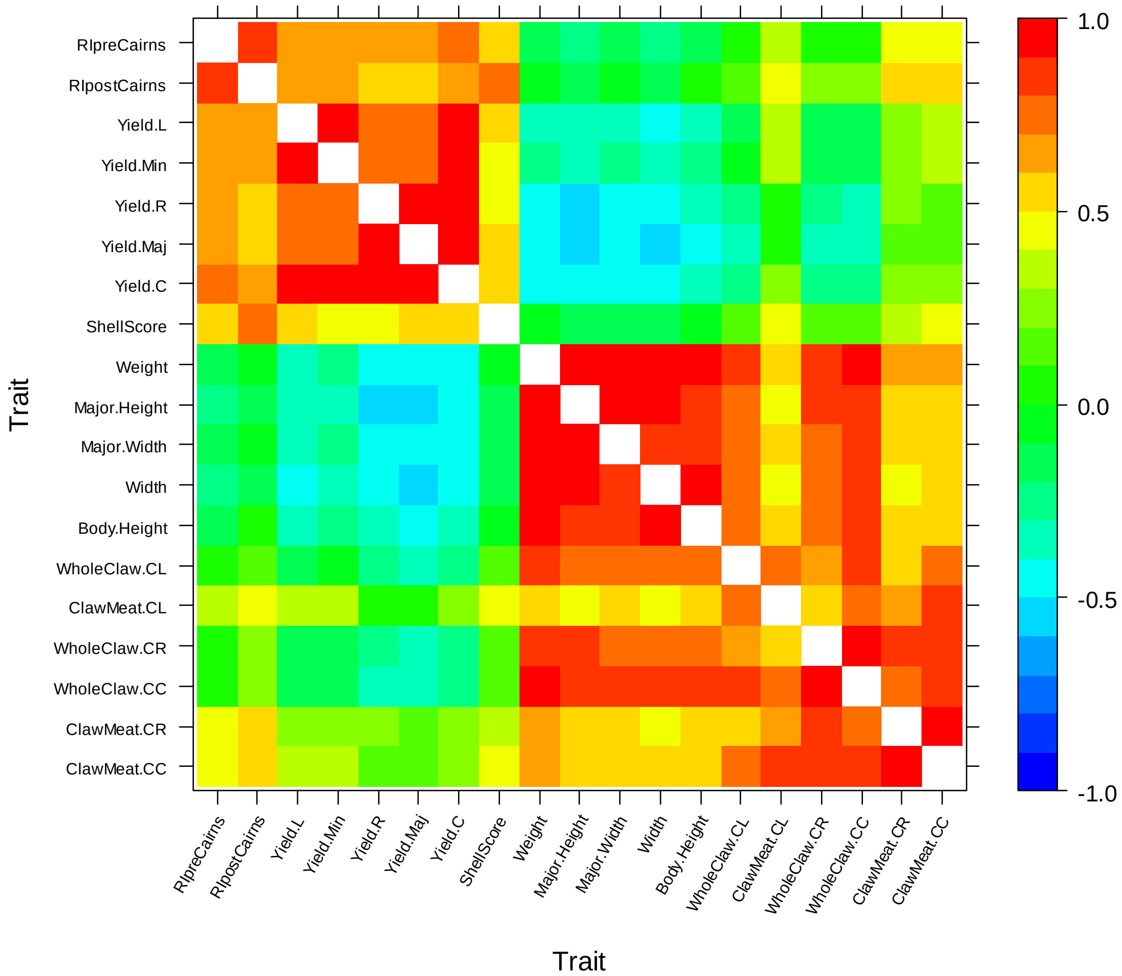


Figure 38: Female crabs. Graphical representation of the correlation matrix for all traits. Legend on the right indicates the magnitude and direction of the correlations between pairs of traits.

Male crabs

Traits are positively correlated in four groups for the male crabs' data. These groups are easier to visualise on the dendrogram initially (Figure 39) than on the heatmap (Figure 40). The dendrogram also highlights that ShellScore is practically uncorrelated with the other traits, failing to make it into any of the clusters formed. This lack of correlation can also be observed on the heatmap where most correlations between ShellScore and the other traits are mainly coloured green, except for the correlations with yield percent of the right claw (which also for most male crabs is the major claw – 36 out of 53), yield percent of the major claw and combined yield percent as well as with claw meat related traits. These correlations range between 0.4 and 0.5.

The first group (top left) comprises all yield percent related traits and RI traits. All traits are generally moderately to highly correlated.

The second group (second from the top left) includes crab weight, width and height and major claw height and width, with all traits generally highly correlated.

The third group (third from the top left) contains only two traits: weight of the left whole cooked claw and weight of the meat in the left claw.

The fourth group (bottom right) includes the remaining traits: weight of the right and combined whole cooked claw and weight of the meat in the right and combined claws.

Traits in Groups 3 and 4 fail to combine into one group because these traits for the left and right claws are weakly correlated.

For the male crabs there are no strong negative correlations between pairs of traits and there are several weak positive correlations between cluster 4 and all the others. RI traits are only correlated with claw meat weight of the left and combined claws and, to a lesser degree, with claw meat weight of the right claw.

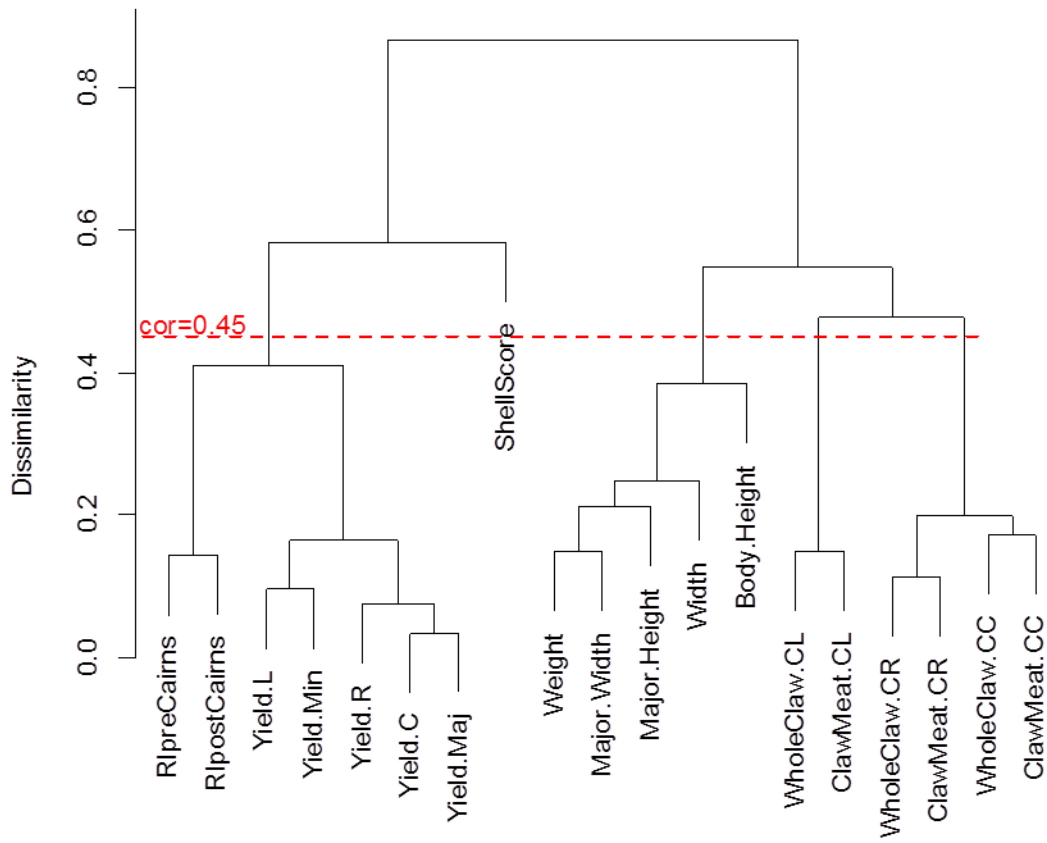


Figure 39: Male crabs. Dendrogram from cluster analysis applied to the correlations matrix for all traits. Groups of traits that are positively correlated are those formed below the cut-off line of 0.45.

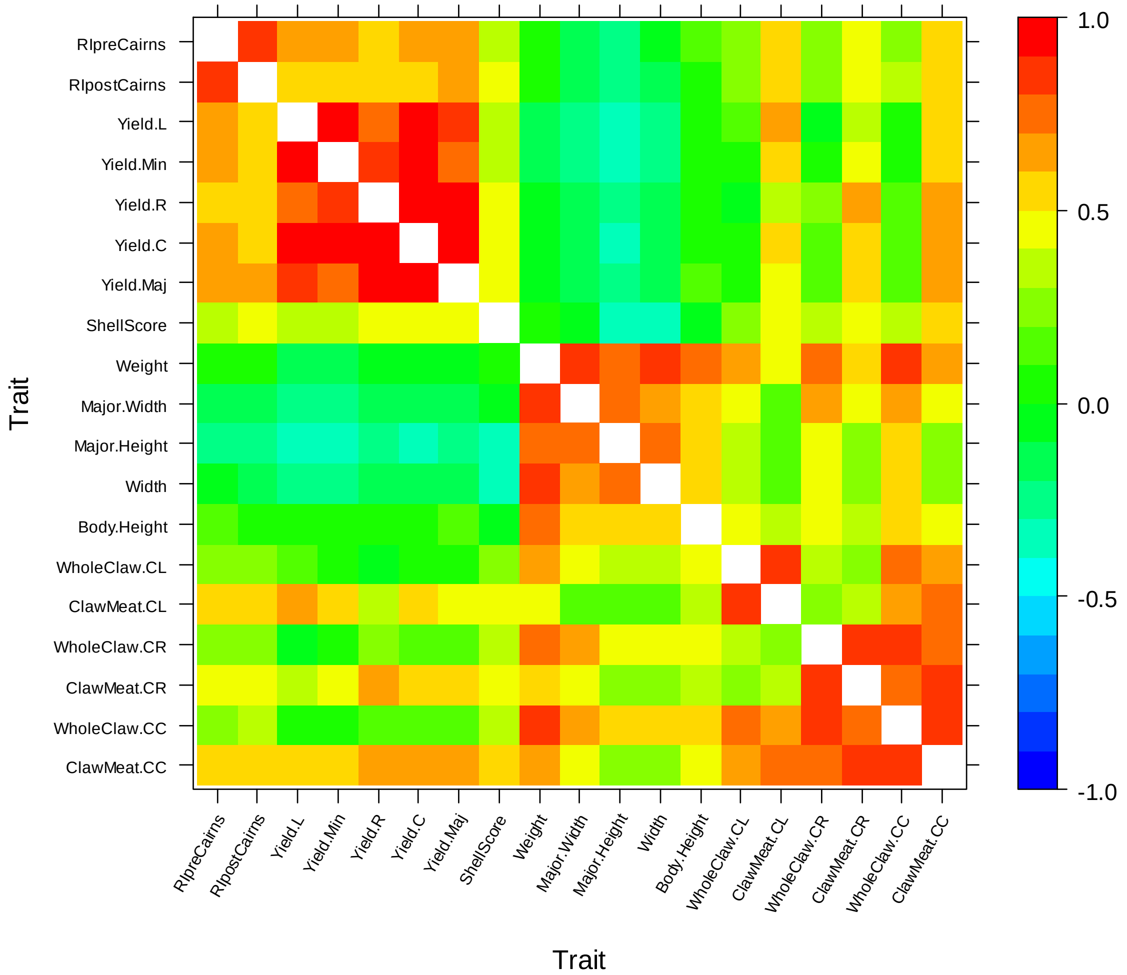


Figure 40: Male crabs. Graphical representation of the correlation matrix for all traits. Legend on the right indicates the magnitude and direction of the correlations between pairs of traits.

Principal components analysis

Female crabs

Principal components analysis was applied to the correlation matrix between traits based on the 50 female crabs with complete observations for all traits. The analysis indicated that two principal components (PC) were enough to explain the variability in the data (two eigen values > 1; 9.2 and 6.7, respectively). The two components combined explain 83% of the total variability in the data (Table 30).

Table 30: Female Crab data: Principal components analysis summary table.

	PC1	PC2
Standard deviation	3.032	2.592
Proportion of Variance	0.48	0.35
Cumulative Proportion	0.48	0.83

The first principal component (PC1) mainly contrasts yield percent related traits (positive loadings) with crab-size related traits (i.e. weight, height and width of the crab), height and width of the major claw, and cooked claws' weight and meat weight (negative loadings, Table 31). Mud crabs with high positive scores on this principal component would generally have high yield percentages, while being generally smaller (width, height, weight), with smaller major claws, lighter cooked claws, and lower cooked meat weight. These crabs appear on the right side of the biplot (Figures 41, 42 and 43) and have been mainly categorised as 'A' grade crabs. Mud crabs with low negative scores would generally have lower yield percentages, while being generally larger, heavier, and with more cooked meat weight. These crabs appear on the left side of the biplot (Figures 41, 42 and 43) and belong to different grade categories depending on the grading trait.

The second principal component (PC2) further separates the crabs based mainly on claw meat weight, yield percentages, RI traits and shell score (traits with the lowest negative loadings, Table 30). Crabs with negative scores on this principal component appear on the bottom of the biplot (Figures 41, 42 and 43) and generally have higher claw meat weight, higher yield percentages, higher RI and shell scores than those crabs with positive values on this component and which appear on the top of the biplot. These crabs have been mainly classified as 'C' grade by the shell hardness test and mainly as 'B' grade based on RI.

Table 31: Female crab data: Trait loadings for the first two principal components.

Trait	PC1	PC2
Weight	**-0.323**	-0.043
Major.Height	**-0.315**	-0.003
Width	**-0.310**	0.002
WholeClaw.CC	**-0.303**	-0.130
Major.Width	**-0.302**	-0.028
Body.Height	**-0.296**	-0.046
WholeClaw.CR	**-0.284**	-0.123
WholeClaw.CL	**-0.275**	-0.116
ClawMeat.CC	**-0.205**	**-0.295**
ClawMeat.CL	**-0.186**	**-0.259**
ClawMeat.CR	**-0.185**	**-0.273**
RIpostCairns	0.036	**-0.329**
ShellScore	0.049	**-0.277**
RIpreCairns	0.079	**-0.320**
Yield.Min	***0.133***	**-0.313**
Yield.L	***0.148***	**-0.305**
Yield.C	***0.187***	**-0.307**
Yield.R	***0.190***	**-0.276**
Yield.Maj	***0.205***	**-0.268**

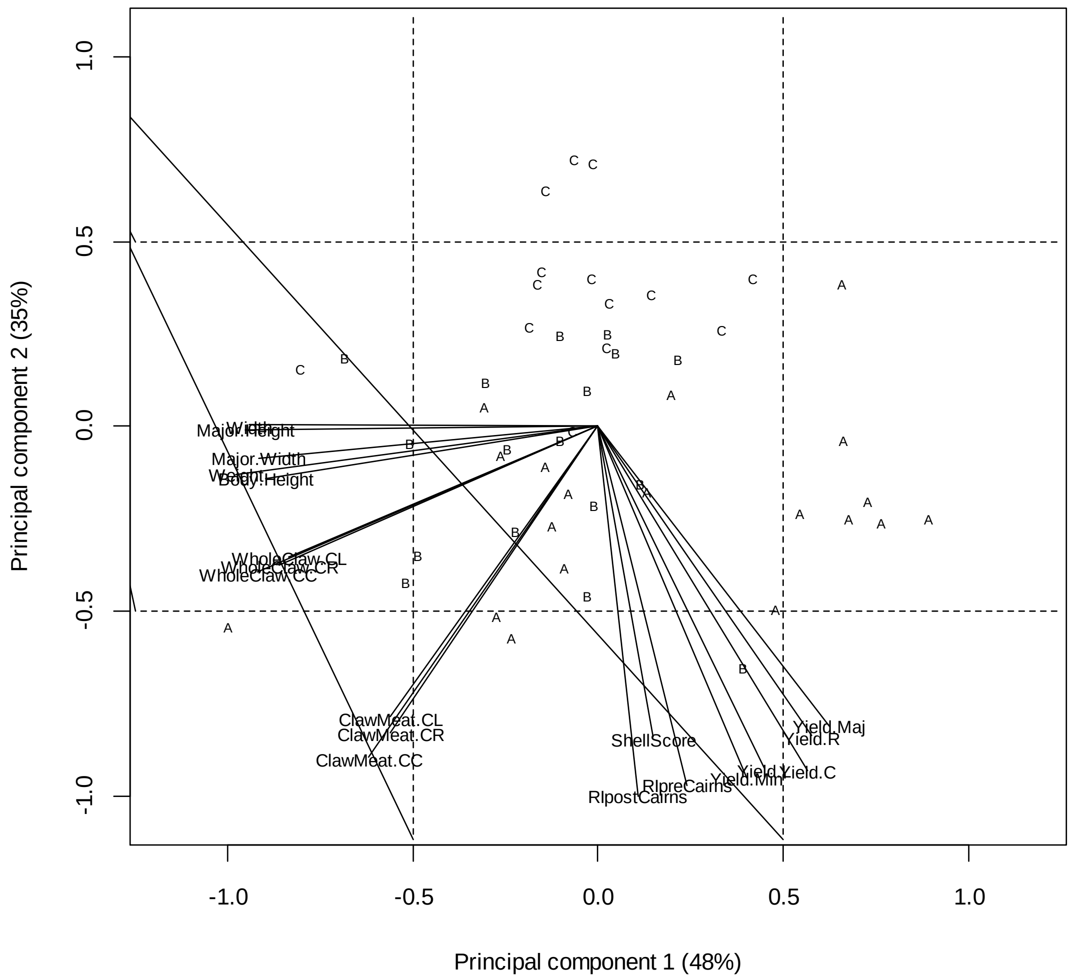


Figure 41: Female crabs. Biplot for the first two principal components with crabs identified according to ResGrade.

The group of seven to eight 'A' graded crabs on the left side of the biplot have high yield percentages, low weight of the cooked claws and smaller measurements overall. Crabs on the right side of the biplot have opposite characteristics and have been given 'A' to 'C' grades. Most 'C' graded crabs appear on the top of the graph. Those crabs have low yield percentages, low RI values, low shell scores and low meat weight in the cooked claws. There are many crabs graded 'A' and 'B' in the centre of the graph, indicating that they are average crabs with respect to the traits included in the analysis.

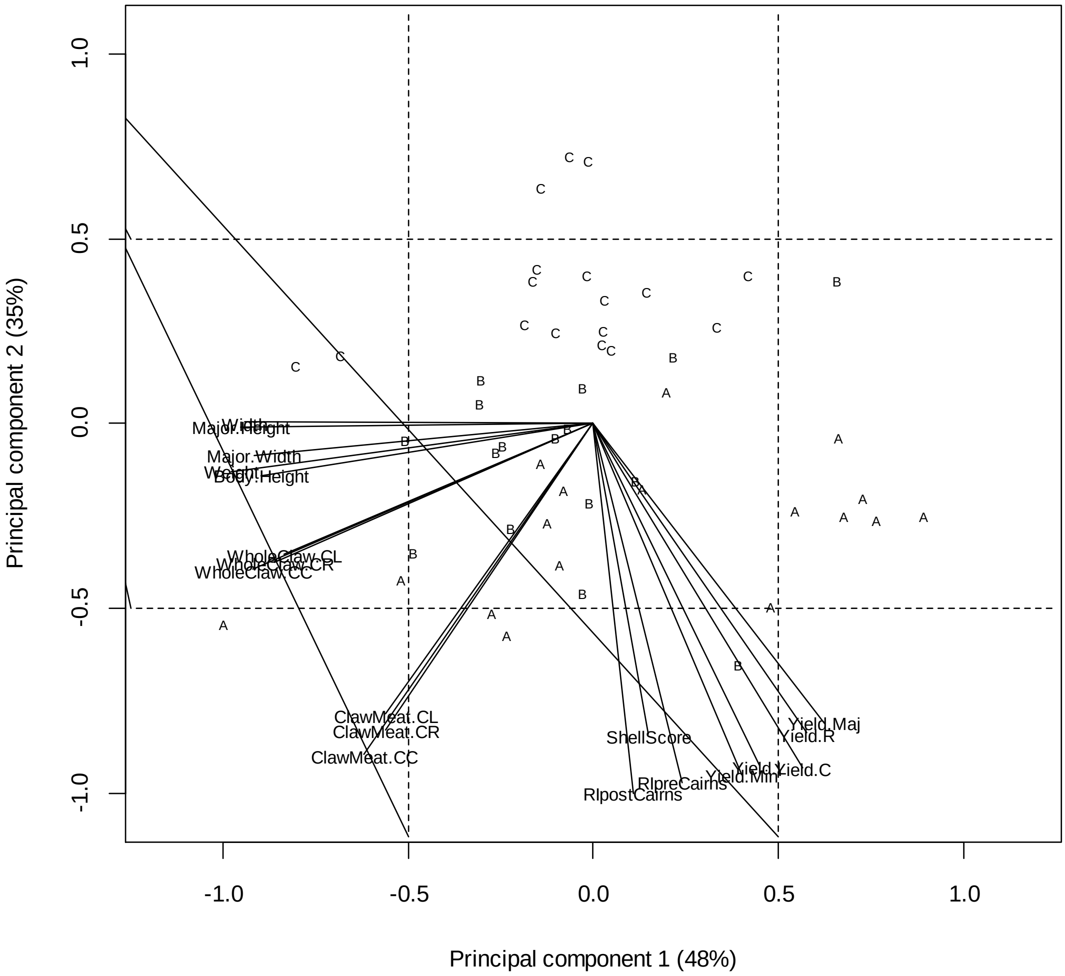


Figure 42: Female crabs. Biplot for the first two principal components with crabs identified according to CrabberGrade.

The group of six to seven ‘A’ graded crabs on the left side of the biplot have high yield percentages, low weight of the cooked claws and smaller measurements overall. Crabs on the right side of the biplot have opposite characteristics and have been given ‘A’ to ‘C’ grades. Most ‘C’ graded crabs appear on the top of the graph. Those crabs have low yield percentages, low RI values, low shell scores and low meat weight in the cooked claws. There are many crabs graded ‘A’ and ‘B’ in the centre of the graph, indicating that they are average crabs with respect to the traits included in the analysis.

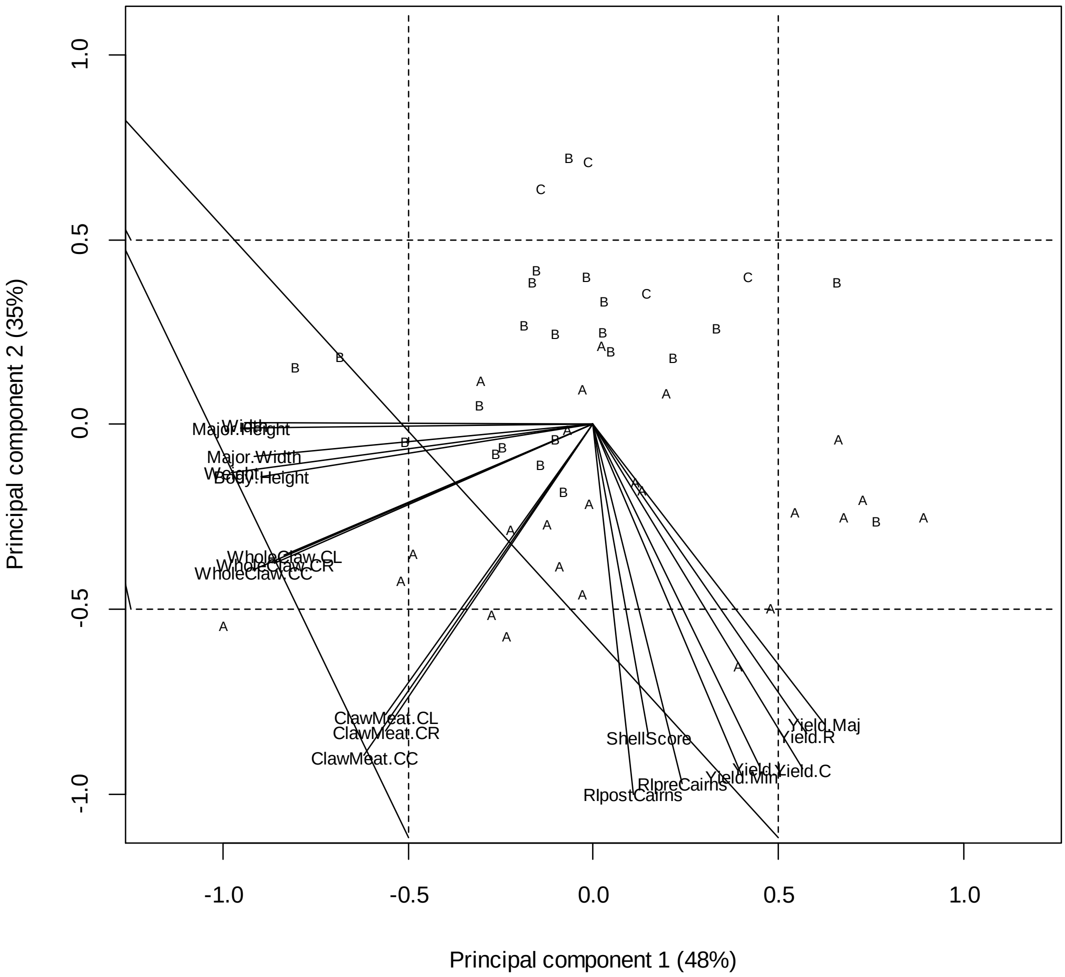


Figure 43: Female crabs. Biplot for the first two principal components with crabs identified according to Grade.by.RI.

The group of crabs on the left and right sides of the biplot have similar composition as in the previous two figures. Most crabs on the top of the graph have now been given 'B' grades, and there are more 'A' grades amongst those closer to the centre, in comparison with the two previous graphs.

Male crabs

Principal components analysis was applied to the correlation matrix between traits for the 50 male crabs with complete observations for all traits. The analysis indicated that four principal components were needed to explain the variability in the data (four eigen values > 1; 8, 6, 1.5 and 1.3, respectively). However, three were enough to explain at least 80% of the variability in the data. The three components combined explain 81% of the total variability in the data (Table 32). The need for more principal components to explain the variability in the male crabs' data is in agreement with the more complex correlation structure between traits observed in cluster analysis (Figures 39 and 40 above). Only ResGrade and Grade.by.RI will be used to identify individual crabs on the male crab biplots because the gradings provided by ResGrade and CrabberGrade are in nearly perfect agreement (Table 27 above).

Table 32: Male Crab data: Principal components analysis summary table.

	PC1	PC2	PC3
Standard deviation	2.824	2.441	1.239
Proportion of Variance	0.42	0.31	0.08
Cumulative Proportion	0.42	0.73	0.81

The first principal component (PC1) is driven by traits related to yield percent, claw meat weight and weight of the whole cooked claws (traits with the lowest negative loadings, Table 33). It mainly separates crabs with high yield percentages, high meat weight and high weight of the cooked claws (located on the left on the biplot and mostly classified as 'A' grade, Figure 44) from crabs with low yield percentages, low meat weight and low weight of the cooked claws (located on the right on the biplot, mostly classified as 'C' grade according to the shell hardness test [Figure 44] and mostly as 'B' grade based on RI [Figure 45]).

The second principal component (PC2) further separates the crabs based on physical traits (crab weight and width and height and width of the major claw) with positive loadings and yield percentage traits with negative loadings, Table 33. The heavier, wider crabs with larger major claws and with lower yield percentages appear on the top part of the biplot. These crabs have been classified into all grades based on shell hardness test (Figure 44) and mainly as 'B' grade according to RI (Figure 45). The lighter, narrower crabs with smaller major claws and with generally higher yield percentages appear on the bottom part of the biplot. These crabs have also been classified into all grades based on shell hardness test (Figure 44) and mainly as 'B' grade according to RI (Figure 45).

The third principal component (PC3) is dominated mainly by a contrast between left and right weight of whole cooked claws, weight of meat in the cooked claws and yield percent of the claws. Crabs that appear towards the top part of the biplot would have heavier left claws and more meat in the left claws (crabs classified as all grades according to the shell hardness test and into 'A' and 'B' categories based on RI, Figures 46 and 47). Those crabs appearing towards the bottom part of the biplot would have heavier right claws, more meat in the right claws and higher yield percent of the right claw (crabs classified as all grades according to the shell hardness test and into 'B' and 'C' categories based on RI, Figures 46 and 47). This principal component only explains an additional 8% of the variability, so the separation that it makes of the crabs is much smaller too. The information that this PC adds, although a still valid partitioning of the remaining variability, reflects the fact that left and right claws are of different sizes, depending on whether they are dominant claws or not.

Table 33: Male crab data: Trait loadings for the first three principal components.

Trait	PC1	PC2	PC3
ClawMeat.CC	**-0.642**	0.125	0.026
ClawMeat.CR	**-0.555**	0.155	**-0.636**
ClawMeat.CL	**-0.517**	0.040	***0.861***
Yield.C	**-0.504**	**-0.431**	-0.297
Yield.Maj	**-0.499**	**-0.389**	-0.366
Yield.R	**-0.476**	**-0.381**	**-0.614**
RIpostCairns	**-0.471**	-0.256	0.344
WholeClaw.CC	**-0.469**	0.481	0.211
RIpreCairns	**-0.457**	-0.274	0.303
Yield.L	**-0.456**	**-0.440**	0.207
Yield.Min	**-0.454**	**-0.441**	-0.121
WholeClaw.CR	**-0.417**	0.439	**-0.498**
ShellScore	-0.372	-0.192	0.109
WholeClaw.CL	-0.357	0.352	***1.000***
Weight	-0.320	***0.646***	-0.027
Body.Height	-0.297	***0.438***	-0.032
Major.Width	-0.197	***0.645***	-0.300
Width	-0.131	***0.604***	-0.171
Major.Height	-0.069	***0.667***	-0.182

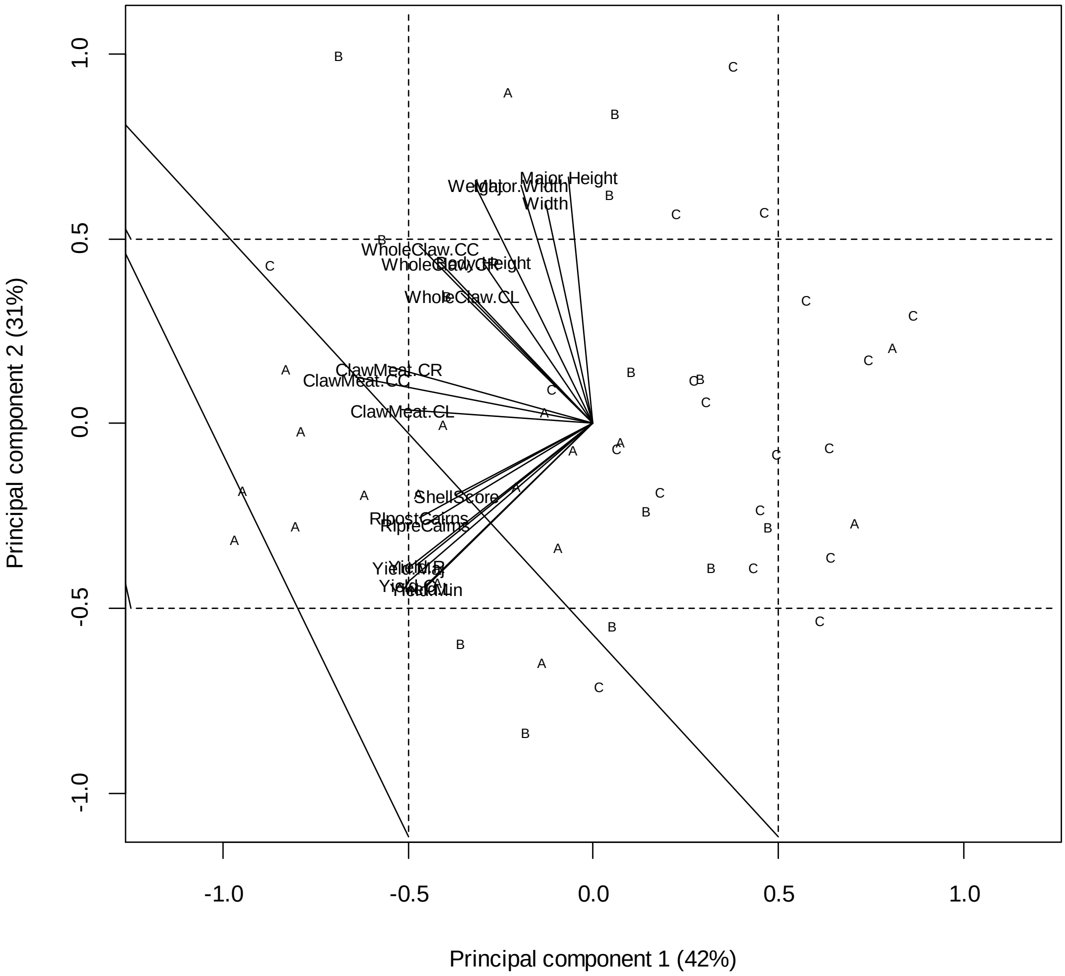


Figure 44: Male crabs. Principal components biplot for the first two principal components with crabs identified according to ResGrade.

There is a group of crabs on the left side of the biplot. Those crabs have high meat weight, yield percentages and weight of the whole claw. Most of them have been given 'A' grades. The group of (mainly) 'C' graded crabs on the right side of the biplot have low meat weight, yield percentages and weight of the whole claw. Crabs on the top of the graph are wider, heavier and have larger major claws while having low yield percentages. They have received mainly 'C' grades. The crabs on the bottom of the graph are narrower, lighter and have smaller claws while having higher yield percentages. Their grades vary from 'A' to 'C'.

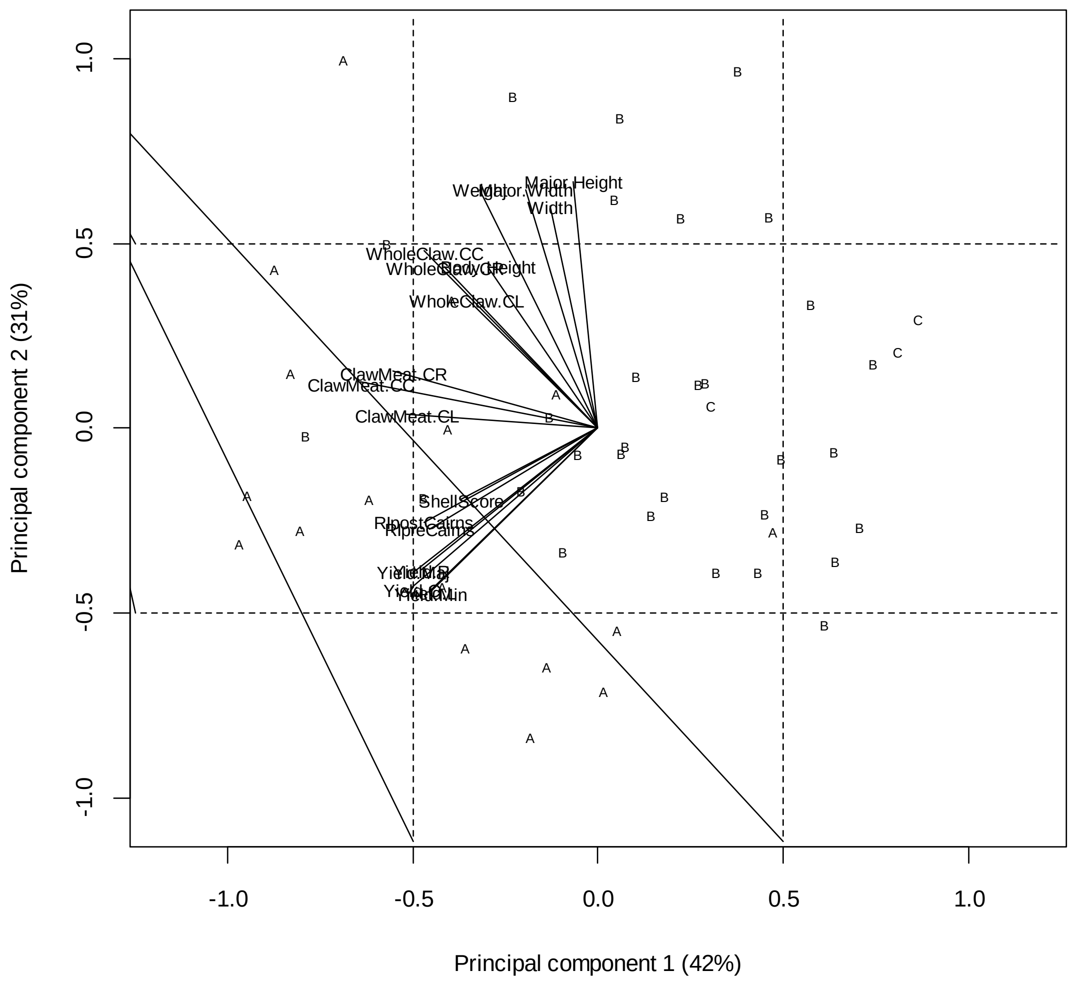


Figure 45: Male crabs. Principal components biplot for the first two principal components with crabs identified according to Grade.by.RI.

There is a group of ‘A’ graded crabs on the left side of the biplot. Those crabs have high meat weight, yield percentages and weight of the whole claw. The group on the right side of the biplot contains mainly ‘B’ graded crabs which have low meat weight, yield percentages and weight of the whole claw. Crabs on the top and bottom of the graph correspond mainly to ‘B’ grades. Those crabs have high weight and width as well as larger major claws while having lower yield percentages. Crabs on the bottom of the graph correspond mainly to ‘A’ grades. Those crabs are lighter and narrower and have smaller major claws while having higher yield percentages.

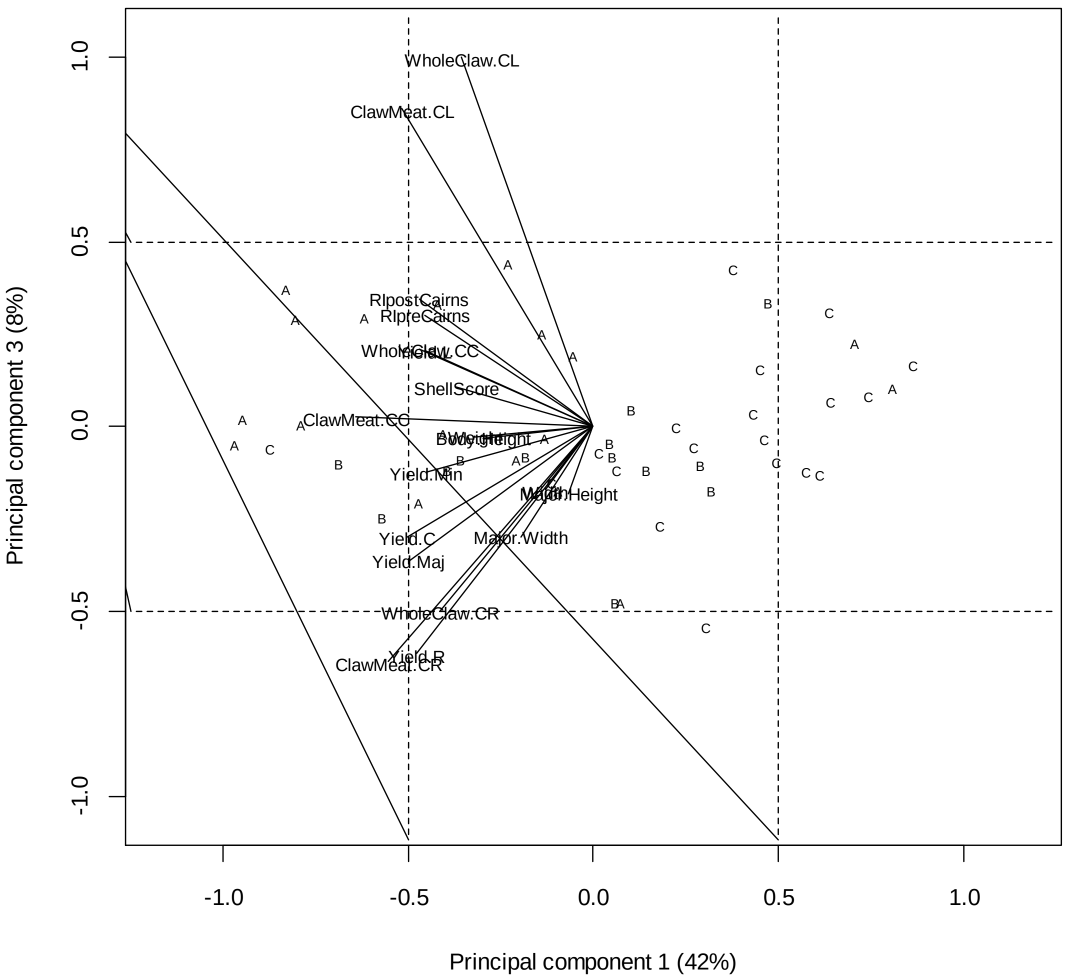


Figure 46: Male crabs. Principal components biplot for PC1 and PC3 with crabs identified according to ResGrade.

The interpretations of the groups with respect to PC1 remain the same as in Figure 44. With respect to PC3, crabs that appear towards the top of the graph have heavier left claws and those on the bottom of the graph have heavier right claws.

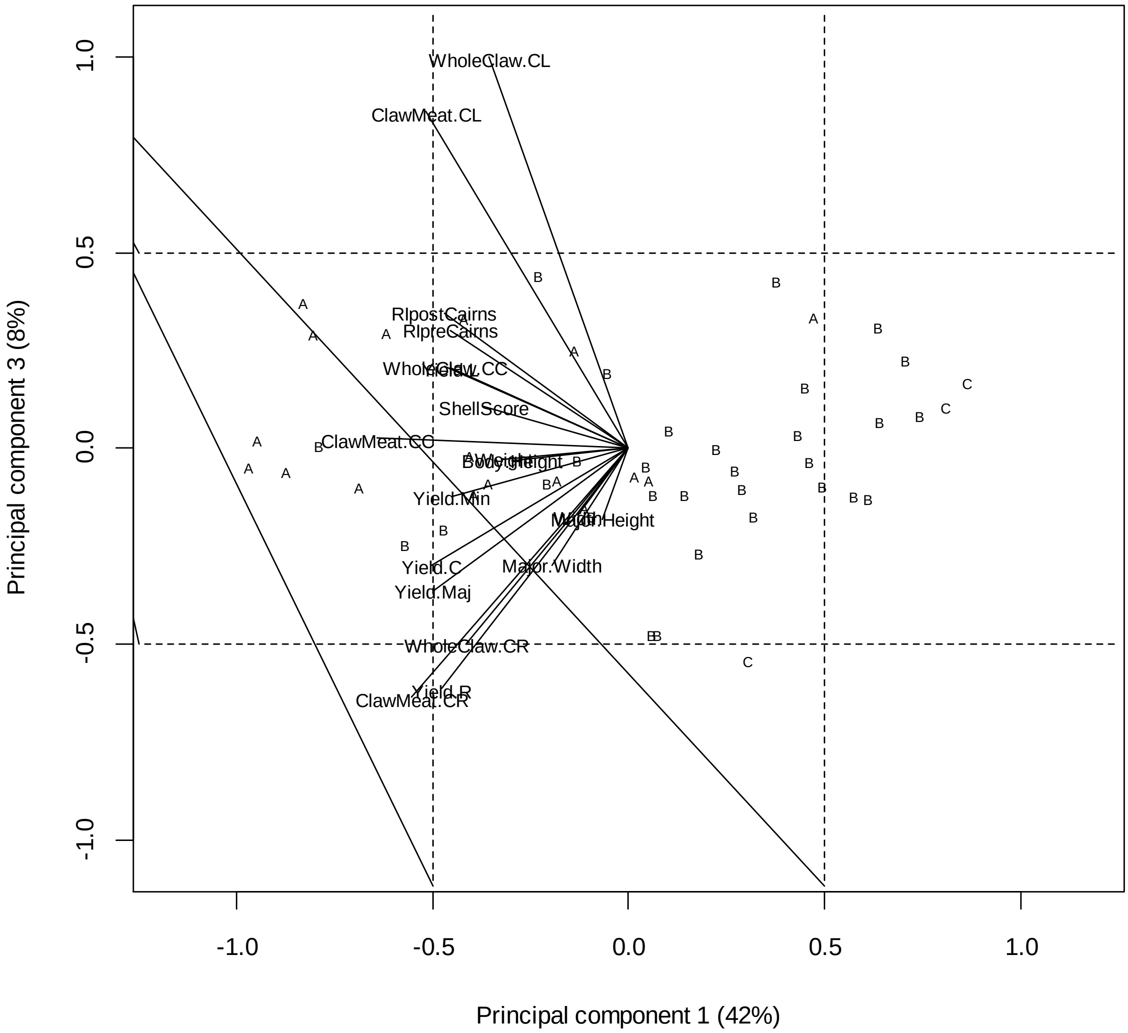


Figure 47: Male crabs. Principal components biplot for PC1 and PC3 with crabs identified according to Grade.by.RI.

The interpretations of the groups with respect to PC1 remain the same as in Figure 45. With respect to groups appearing towards the top and bottom of the biplot, there are ‘A’ and ‘B’ grades towards the top (heavier left claws with more meat) and ‘B’ and ‘C’ grades towards the bottom (heavier right claws with more meat and higher yield percent).

4.5.4 **Discussion**

Studies of the consistencies between the three methods of grading the crabs, specifically the two based on shell hardness tests undertaken by two different regimes (ResGrade and CrabberGrade) and the one based on thresholds on the RI values (Grade.by.RI), revealed that the grades based on hardness of the shell were very consistent, nearly agreeing perfectly for male crabs. However, while for female crabs there was consistency in the gradings based on the shell hardness tests and on RI values, these can be considered independent for male crabs. This means that the grading according to the shell hardness tests have no correlation with the grading according to RI values. The latter was found to mainly grade into ‘A’ and ‘B’ grades, and more often up-grading than down-grading with respect to shell hardness tests.

Cluster analysis of the correlation matrices between traits identified groups of traits that are positively correlated for male and female crabs. The groups were clearer for female crabs: two groups of traits with strong positive correlations were identified. Moderately strong negative correlations were observed between traits from these two groups. For the female crabs the shell scores were correlated with RI and yield percent related traits.

For male crabs, four groups were formed and the groups were more complex to interpret, with positive correlations between traits across groups. For the male crabs the shell scores were weakly correlated with some yield percent related measurements and claw meat content, but nearly uncorrelated with RI traits. Negative correlations were absent between groups.

For all crabs combined, the group of traits that contains the RI and yield percent related traits somehow aligned with what was observed for male or female crabs, although the magnitude of the correlations were not the same. The other groups do not reflect male or female groups which highlights the fact that the structure of the correlations between traits for male and female crabs follows different patterns.

Principal component analysis was applied to the female and male data separately and not to the combined data. As expected from cluster analysis, the female dataset required only two principal components to explain most of the variability in the data, while the male dataset required three.

Principal components analyses revealed some patterns in the correlations of traits that involve physical characteristics of the crabs as well as yield percent and meat content traits. Identification of the scores for crabs on the biplots according to the different grading methods showed that for female crabs the grading based on the shell hardness test tend to show more meaningful groups than the grading based on RI. For male crabs, however, it seems to be that the grading based on RI is the one showing more meaningful groups. Independently of the pre-given grades and whether a sensible interpretation can be done of them in conjunction with the interpretation of the individual principal components, some groups of crabs were identified.

Developing a classification model for crabs that would predict the yield percent of the crabs is the next step in this study and will explore further the correlations between RI values and yield percent.

4.6 Industry Workshop

This was an industry forum to update on the project work undertaken. On the day, Chris Calogeras chaired discussions and John Mayze provided project findings. It was highly noticeable from the start that, although individuals had strong views on particular grading aspects, the atmosphere was positive, interactive and communicative – a true discussion!

Sydney Fish Market kindly provided the venue which gave the participants the added advantage of viewing the live mud crab auction and a tour of the market floor. A few of the crabbers had not been to SFM for many years and all participants gained an update on the latest improvements SFM have introduced to their market systems.

The participants were representatives of all major mud crab harvest areas and supply chain sectors (Table 34). Unfortunately on the day, one of the SFM buyers withdrew from the workshop as the Friday trade was too busy for him to attend. The Workshop Presentation is presented in Appendix 7.

Table 34: Workshop participants

Erik Poole	NSW	Customer Account Manager, SFM
Phil Hilliard	NSW	CEO, Ballina Fishermen's Co-operative Ltd
Sue McEnally	NSW	Retail Manager, Wallis Lake Fishermen's Co-op
Tricia Beatty	NSW	EO, Professional Fishermen's Association Inc
Troy Billin	NSW	Fisher, Clarence River
Claudine Ward	QLD	QSIA and GoCCFA representative
David Swindells	QLD	QSIA representative Central Queensland
Peter Jackson	QLD	President, East Coast Crabfishers Industry Network Inc
Tony Hurley	QLD	Operations Manager Group Acquisition Manager, A. Raptis & Sons
Tony Riesenweber	QLD	Fisher, Moreton Bay, Bay & Ocean Commercial Fishing
Wes Gordon	VIC	Wholesaler, FNQ Seafood Pty Ltd, Victoria
Chris Calogeras	NT/QLD	Project CI, Representative NT Mud Crab Licence Committee
Sue Poole	QLD	Project CI
John Mayze	QLD	Project PI

4.6.1 **Purpose**

- describe the development of the AILMCGS
- inform of research findings on anomalies and investigations of cause
- inform of research findings on alternate technologies
- discuss amendments to current grading system
- demonstrate change resulting from amendments

4.6.2 **Proceedings**

With the strong current of feeling aroused by 'C' grade accepted to market – one harvester specifically sent 'B' grade crab to the SFM floor for auction the second morning (Friday sales) of the workshop. Participants were also provided four boxes of mixed grade crabs for assessment:

- discussion on grades under V2 and how changed under V3
- a crabber new to the industry supplied box marked 'A' grade crab – consensus was that only 1 of the 10 crab was 'A' – under either scheme
- unsure of impact of new version on revenue return
- likely buyers will still decide by supplier reputation

- the 'B' grade box of crabs sold for high price at auction – two major mud crab buyers both commented they would consider the crab as "good 'A' crabs"

4.6.3 Agreement

- that V3 is only a slight shift in thresholds
- benefits crabber
- buyers will pay accordingly

4.6.4 Requested outputs

- recalculate research correlation data based on AILMCGS – Version 3 and determine shift in thresholds for grades
- detailed factsheet on how to grade
- more detail on pressure that should be applied to carapace and underside segments

4.6.5 Industry interaction

The following is a summarised transcription of industry input, with direct quoted words in italics. Individual industry members have not been identified for each statement.

All industry members around the table brought a positive attitude as exemplified right from the round table introductions. However, there were issues of concern and these were raised immediately:

- the *subjective nature of the* thumb pressure shell hardness *test*
- from the harvesters: *sellers cannot choose their buyers nor refuse to sell to them, whereas buyers can choose their suppliers. Can this be evened out?*

Development of AILMCGS

The AILMCGS was developed under FRDC project 2011/255 in which key industry representatives and participants who had expressed overwhelming support and a desire to participate in forums to resolve issues around grading definitions. As a few participants had not attended previous AILMCGS workshops within this or the previous project, the background in the schemes development was explained. An overview of the research that had been presented and that led to the revised Version 1 of the scheme was provided. Participants acknowledged that the removal of the top carapace flex for male crabs had been a great improvement in the scheme, but there were still some anomalies, in particular in relation to some harvest regions.

AILMCGS Version 2

- *has been better since Version 2 applied*
- *better price gained*

- *but still concerned about subjectivity of test*

Version 2 – still some 'mis-fit' crabs – resulting in downgrades and lower price achieved

Shell hardness – dry emersion

- *tanked crabs change from 'C' to 'B' or 'A'*
- *females don't harden in water*
- *haven't noticed change during emersion*
- *some crabbers keep crabs (tanked) 6-8 weeks - but have little meat - bad for market*
- *buyers know who these crabbers are*
- *some 'A's become 'B' grade in my opinion*

Salinity trials

- worth looking at this immediately after flood season – more nutrients so animal nourished well?

Meat fullness

- *'C' grades pull price of others down*
- MANY comments of: '*C' grades should GO – don't want them*
- *Qld trashed by this* – meaning 'C' grade permitted to be sent to market
- *SFM introduced 'C' grade as a 3 month trial – and it never ended!*
- *SFM lobbied hard by NSW to take 'C' grade – should this be restricted to NSW crab?*
- *noted that crabs harvested 1h distant from each other can be completely different animals*
- *if there are exceptions for different crabs from different areas – makes a* nonsense *of the National scheme*
- *shell hardness – not the correct measure – need another, If can't – then have to have regional schemes – not a National scheme*
- *Melbourne don't really have a market for 'C's*
- *several crabbers stopped taking 'C's – therefore fishery lasts longer: instead of ending in June – carries on throughout the year. Worth it – make more income over the year*
- *need to educate fishermen to 'suffer' for a few weeks while leaving the 'C's in the sea!*
- *40 crabbers in the Clarence – if 1 crabber leaves the 'C' then the guy behind takes it*

RI and meat yield

- RI does not appear to reliably predict meat yield for all grades – *OK for 'A' grade males*
- *old 'crusties' always a problem*

AILMCGS Version 3

- includes amended thresholds between grades, based on refined pressure test for males and females
- industry came to agreement on the small changes and assisted with unambiguous wording to make descriptions fit the pressure measures
    - agreed grade differences for <u>male</u> crab underside
      'A' – No flex or slight flex on only one middle segment (either side)
      'B' – Slight flex on both middle segments, more flex on outer segments
      'C' – Easily flexed on all segments
    - agreed grade differences for <u>female</u> crab top carapace
      'A' – No flex or slight flex on only one side (either side) and no flex in middle section
      'B' – Slight flex on both sides and no flex on middle section
      'C' – Easily flexed on both sides and some flex on middle section
- *want to know the amount of 'C' grade through SFM and from where it is coming (NSW and QLD %s)*
- *can't agree to V3 as stands without recognition of differences in Wallis Lake crabs – these should be acknowledged as different "Central NSW" – and need seasonal in there too*
- *a pressure tool – G clamp style? - not conducted at harvest – need to wait till landed – only on those crabs that are doubtful*
- *this is the best method at this time* – meaning the thumb pressure test
- *seller may mix grades a little – thinking to get better return*
- *buyer won't go back to that supplier!*
- *Melbourne market works on demand – this influences whether buyers are happy and quibble or not – no formal QA system there*
- *want consistency*

Comments on grades

'A' grade

- *must be pressed with flat of thumb – most crabbers use point of thumb which is greater pressure on one point – therefore anything will flex*
  Response from all – dictate that scheme is based on flat of thumb

- *sell most crab outside SFM due to subjective pressure test*
- *top end no problem – can 'guarantee' premium quality crab*
- *want A slight flex both sides* (underside)

'B' grade

- *"soft" a bad word to use – opens to abuse from all potentially*

'C' grade

- *should be 323 322 (*male underside segment shell hardness scores) – *but they take lower than this*
- *but 'C' is legal take – and buyers don't reject*

- *What is the mortality rate of 'C's ? - SFM : High ! - therefore we are wasting resource! Need to educate the crabbers!!*

The PI – committed to recalculating data correlations under the Version 3 structure – to see how well it fits for the purpose

General Discussion Version 3

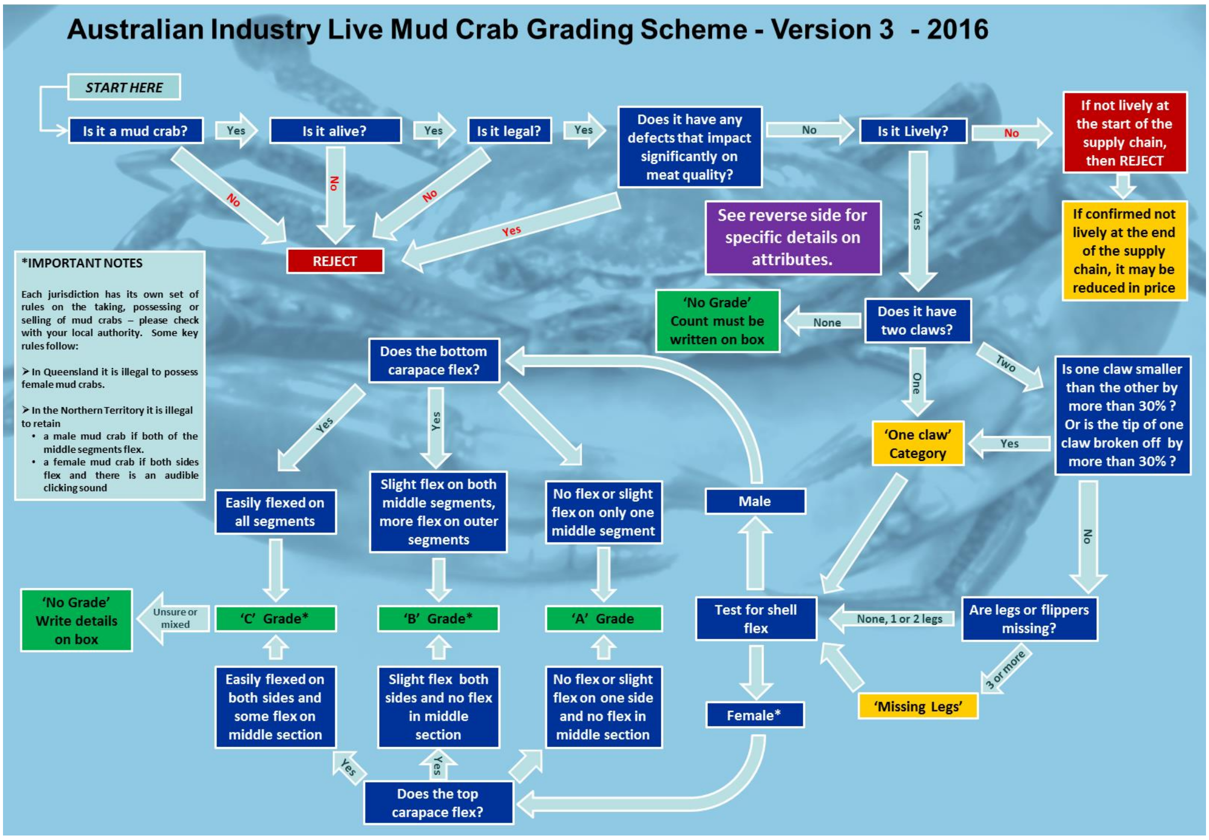
- *Co-ops pool returns to the crabbers – therefore no pain felt*
- *Qld crab groups want 'C' gone*
- *there should be no take of 'C' grade – Recs included*
- *ONLY way to change no take of 'C's is to legislate*
- *Quota – whether advocate or not – would fix 'C' grade … crabber needs max return from restricted amount of crab caught*
- *difference between Commercially Unsuitable Crab* (NT law) *and Commercially Unsaleable Crab*
- *view point from SFM with regard to potential future changes to QA process*

Objective tools

- interested – saw the limitations of different methods
- overall – saw potential of NIR
- asked how to progress – perhaps ARC with JCU and DAF – Cairns unit – student
- mud crab industry would support
- serious talk of proposal – SP to speak with Rapid Assessment Unit, DAF, Cairns

Confirmation of Version 3

Following the workshop, the scheme (Image 20) was distributed to the participants for discussion with their relative representative bodies and for final approval. One slight addition was agreed to be included in an effort to discourage the taking of 'water bags' as much as possible. During the earlier stage of the project it was decided not to introduce a reject class based on very soft shell hardness. It was considered that the wastage in the supply chain has too many negatives. Neither this project nor the Project Steering Committee has the authority to enforce regulations, hence the inclusion of 'Out of grade – return to water' for crabs with a carapace score below the minimum cut off score was included to address this concern.



Is it a mud crab - *Scylla* species  A mud crab has nine similarly sized spines on each side of the carapace. If not, it must be rejected.	**Bleeding**  If there is a significant amount of blood, reject the crab. A small amount of blood may not be 'A grade'.	**Damaged or deformed**  If damage or deformity is significant **and likely to impact on meat quality or survivability**, reject the crab. Minor damage and excessive barnacles are not defects.	**Old empty crabs**  If scarring is significant, claw teeth completely worn **and** the crab is light in weight for its size, reject the crab.
Frothing  If the froth is black or yellow, reject the crab. If there is a significant amount of clear froth and the crab is slow, it may be downgraded. Short exposure to cold can cause temporary frothing and the crab will recover.	**Parasite**  *Loxothylacus ihlei* (Loxy) appears as a mass under the flap which can be confused for an egg bearing female. If evident, reject.	**Is it lively?**  A lively crab's legs will provide resistance or push back against you, and their eyes react to movement. A cold crab may appear to be slow and can be revived. Crabs placed on their back may appear motionless, so confirm liveliness by untying or wetting.	**Two normal and complete claws**  If one claw is smaller than the other by more than 30% or the top tip is broken off by more than 30% and signs of spoilage, then 'One claw' category.

Male shell flex test

Hold the crab in both hands, with your palms facing upwards and the abdominal flap of the crab facing upwards. Place the flat of your thumbs on the middle segments (next to the 2nd walking legs and either side of the flap, see **X** on diagram) and press gently at first.

'A' Grade - No flex with firm pressure (~6kg) or slight flex on only one middle segment

'B' Grade – Slight flex with moderate pressure (~4kg) on both middle segments, more flex on outer segments

'C' Grade – Easily flexed (~2kg) with minimal pressure on all segments. Excessively soft on most segments are out of grade and should be returned to the water.

Note:
- Only press once. Repeated pressure will damage the shell.
- Segments already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a male mud crab if both of the middle segments flex.

'No Grade' - Write details on box.

Accessed only for liveliness, shell damage, missing legs or claws and other 'defects'. Details to include:- sex, one or no claws, 'missing legs', count & weight of each category.
Mandatory that number of no claws crabs be written on box or buyer can reject.

Female shell flex test

Hold the crab in both hands, palms facing upwards and the abdominal flap facing down. Place the flat of your thumbs on the carapace, in line with the widest part of the carapace and where the string is (or would be if the crab was tied up, see **X** on the diagram), and press gently at first.

'A' Grade - No flex with firm pressure (~6kg) or slight flex on only one side (either side) and no flex in middle section

'B' Grade – Slight flex (~4kg) on both sides and no flex in middle section

'C' Grade - Easily flexed (~2kg) on both sides and some flex on middle section. Excessively soft all over top carapace are out of grade and should be returned to the water.

Note:
- Only press once. Repeated pressure will damage the shell.
- Carapace already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a female mud crab if both sides flex and there is an audible clicking sound.

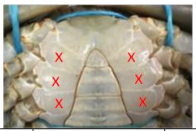
Australian Industry Live Mud Crab Grading Scheme – Version 3

Pressure is applied by using the pad of a straight thumb, <u>not</u> the tip of the thumb with a bent knuckle.

A segment that is already damaged cannot be used to determine shell hardness.

The following tables can be used to determine grades with greater precision when there is uncertainty.

Shell hardness grade	Description
4	No flex using firm pressure ~ 6kg
3	Slight flex with moderate pressure ~ 4kg
2	Easily flexed with light pressure ~ 2kg
1	Very soft, easily flexed with minimal pressure ~1kg



Grade	Male	Segments (x)	Total score	Female	Zone (x)	Total score
A	No flex or slight flex on only one middle segment (either side)	444,444 - 434,444	24-23	No flex or slight flex on only one side (either side) and no flex in middle section (M)	4,4 - 4,3	8-7
B	Slight flex on both middle segments, more flex on outer segments	434,434 - 323,323	22-16	Slight flex on both sides and no flex in middle section	3,3 - 3,2	6-5
C	Easily flexed on all segments	323,322 - 212,212	15-10	Easily flexed on both sides and some flex on middle section	2,2	4
	Out of grade – return to water		<10	Out of grade – return to water		<4

Image 20: AILMCGS Version 3 released to industry June 2016

Industry response to Version 3

After release of Version 3 of the AILMCGS to the workshop participants and Project Steering Committee all response received were favourable; a selection follows:

- *John, thank you for all your work on the grading system. Well put together and easily understood.*
  Regards. Keith Harris. Senior Vice President Queensland Seafood Industry Association.

- *From: Marine Care [mailto:marinec@bigpond.net.au] Project CI*
  Thanks for keep me up to day, as always a pleasure to work with you. Tony

- *From: Eric Perez [mailto:eo@qsia.com.au] Well done – cheers mate Eric*

- *Thanks again John for all your hard work to achieve a positive outcome . Troy*

- *well done john David Swindells*

- *Thanks John, I think this project is the ONLY step forward in the mud crab fishery since the early nineties, let's hope we soon get some sensible management to compliment your hard work.*
  cheers jacko

- *Thanks John Suzie*
- *Thanks John…… Great work Mr Shane Geary*
- *Thanks John Regards, David Caracciolo*

5 Conclusion

Industry response to initial scheme

The initial AILMCGS was distributed in November 2012 as part of FRDC Project 2011/225. This release was later than planned due to delays in finalising all of the video material for the extensive information package launch. As such, within the project timeframe, the full level of adoption of the scheme had been hard to quantify. The first objective in this project was to establish the level of adoption since its launch via a wide reaching electronic and paper based survey. From survey results it was clear that industry supported the concept of having a national live mud crab grading scheme. 83% of responders were aware of the AILMCGS indicating that communication of the scheme was successful since its inception. Survey results confirmed the need for this current project with the highest percentage (24%) of responses choosing 'Extremely dissatisfied' as their response to the question '*Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied with the Grading Scheme?*' It was very evident that there were concerns related to the amount of pressure thumb force to apply, effect of repeated pressure tests and application of scheme along the distribution chain. All responders wanted to see modifications to the initial AILMCGS. Despite a level of dissatisfaction with the scheme since its implementation, most responders said they changed their grading practices as per the scheme. Education on grading techniques was seen to be beneficial to the majority of responders.

AILMCGS Version 2

Version 1 of the AILMCGS had thumb pressure test sites on the top carapace for male crabs as well as the underside. During site visits to several NSW Fishermen's Co-operatives, assessments showed that consignments of male crabs were predominantly crabs with some flex on the top carapace, but were hard shelled on the underside. 'A' grade male crabs are defined as having no flex on the bottom carapace. Under the grading scheme these crabs would be determined as 'C' grade crabs due to the top carapace flex, yet they corresponded to having high meat fullness as assessed by RI and subsequent cooked meat yield analysis on sample set of crabs. Observations of a large percent (~65%) of crabs from one crabber illustrated this phenomenon and crabbers from all Co-operatives were able to show examples of similar crabs. The Project Steering Committee unanimously proposed two immediate interim recommendations effective from 22 January 2015:

1. **Sydney Fish Market will no longer use the 'top of carapace flex test' for grading male mud crabs.**

2. **If suppliers are unsure if their crab is 'B' or 'C' grade they are recommended to label the box as ungraded.**

In conjunction with the co-investigators and steering committee members, a revised AILMCGS Version 2 was developed and distributed on the 27 May 2015.

Regional anomalies

Regional anomalies of crabs with high meat fullness as assessed by RI and cooked meat yields were observed most frequently in mud crabs harvested from NSW estuarine waters. Research trial demonstrated that this anomaly is not related to salinities as hypothesised. From the results of investigation, environmental salinity difference does not appear to affect mud crab shell hardness.

Shell hardness

Accounts from some harvesters proposed that shell hardness changed from full hardness to slight flex during emersion over the transport time from capture to market assessment. Shell hardness changes during emersion are only minor and would not cause a complete grade change. Equally, no clear pattern of shell regaining hardness is illustrated for crabs re-immersed as could be expected if the shell hardness change occurs due to simple dehydration effects.

Industry and consumer attitude to meat fullness

Results from a survey elucidating responses from images of cooked claw meat indicate that crab grades are meeting satisfaction and price points. The relationship between both satisfaction and willingness to pay against crab grade and RI values was strongest for the professional crabber sector and less so for consumers. This supports the findings from the previous grading scheme survey that crabbers do care about crab quality in relation to meat fullness and that in general, the consumer is getting what they pay for. However, for 'C' grade crab the willingness to pay values given within the survey from all sectors were lower than the actual relative price attained at SFM auction. This backs many crabber's views that the sale of 'C' grade crab has an overall negative effect on consumer satisfaction, willingness to pay and the ever important return purchase.

Crab quality parameters

Initial results indicated that female grades did not align closely with RI values or cooked meat yields. Further sampling and analysis has shown this not to be the case.

The feasibility of developing a classification scheme for mud crabs that would predict their meat yield identified relationships amongst the traits, and which traits are more closely related to meat yield. Overall, for both sexes of crabs, the RI values correlate to meat yield percentage but are not correlated to physical characteristics of the crabs. These studies of the consistencies between methods for grading the crabs (i.e. method based on shell hardness and method based on RI values) revealed that they were fairly consistent for female crabs, but for male crabs they can be considered independent. One finding was that shell hardness was correlated to RI values for females and not for males. Further analyses on the numerical traits applied to female and male crab data separately revealed that although several correlation patterns can be identified and several groups of crabs can be formed, the grading that these crabs receive based on shell hardness scores or RI values are not consistent. Also, heavier crabs with larger, wider and heavier cooked claws have lower yield percentages. Conversely, lighter, smaller crabs with smaller major claws tend to have higher yield percentages. This may be one of the reasons that Asian buyers and consumers typically prefer and pay more for small female crab.

Objective methods investigated

Haemolymph protein - RI

For female and male crabs, the RI values are correlated to yield percentage traits, but are not correlated to physical characteristics of the crabs. The grade provided by choosing arbitrarily cut-points on the RI scale shows the same tendency for male and female crabs to grade the crabs higher than using the shell hardness test.

X-Ray

The conclusion of investigations of x-ray systems used in other crustacean industries around the world is that the system would only be suitable for a very large throughput of product at major market facilities and not suitable at all for the wider and geographically dispersed Australian mud crab industry. It was considered imperative that any grading tool recommended from this project be equally applicable and available to both large markets and individual crabbers.

Candling

From the preliminary investigation, results indicate there was no obvious correlation between the percentage meat yield of the cooked claws versus the illumination of both the carapace and the dominant claw. The candling method could be further investigated using other techniques of image capturing to see if enhancing the image could improve the correlation performance.

Acoustic velocity

Results show that acoustic information can provide a useful predictive tool if a clear measurement signal could be obtained. Ultrasound transducers are small and inexpensive, so this is a technology potentially suited to practical deployment within the industry. If the signal clarity issues could be resolved then the evidence collected shows that acoustic measurements can effectively predict meat yield, at least in terms of broad grade categories.

Near Infrared (NIR)

The potential of NIR in diffuse reflectance mode as a rapid and non-invasive technique for assessing mud crab fullness based on percentage yield recovery of cooked meat from individual mud crab claws was investigated. Preliminary PLS calibration models were developed that could predict percent meat yield to ±4.99 – 5.68% with and R^2 of 0.54 – 0.65 depending on NIR spectra collection site and NIR system used for collection. Preliminary PCA-LDA models separating mud crabs into three classes: A, B, C based on meat yield showed positive results. The current study showed that no grade ‘A’ mud crabs were classified as ‘C’ and no ‘C’ crabs classed as ‘A’. The best PCA-LDA model developed on a small number of crabs performed best when both male and female mud crabs were combined into one population to increase the sample size and biological variation of the data set. The NIR methods require further research in refining both the method and the spectra collection platform, plus assessment of sufficient mud crab numbers to enable construction of robust calibration models to predict mud crab samples.

SFM auction grading developments

SFM have been keen supporters of the AILMCGS as the effort required in the Quality Assurance process of live mud crabs is extensive, time consuming and at times contentious. SFM were the first to adopt and promote the scheme throughout its evolution. Their auction system, QA process and internal systems have undergone continual improvement to increase the fairness to both sellers and buyers. There is now a greater emphasis on a crabber's reputation and the consistency of the quality of the crab they supply.

As of 5 September 2016, SFM no longer permit the downgrading of mud crab based on shell flex (flex test) at auction. SFM informed all mud crab clients on the 26 August 2016 (Appendix 8) that they are of the view that the grading of mud crabs is the responsibility of the fisher and that excessive "flex test" further down the supply chain is detrimental to mud crabs. Suppliers of mud crabs to SFM are therefore required to grade in accordance with the AILMCGS and quote the respective grade on their crate/carton label. This is a natural and positive business progression in line with SFM's diligent commitment to continual improvement and evidence of industry indorsement of the scheme at the highest level.

6 Implications

Once again the industry workshop model proved to be successful process to report on research findings. The workshop process, focussing on industry input along with science based support and independent facilitation, was supported by participants, and would appear to be a sound model for whole of industry supply chain issues to be addressed in the future.

The volume of downgrade crabs at SFM has been made available but comparing the figures across the period of the project is not possible as the baseline of their QA process and codes have changed since the introduction of the AILMCGS.

The grade scores given for every crab tested in this project (n=370) were recalculated based on Version 3 of the scheme. The shifts in assigned grades of crabs between Version 2 and Version 3 of the scheme indicate an increase in revenue based on the average Friday July 2016 SFM auction prices of $2.18/kg for male crab (Table 35) and $2.80 /kg for female crab (Table 36) across all grades. Based on pre-Christmas 2015 values the increase in revenue would be $4.52/kg for males (Table 37) and $3.66/kg for females (Table 38). The increase in revenue is a demonstrable industry benefit from the refinement of the scheme.

Table 35: SFM average male Friday sale price July 2016

	SFM average male sale price July 2016					
		Version 2		Version 3		
Grade	**$/kg**	**Weight (kg)**	**Value**	**Weight (kg)**	**Value**	**Increase**
A	$ 39.41	51	$ 2,009.71	58	$ 2,285.55	
B	$ 32.18	29	$ 933.22	60	$ 1,930.80	
C	$ 23.12	101	$ 2,334.92	63	$ 1,456.43	
Total		181	$ 5,277.84	181	$ 5,672.78	$ 394.94
$/kg						$ 2.18

Table 36: SFM average female Friday sale price July 2016

	SFM average female sale price July 2016					
		Version 2		Version 3		
Grade	**$/kg**	**Weight (kg)**	**Value**	**Weight (kg)**	**Value**	**Increase**
A	$ 53.98	42	$ 2,267.08	66	$ 3,562.55	
B	$ 44.14	67	$ 2,957.11	58	$ 2,559.89	
C	$ 24.65	80	$ 1,972.16	65	$ 1,602.38	
Total		189	$ 7,196.35	189	$ 7,724.82	$ 528.47
$/kg						$ 2.80

Table 37: SFM average male sale price pre-Christmas

	SFM average male sale price pre-Christmas						
		Version 2		Version 3			
Grade	**$/kg**	**Weight (kg)**	**Value**	**Weight (kg)**	**Value**	**Increase**
A	$ 64.57	51	$ 3,293.07	58	$ 3,745.06	
B	$ 44.05	29	$ 1,277.45	60	$ 2,643.00	
C	$ 26.28	101	$ 2,654.28	63	$ 1,655.64	
Total		181	$ 7,224.80	181	$ 8,043.70	$ 818.90
$/kg						$ 4.52

Table 38: SFM average male sale price pre-Christmas

	SFM average female sale price pre-Christmas					
		Version 2		Version 3		
Grade	**$/kg**	**Weight (kg)**	**Value**	**Weight (kg)**	**Value**	**Increase**
A	$ 66.13	42	$ 2,777.46	66	$ 4,364.58	
B	$ 48.86	67	$ 3,273.62	58	$ 2,833.88	
C	$ 30.42	80	$ 2,433.60	65	$ 1,977.30	
Total		189	$ 8,484.68	189	$ 9,175.76	$ 691.08
$/kg						$ 3.66

Based on the Status of Key Australian Fish Stocks Reports 2014, the national commercial catch of mud crab is 1,670 tonne per annum with a conservative value (using the average 2014/15 SFM price/kg of $25.44 for all crabs) of $42.5M per annum. With a modest increase in value ($2.20/kg) attributed to Version 3 of the scheme, it is estimated that value of the fishery is $46.2M per annum.

The equivalent figures for SFM 2014/15 mud crab sales indicate a potential increase from $11.4M to $12.4M attributed to Version 3 of the scheme.

7 Recommendations

Continue positive reinforcement that the onus is on the supplier to grade in accordance with the AILMCGS at harvest point, so as not to be penalised by downgrades in the supply chain, especially as a result of shell damage from multiple shell pressure tests. All efforts to be made to continue to encourage fisher groups to release newly moulted crabs at the harvest source.

It is greatly desirable to maintain the NMCIRG for future discussions on issues e.g. NT Gulf female crab restrictions, take of 'C' grade crabs in QLD, and export opportunities.

The principal and co-investigators remain available to contribute to the post-harvest mud crab issues, if and when required. The investigators are also to keep abreast of industry's desire for and seek potential funding opportunities to further develop the identified non-invasive objective technologies, in particular the NIR option. All opportunities to educate the recreational sector about the grading scheme and other mud crab handling information via the Fact Sheets should be ongoing.

7.1 Further development

Ultrasonics

There are a number of different experimental parameters and configurations that were not sampled in this investigation and require further investigation/sampling in order to optimise this technology. These include:

Frequency mode: Sound at 5 MHz was strongly attenuated in the crab claw. A lower frequency may provide additional penetration and allow for a clearer signal to be obtained. Changing the frequency would require the purchase of additional transducers with new resonant frequencies.

Transmission power: The function generator driving the transmitter was limited in its output power. It is recommended that any future experiments utilise an amplification circuit to boost the power supplied to the transmitter to ensure there is significant signal

Operational mode: All measurements reported here were conducted in transmission mode. A reflectance mode might be useful and it should be explored as an alternative measurement type. A handheld instrument with reflectance mode ultrasound would be portable and very convenient for practical use. To implement reflectance mode, a modified circuit would need to be built to disconnect the transmit source quickly, in time for the receive pulse to be detected. There are off-the-shelf integrated circuits designed for this purpose.

Analysis of the signal attenuation: In the current study we have only extracted two quantities from the raw transients – (i) the acoustic velocity measured using the difference in the received start pulse signal time, and (ii) the "received signal strength" measured as the change in the RMS amplitude of the received signal. Within the received signal however, there is a wealth of information that reflects the path of the sound waves through the crab claw. For example, the temporal attenuation coefficient (i.e. the reduction in amplitude of the received signal with time) may be more representative of distinguishing flesh-based paths from shell-based paths of the sound waves.

Near Infrared (NIR)

The NIR methods require further research in refining both the method and the spectra collection platform, plus assessment of sufficient mud crab numbers to enable construction of robust calibration models to predict mud crab samples.

Market processes

Major markets should not be involved in ‘policing’ grades. The extra interrogation on the crabs adds to the stresses already incurred in the supply chain and increases the chance of carapace damage from further shell tests. The only market QA processes recommended are for short weights, major defects and dead crab as per the scheme.

Branding of product

Suppliers should be encouraged to brand their product for easy recognition for buyers as the product is predominately bought on crabber reputation and not reliant on individual crab grade assessment.

8 Extension and Adoption

There has been adoption of the scheme at a number of levels, from individual fishers along the supply chain to retailers. A key to the adoption of the scheme has been the decision by the SFM to use the AILMCGS as the market guideline for live mud crab as of 3 December 2012. The SFM guidelines act as a proxy for the Australian industry for many species and they are a key player in the Australian mud crab market. Price and grading is set de facto through the market and influences the supply chain across the country. Further evidence of adoption is highlighted by SFM's decision to cease downgrading mud crabs based on shell hardness (flex test) as reported in the Conclusion section.

From the initial survey of industry response to the AILMCGS, 83% of responders were aware of the scheme indicating that communication of the scheme was successful since its inception. The communication channels used for the initial release have been used successfully throughout this project. The industry is well represented by a number of peak bodies and communication of industry issues, events and information is strong.

Site visits can be an avenue of disseminating research information but the success is limited as crabbers are generally time poor. However, they do appreciate interaction with researchers and openly share their views and concerns.

Media has shown to be an effective resource for distributing information to all sectors of the industry and the community. Interest is being sparked by all releases, both nationally and internationally. There has been recent overseas interest and requests for information on the grading scheme for crab fattening enterprises. International collaboration has been offered to further develop a non-invasive objective grading tool. This will be explored in the future.

Industry websites provide access to the scheme and other mud crab fact sheets. The majority of industry personnel spoken to are aware of these resources as supported by previous survey results.

8.1 Project coverage

The following article 'How to tell if your mud crab is full of meat or mud' was published in:

- frasercoastchronicle.com.au - Fraser Coast Chronicle
- gladstoneobserver.com.au - The Observer, Gladstone
- MySunshineCoast.com.au – My Sunshine Coast
- www.newsport.com.au – Douglas Shire's Online Newspaper

FRASER COAST Chronicle

SPORT

How to tell if your crab is full of meat or mud

16th Jan 2015 11:15 AM

An empty mud crab.
DAFF

OPENING up a crab to find it empty of meat is disappointing, not to mention a waste of a good crab.

Queensland Boating and Fisheries Patrol district manager Rob McDonald said there were methods people could use to assess whether their prized crab was full or empty.

"Generally, crabs that are low on meat have recently moulted their shell and have not had a chance to fill their body cavity with flesh," Mr McDonald said.

"Recently moulted crabs will often contain mostly liquid or a jelly mass with little edible flesh.

"Whether you're an avid crabber, or you buy them at the local market, you can ensure every crab you catch or buy is full by following a few simple tips.

"Firstly, take a look at the shell condition. A crab that has recently moulted will have a very clean, shiny and intact shell.

"Sometimes the shell will appear translucent.

"Full mud crabs often have algae or barnacles on the shell. Their shells are also likely to exhibit some general signs of wear and tear, such as worn inner 'teeth' on the claws.

"You should also look for the darker coloured maltese cross on the underside of the crab."

Mr McDonald said there were also areas on the crab shell that could be pressed in order to get an indication of fullness.

"You can apply pressure with your thumb and finger either side of the carapace or by turning the crab over and pressing firmly on the abdomen plates adjacent to the third leg. If the shell flexes at all, the crab is not full.

"For crabs where the shell appears new, be careful not to press too hard as your thumbs will penetrate the shell.

"Crabbers should ensure the crab is firmly tied or restrained before attempting to test the shell."

Mr McDonald urged crabbers to return empty mud crabs to the water as soon as possible.

"Mud crabs grow very rapidly after moulting their shells," he said.

"When empty mud crabs are returned to the water they become full of meat and are a better quality catch within a few weeks.

"Returning empty mud crabs to the water is important for the sustainability of the fishery."

For more information on Queensland's crabbing rules, visit www.fisheries.qld.gov.au, call 13 25 23 or download the free 'Qld Fishing' app from Apple and Google app stores.

THE OBSERVER

PFA Update *1 May 2015*

PROFESSIONAL FISHERMEN'S ASSOCIATION

The PFA represents its members' interests. If you need our help on any issue please do not hesitate in contacting the PFA head office (6652 7374) &/or the Executive Officer (0429303371).

Mud Crab

DAF researchers are ensuring you know how full your mud crab is, whether you catch your own or buy them. This survey is part of a Fisheries Research and Development Corporation project (2014/218) to improve the precision in grading mud crabs.

5/364A Harbour Drive
Coffs Harbour NSW 2450

ph 02 6652 7374
mob 0429 303 371

Your feedback will help define the grading scheme used within Australian markets and provide information to the recreational sector on what crabs are best to keep and what to release so they can fatten up. Please contact John Mayze on (07) 3276 6023 or Tricia Beatty on 0429 303 371

https://www.surveymonkey.com/s/7HSQ5PP

PFA Update *29 May 2015*

Attention Mud Crabbers

In November 2012 the Australian Industry Live Mud Crab Grading Scheme - Version 1 was released to the entire Australian mud crab industry. The Scheme was developed by the National Mud Crab Industry Reference Group as part of the FRDC Project 2011/225 supported by funding on behalf of the Australian Government. Following the schemes uptake, some issues with regional and seasonal anomalies, as well as the use of and interpretation of the scheme were identified. As such the DAF Queensland with the support of the NSW PFA, SFM and the FRDC have investigated ways to address these issues through Project 2014/218.

The Project Steering Committee and the NMCIRG have reviewed and endorsed Version 2 of the Scheme. Please contact our office for a copy of the scheme. The project team is currently investigating alternative technologies to objectively grade mud crabs without the inherent problems of the subjective shell flex test and the associated damage and downgrades caused by frequent pressure tests. Recent results of non-invasive meat content scanning equipment are very encouraging.

As part of the research to define grade categories a short survey has been distributed. To date the response rate from the professional mud crab sector has been disappointing (23/177) so please complete this “How full is your mud crab?” survey to provide your professional expectation of ‘meat fullness’ from a series of photographs of cooked claws.
https://www.surveymonkey.com/s/7HSQ5PP

If you have any questions please do not hesitate in contacting John Mayze on (07) 3276 6023 or Chris Calogeras on 0401 692 601.

NORTHERN TERRITORY Seafood Council News

June 2015

GREAT OR MISERABLE EXPECTATIONS?

An online survey is underway to better understand expectations when a cooked mud crab claw is opened up to reveal how much delicious meat is inside.

Appropriately titled, "how full is your mud crab?" the survey is seeking feedback from all sectors on their thoughts after viewing photographs of cooked claws with respect to how satisfied they would be with crab claws and how much they would be willing to pay for it.

Data collected through the survey will help the introduction and identification of a grading system. The research project team is currently investigating alternative technologies to objectively grade mud crabs without the inherent problems of the subjective shell flex test and the associated damage and downgrades caused by frequent pressure tests. Recent results of non-invasive meat content scanning equipment are very encouraging.

Professional fishers are strongly encouraged to participate in the survey so that the results can be analysed from the different perspectives.

To complete the survey visit **www.surveymonkey.com/s/7HSQ5PP**

If you have any questions please do not hesitate in contacting John Mayze on **07 3276 6023**.

PFA Update 2 October 2015

PFA PROFESSIONAL FISHERMEN'S ASSOCIATION

The PFA represents its members' interests. If you need our help on any issue please do not hesitate in contacting the PFA head office (6652 7374) &/or the Executive Officer (0429303371).

Mud Crabs – Please Help!

The current FRDC funded mud crab project, 2014/218 "Building precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through addressing grading and regional anomalies" is investigating the effect low salinities have on shell hardness and meat yield.

Due to the unseasonal low volume of crabs the research team is asking mud crab fishermen to supply SFM with as many newly moulted soft shell 'C' grade crabs as possible to be on sold to the project team for their research trials**. Fishers will receive the given auction price of the day.** Crabs obtained through this process will also be used for upcoming scanning technology trials with the aim of developing and objective tool for industry to grade crabs.

Mud crabs go under the spotlight as researchers aim for fairer grading system

ABC Far North
By Mark Rigby

Posted 21 Apr 2016, 12:24pmThu 21 Apr 2016, 12:24pm

Photo: Live mud crabs were flown from Brisbane to Cairns to be used in the study, before they were repacked and sent back. (ABC Far North: Mark Rigby)

Map: Cairns 4870

James Cook University (JCU) and government researchers are trialling new technologies to improve the way mud crabs are graded, to make the process more equitable for fishers and consumers.

Scientists from JCU and Queensland Department of Agriculture and Fisheries (QDAF) flew 120 live mud crabs from Brisbane to Cairns this week to test technologies they hope will replace the current grading method.

> All the hassle and the argy-bargy that goes on with haggling over which crabs are good or bad can just be ruled out and made seamless.
>
> John Mayze, QDAF principal seafood technologist

Currently when being graded, crabs are squeezed by hand to test the amount of flex in the shell.

"There's a few problems with grading crabs too much because you can end up downgrading them," QDAF's principal seafood technologist John Mayze said.

"If you squeeze them too much, you can break the shell, which could kill the crab, or it'll downgrade that good crab from an A-grade, that'll be $38 per kilo, to something that's only worth $18 per kilo.

"Crabs can go through a dozen hands, all squeezing the crab to try and guess how much meat's in it.

"We're not going to guess how much meat's in it, we're going to tell you definitively."

Lights, sound, action

Professor Ron White, a physicist with JCU's Rapid Assessment Unit, said both sound and light could be used to grade crabs, with candling being the least technologically-advanced method.

"It's essentially putting a light underneath the crab and then looking at the image that comes out the top, similar to what they use in egg fullness tests," he said.

Photo: Researchers hope to further develop this acoustic velocity technology. (ABC Far North: Mark Rigby)

Another method also involving light is called near infrared spectroscopy, and while significantly more advanced than candling, could be used in fish markets as soon as next year.

By shining light on the crab's shell and analysing the light that bounces off it, computers are able to measure the chemical composition of the crab itself.

"There's some correlation between the chemical composition of the crab itself and what the fullness is and how hard the shell is," Professor White said.

He said the technology most likely to find its way onto crabbing boats used sound to measure how full of meat a crab was.

"With this we want to measure the acoustic velocity — how fast sound travels through the crab," he said.

"If it's full, it's going to have a different speed than if it's empty.

"The aim is to develop something nice and simple, something [crabbers] can pop on the claw of a crab that will tell us its size, the acoustic velocity inside of the crab and then tell straight away if it's an A, B or C-grade crab."

Technology to benefit all levels of supply chain

According to Mr Mayze, the seafood industry has been waiting for this kind of technology for some time and Sydney Fish Market has plans to incorporate it into their new premises.

"They're prepared to spend a couple of million dollars so that their number one sale by volume [item] can be completely automated," he said.

Photo: Mr Mayze shines a light on a C-grade mud crab to show how little meat is inside its claw. (ABC Far North: Mark Rigby)

"All the hassle and the argy-bargy that goes on with haggling over which crabs are good or bad can just be ruled out and made seamless."

Mr Mayze said as well as fish markets, crabbers and consumers would benefit from the technology.

"Crabbers can put those recently moulted crabs that are going to be empty back in the water and they can fill up within a few weeks and get that ideal value for the industry," he said.

"And when the consumer gets it, they're guaranteed to be getting a full mud crab because there's nothing more disappointing than opening what looks like a good mud crab to find there's no meat in it."

PFA Update *24 June 2016*

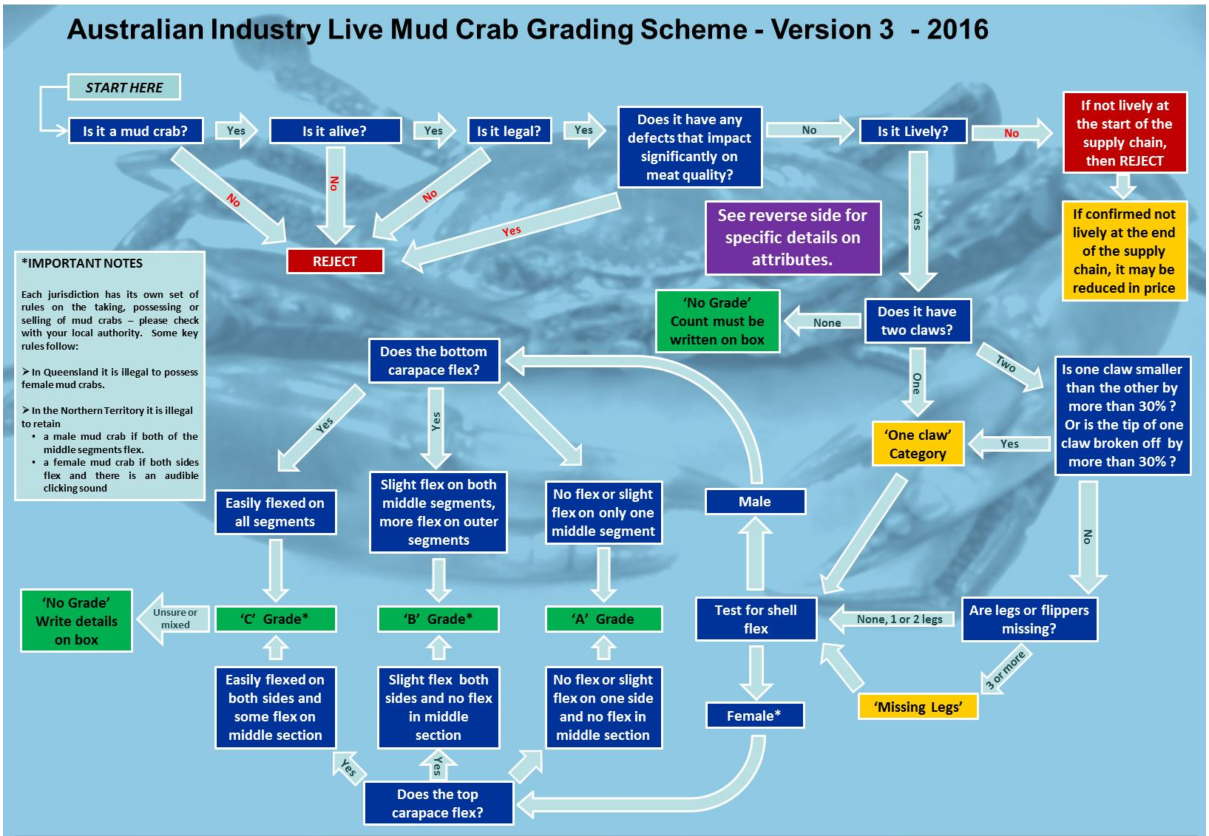
PFA PROFESSIONAL FISHERMEN'S ASSOCIATION

The PFA represents its members' interests. If you need our help on any issue, please do not hesitate in contacting the PFA head office (6652 7374) &/or the Executive Officer (0429303371)

MUD CRAB GRADING

A final version of the Australian Industry Live Mud Crab Grading Scheme IS NOW AVAILABLE. Version 3 of the grading scheme was developed from research findings presented at a workshop held recently at Sydney Fish Market. The workshop participants, who were the majority of the Steering Committee of the FRDC project 'Building precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) – including the PFA - through addressing grading and regional anomalies', reached agreement to modify the existing scheme to better reflect the regional variations that occur in mud crab shell hardness in relation to meat fullness.

Version 3 AILMCGS.



Is it a mud crab - *Scylla* species

A mud crab has nine similarly sized spines on each side of the carapace . If not, it must be rejected.

Bleeding

If there is a significant amount of blood, reject the crab. A small amount of blood may not be 'A grade'.

Damaged or deformed

If damage or deformity is significant **and likely to impact on meat quality or survivability**, reject the crab. Minor damage and excessive barnacles are not defects.

Old empty crabs

If scarring is significant, claw teeth completely worn **and** the crab is light in weight for its size, reject the crab.

Frothing

If the froth is black or yellow, reject the crab. If there is a significant amount of clear froth and the crab is slow, it may be downgraded. Short exposure to cold can cause temporary frothing and the crab will recover.

Parasite

Loxothylacus ihlei (Loxy) appears as a mass under the flap which can be confused for an egg bearing female. If evident, reject.

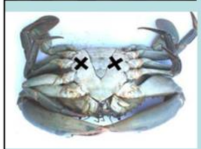
Is it lively?

A lively crab's legs will provide resistance or push back against you, and their eyes react to movement. A cold crab may appear to be slow and can be revived. Crabs placed on their back may appear motionless, so confirm liveliness by untying or wetting.

Two normal and complete claws

If one claw is smaller than the other by more than 30% or the top tip is broken off by more than 30% and signs of spoilage, then 'One claw' category.

Male shell flex test



Hold the crab in both hands, with your palms facing upwards and the abdominal flap of the crab facing upwards. Place the flat of your thumbs on the middle segments (next to the 2nd walking legs and either side of the flap, see **X** on diagram) and press gently at first.

'A' Grade - No flex with firm pressure (~6kg) or slight flex on only one middle segment

'B' Grade – Slight flex with moderate pressure (~4kg) on both middle segments, more flex on outer segments

'C' Grade – Easily flexed (~2kg) with minimal pressure on all segments. Excessively soft on most segments are out of grade and should be returned to the water.

Note:
- Only press once. Repeated pressure will damage the shell.
- Segments already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a male mud crab if both of the middle segments flex.

'No Grade' - Write details on box.

Accessed only for liveliness, shell damage, missing legs or claws and other 'defects'. Details to include:- sex, one or no claws, 'missing legs', count & weight of each category.
Mandatory that number of no claws crabs be written on box or buyer can reject.

Female shell flex test

Hold the crab in both hands, palms facing upwards and the abdominal flap facing down. Place the flat of your thumbs on the carapace, in line with the widest part of the carapace and where the string is (or would be if the crab was tied up, see **X** on the diagram), and press gently at first.

'A' Grade - No flex with firm pressure (~6kg) or slight flex on only one side (either side) and no flex in middle section

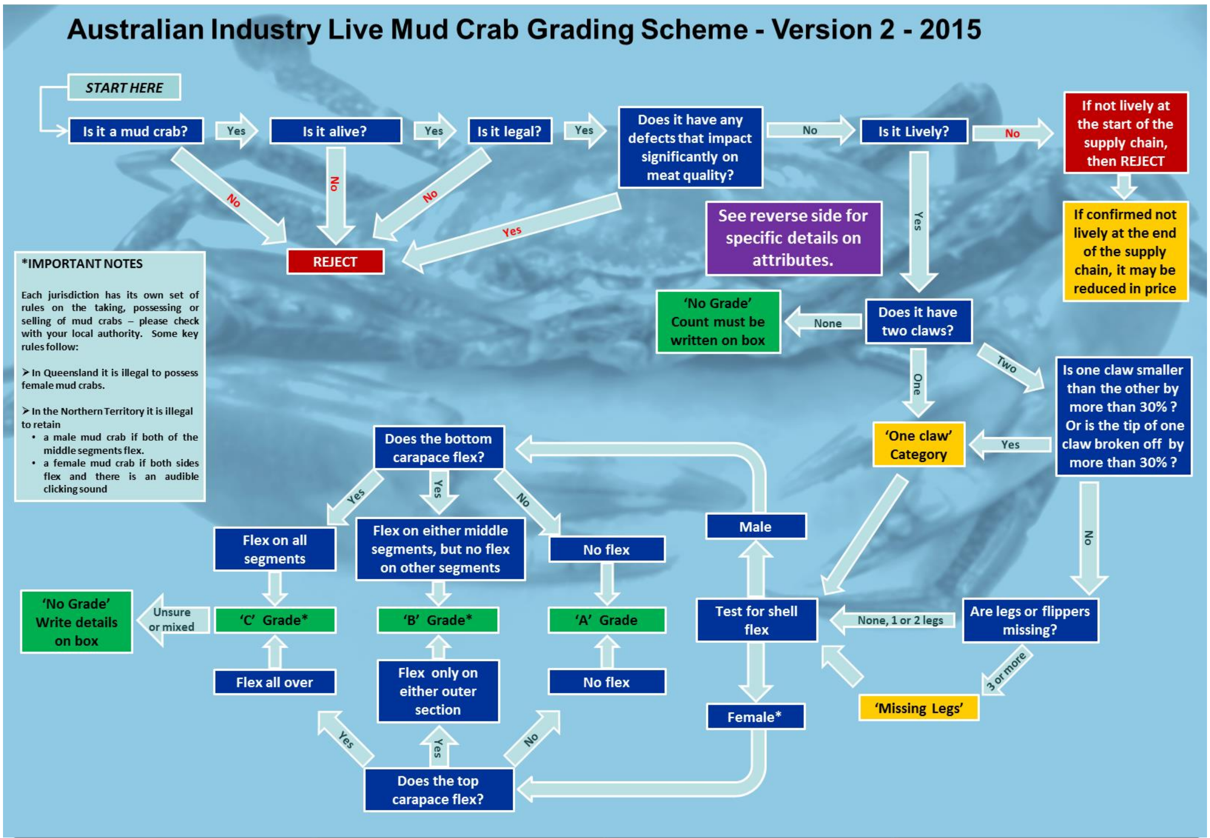
'B' Grade – Slight flex (~4kg) on both sides and no flex in middle section

'C' Grade - Easily flexed (~2kg) on both sides and some flex on middle section. Excessively soft all over top carapace are out of grade and should be returned to the water.

Note:
- Only press once. Repeated pressure will damage the shell.
- Carapace already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a female mud crab if both sides flex and there is an audible clicking sound.

9 Project materials developed

AILMCGS Version 2



Is it a mud crab - *Scylla* species

A mud crab has nine similarly sized spines on each side of the carapace . If not, it must be rejected.

Bleeding

If there is a significant amount of blood, reject the crab. A small amount of blood may not be 'A grade'.

Damaged or deformed

If damage or deformity is significant **and likely to impact on meat quality or survivability**, reject the crab. Minor damage and excessive barnacles are not defects.

Old empty crabs

If scarring is significant, claw teeth completely worn **and** the crab is light in weight for its size, reject the crab.

Frothing

If the froth is black or yellow, reject the crab. If there is a significant amount of clear froth and the crab is slow, it may be downgraded. Short exposure to cold can cause temporary frothing and the crab will recover.

Parasite

Loxothylacus ihlei (Loxy) appears as a mass under the flap which can be confused for an egg bearing female. If evident, reject.

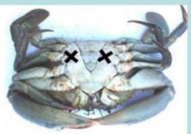
Is it lively?

A lively crab's legs will provide resistance or push back against you, and their eyes react to movement. A cold crab may appear to be slow and can be revived. Crabs placed on their back may appear motionless, so confirm liveliness by untying or wetting.

Two normal and complete claws

If one claw is smaller than the other by more than 30% or the top tip is broken off by more than 30% and signs of spoilage, then 'One claw' category.

Male shell flex test



Hold the crab in both hands, with your palms facing upwards and the abdominal flap of the crab facing upwards. Place the flat of your thumbs on the middle segments (next to the 2nd walking legs and either side of the flap, see **X** on diagram) and press gently at first.

'A' Grade - No flex with firm pressure

'B' Grade – Shell flexes with moderate pressure on either middle segment and no flex on the other segments

'C' Grade - Shell flexes with minimal pressure on all six segments

Note:
- Only press once. Repeated pressure will damage the shell.
- Segments already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a male mud crab if both of the middle segments flex.

'No Grade' - Write details on box.

Accessed only for liveliness, shell damage, missing legs or claws and other 'defects'.
Details to include:- sex, one or no claws, 'missing legs', count & weight of each category.
Mandatory that number of no claws crabs be written on box or buyer can reject.

Female shell flex test

Hold the crab in both hands, palms facing upwards and the abdominal flap facing down. Place the flat of your thumbs on the carapace, in line with the widest part of the carapace and where the string is (or would be if the crab was tied up, see **X** on the diagram), and press gently at first.

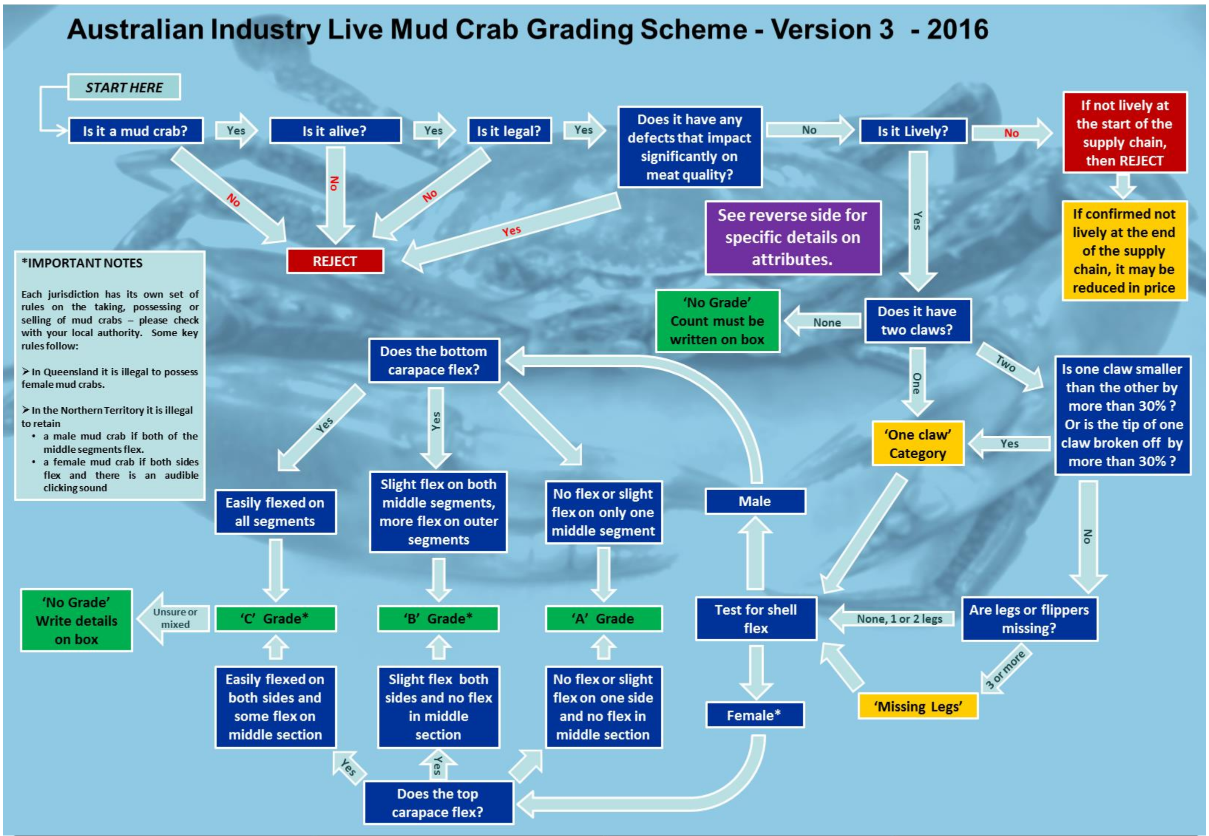
'A' Grade - No flex with firm pressure

'B' Grade - Shell flexes with moderate pressure on either side

'C' Grade - All the top carapace (sides and centre) flexes with minimal pressure

Note:
- Only press once. Repeated pressure will damage the shell.
- Carapace already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a female mud crab if both sides flex and there is an audible clicking sound.

AILMCGS Version 3



Is it a mud crab - *Scylla* species

A mud crab has nine similarly sized spines on each side of the carapace. If not, it must be rejected.

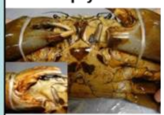
Bleeding

If there is a significant amount of blood, reject the crab. A small amount of blood may not be 'A grade'.

Damaged or deformed

If damage or deformity is significant **and likely to impact on meat quality or survivability**, reject the crab. Minor damage and excessive barnacles are not defects.

Old empty crabs



If scarring is significant, claw teeth completely worn **and** the crab is light in weight for its size, reject the crab.

Frothing

If the froth is black or yellow, reject the crab. If there is a significant amount of clear froth and the crab is slow, it may be downgraded. Short exposure to cold can cause temporary frothing and the crab will recover.

Parasite

Loxothylacus ihlei (Loxy) appears as a mass under the flap which can be confused for an egg bearing female. If evident, reject.

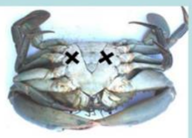
Is it lively?

A lively crab's legs will provide resistance or push back against you, and their eyes react to movement. A cold crab may appear to be slow and can be revived. Crabs placed on their back may appear motionless, so confirm liveliness by untying or wetting.

Two normal and complete claws

If one claw is smaller than the other by more than 30% or the top tip is broken off by more than 30% and signs of spoilage, then 'One claw' category.

Male shell flex test



Hold the crab in both hands, with your palms facing upwards and the abdominal flap of the crab facing upwards. Place the flat of your thumbs on the middle segments (next to the 2nd walking legs and either side of the flap, see **X** on diagram) and press gently at first.

'A' Grade - No flex with firm pressure (~6kg) or slight flex on only one middle segment

'B' Grade – Slight flex with moderate pressure (~4kg) on both middle segments, more flex on outer segments

'C' Grade – Easily flexed (~2kg) with minimal pressure on all segments. Excessively soft on most segments are out of grade and should be returned to the water.

Note:
- Only press once. Repeated pressure will damage the shell.
- Segments already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a male mud crab if both of the middle segments flex.

Female shell flex test

Hold the crab in both hands, palms facing upwards and the abdominal flap facing down. Place the flat of your thumbs on the carapace, in line with the widest part of the carapace and where the string is (or would be if the crab was tied up, see **X** on the diagram), and press gently at first.

'A' Grade - No flex with firm pressure (~6kg) or slight flex on only one side (either side) and no flex in middle section

'B' Grade – Slight flex (~4kg) on both sides and no flex in middle section

'C' Grade - Easily flexed (~2kg) on both sides and some flex on middle section. Excessively soft all over top carapace are out of grade and should be returned to the water.

Note:
- Only press once. Repeated pressure will damage the shell.
- Carapace already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a female mud crab if both sides flex and there is an audible clicking sound.

'No Grade' - Write details on box.

Accessed only for liveliness, shell damage, missing legs or claws and other 'defects'.
Details to include:- sex, one or no claws, 'missing legs', count & weight of each category.
Mandatory that number of no claws crabs be written on box or buyer can reject.

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11 Appendices

11.1 Intellectual Property

There is no intellectual property arising from this research project.

All results, findings and developed methods have already been extended into the mud crab industry and supply chains. All information belongs in the public domain.

11.2 Project staff

Principal Investigator:

John Mayze, Principal Technician, IFT, DAF Queensland

Co-Investigator:

Chris Calogeras, C-AID Consultants

Technical staff:

Sue Poole, Principal Seafood Scientist, IFT, DAF Queensland

Paul Exley, Senior Technician, IFT, DAF Queensland

Jimmy Baker, Scientific Assistant, IFT, DAF Queensland

11.3 Steering Committee members

John Mayze, Principal Investigator, DAF Qld

Sue Poole, Principal Seafood Scientist, DAF Qld

Chris Calogeras, C-AID Consultants, Co-Investigator

Tricia Beatty, EO Professional Fishermen's Association Inc, Co-Investigator

Tony Riesenweber, Co-Investigator

Peter Jackson, President, East Coast Crabfishers Industry Network Inc, Co-Investigator

Erik Poole, Customer Account Manager, Sydney Fish Market

Phil Hilliard, CEO, Ballina Fishermen's Co-operative Ltd

Troy Billin, NSW Clarence River Fishermen's Co-Operative, fisher

Shane Geary, Operations Manager, Coffs Harbour Fishermen's Co-operative Ltd

Lawrie McEnally, Director, Macleay River District Fisherman's Co-operative, fisher

Greg Golby, Chairman, Wallis Lake Fishermen's Co-Operative, fisher

Tony Hurley, Operations Manager, A Raptis & Sons

Doug Neville, NTMCLC

Sherwood Thorbjornsen, NT crabber

David Caracciolo, Director, Mackay Reef Fish Supplies

Robert Gauta, General Manager, Commercial Fishermen's Co-operative Limited

Eric Perez, EO, Queensland Seafood Industry Association

Keith Harris, Chairman QSIA crab committee

Additional contacts:

Robert Pender, The Fishermens Portal Inc.

Pauline Ward, Gulf of Carpentaria Commercial Fishermen's Association

Malcolm McLaughlin, Managing Director, McLaughlin Consolidated Fishermen Ltd

Katherine Winchester, CEO, Northern Territory Seafood Council

11.4 Investigation of Technology to Accurately and Non-Invasively Assess the Meat Content of Mud Crabs

Thesis submitted to James Cook University, College of Science, Technology and Engineering by Stuart Fordyce, 8th May 2015

11.5 Live mud crab grading scheme. Survey on the current status of issues relating to the AILMCGS

Survey and results

11.6 How full is your mud crab? Survey on satisfaction of meat fullness

Survey and results

11.7 Workshop presentation

Presentation delivered at SFM workshop

11.8 SFM notice - Mud Crab Grading

Notice sent to SFM customers 26 August 2016 – downgrading due to shell hardness not permitted

Appendices 4-8 follow.

Appendix 4 – Investigation of Technology to Accurately and Non-Invasively Assess the Meat Content of Mud Crabs

Thesis submitted to James Cook University, College of Science, Technology and Engineering by Stuart Fordyce, 8th May 2015

JAMES COOK UNIVERSITY

COLLEGE OF SCIENCE, TECHNOLOGY AND ENGINEERING

EG4011
ELECTRICAL ENGINEERING

INVESTIGATION OF TECHNOLOGY TO ACCURATELY AND NON-INVASIVELY ASSESS THE MEAT CONTENT OF MUD CRABS

STUART FRANCIS FORDYCE

Thesis submitted to College of Science, Technology and Engineering
in partial fulfilment of the requirements for the degree of:

Bachelor of Engineering
(Electrical and Electronic)

8th May 2015

Table of Contents:

List of Figures:

List of Tables:

Word Count:

5932 Words – Excluding references, appendices, headings tables and figures.

Chapter 1 – Introduction

1.1 Background

Mud crabs (Scylla Serrata) have become a popular seafood and are farmed on a commercial scale in many tropical countries [2]. Mud crab is now monocultured in increasing density to supply the growing market demands. Reliable quality assurance and consistent grading in the Australian Mud Crab industry is crucial to meet the demand and expectations of consumers. The inconsistencies and anomalies that occur using the current grading method often results in under-grading of the product yielding loss in profits and causing disputes. This has become quite a prevalent issue within the Queensland industry.

Mud crabs undergo 'molting' cycles in order to grow which involves shedding of their shell and expanding their body [3]. For several weeks after molting, mud crabs may look to be of reasonable size but lack muscle (meat) which is why it is necessary for mud crabs to be individually graded. The current grading scheme assesses the mud crab fullness based on shell hardness and categorises them into grades for sale (grade A, B and C). This traditional method is very widely used in the mud crab industry but has proven to be quite subjective and inaccurate in practice. The shell hardness is tested by the individual applying firm thumb pressure to specified locations and estimating the extent of flex in the shell. Naturally the test method is not consistently applied throughout the industry and other variables that dictate shell hardness can affect grading [4]. There has long been the need within the industry to bring consistency into the grading scheme and to develop a non-subjective method or tool for determining the meat content of mud crabs so that the accuracy of grading can be improved.

The method of testing would need to be capable of a reasonably high throughput so that it would be suitable for commercial applications. The grading of mud crabs occurs immediately after catching and ideally, the modified method of grading would be able to assess the quality of the live crab very quickly and if it is unsuitable, could be returned back to the water without harm. A recent introduction into industry is the refractometer. This passive device is capable of measuring the refractive index of the crabs hemolymph (blood) to estimate the meat content; however, it requires taking a blood sample from the live crab which is not only time consuming but very invasive [5].

Unfortunately, there is currently no commercially available, non-invasive technology or equipment that is capable of estimating the fullness of mud crabs. In addition it is apparent that there is little known literature covering the assessment of mud crabs using non-invasive techniques.

1.2 Scope and Objectives

This thesis will thoroughly analyse the feasibility and accuracy of several techniques of estimating the meat content of mud crabs. The objectives of this research are to:

1) Identify and investigate possible methods of estimating the meat content of mud crabs.
2) Test and analyse the effectiveness and accuracy of each of the methods.
3) Demonstrate a proof of concept for the technique on mud crabs.
4) Identify the most accurate grading method and test its accuracy.
5) Time permitting, design and build and commercial product.

The project will work closely with the Department of Agriculture, Fisheries and Forestry.
To investigate this problem, several different technologies will be thoroughly investigated, and applied and tested in order to identify and/or develop a method which is more accurate and less invasive that existing techniques. Such techniques that will be considered are near-infrared spectroscopy, ultrasonic/acoustic analysis, magnetic resonance imaging, electrical impedance tomography and x-ray. The scope of this research is limited to only the application of different technologies to male mud crabs (bucks).

Chapter 2 – Literature Review

The following review is intended to provide a background of mud crab's physiology and the existing technologies capable of possibly estimating the meat content of mud crabs. Specifically, this review is focused of the flaws in each of the techniques currently available.

2.1 Mud Crab Physiology

As with all crustaceans, linear growth in mud crabs is prohibited by their hard exoskeleton (shell). Because of this, they must undergo successive stages of shedding their shell called 'molting'. This occurs at least 18 times in a lifetime of a mud crab [6]. When a mud crab's muscles have grown to fill its shell, it begins to molt by first absorbing some of the existing calcium carbonate from its existing exoskeleton and then secrets enzymes to separate the shell from the epidermis (underlying skin). Over the next several weeks, the crab redeposits the previously absorbed calcium carbonate to create a new soft, paper-like shell under the epidermis [7].

Leading up to the actual molt, the crab absorbs seawater to expand the underlying shell to help break out of the existing exoskeleton. After the crab has fully removed itself, its soft body tissue continues to expand to enlarge the soft new shell [3]. This process typically last roughly 15 minutes [7]. Over the next several weeks the crab feeds ferociously in order to harden is new exoskeleton and for its muscle to grow [3]. This steady process allows fishermen to vaguely estimate the muscle (meat) content of a crab based on the hardness and flex in a mud crabs shell.

2.2 Current Grading Scheme and Existing Testing Methodology

Crabs are categorised into three grades for commercial sale A, B and C. A grade crabs are fully developed for their size, have a very high meat yield, and when cooked, their meat completely fills the shell. B grade crabs have a reasonably high meat content and C grade crabs have very little at all. An example of each of these grades can be seen below in Figure 1. The commercial grading of mud crabs in currently controlled by the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) which outlines legal thresholds and grading methodology and requirements.

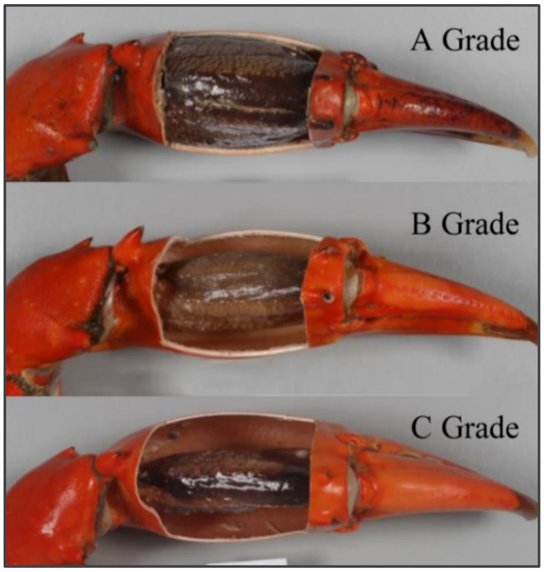

Figure 1 – Examples of A,B & C grade mud crabs after being cooked [1]

The current grading scheme involves an individual applying firm thumb pressure to both the top and bottom carapace (outer shell of crustacean body) and judging the extent of flex in the shell. The test locations for male and female mud crabs can be seen in Figure 2 below. Because the crab develops muscle and its shell simultaneously, it is possible to roughly estimate meat fullness using this method.

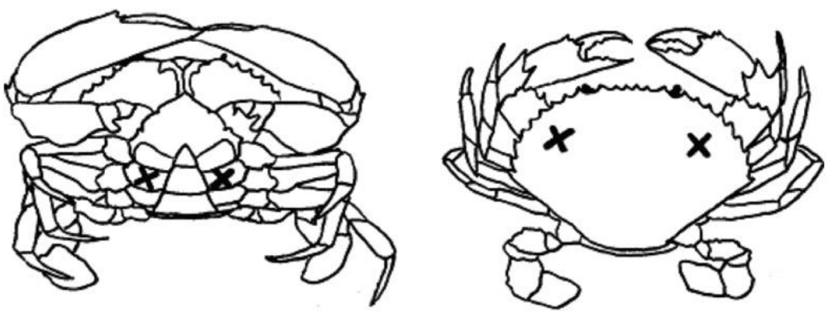

Figure 2 - Location of shell hardness test sites on male (left) and female (right) [6].

However, the rate of shell hardening and muscle growth during a crab's molting period are influenced by many factors such as salinity, water temperature, availability of food and season [8]. Thus an individual crab can develop muscle at a different rate to its shell. This can lead to anomalies in the current grading method as crabs can appear to have hard developed shells but severely lack muscle content. A method of this type, by nature, is also very subjective as the technique may differ considerably from person to person. Both these factors lead to grading anomalies and over-grading of crabs and in commercial industries, loss of profit and customer dissatisfaction.

Fortunately, a recent development in the industry, the refractometer, has brought a more accurate approach to mud crab grading [5]. There is a direct correlation between the proteins present in the hemolymph (blood) of a mud crab and the muscle content. The proteins present influence a change in the refractive index of the hemolymph which this device can measure. It has been proven to be capable of grading mud crabs less subjectively and more accurately than the existing method. On the other hand, this method requires taking a blood sample which is not only quite invasive but also time consuming.

2.3 Non-Invasive Technology

A non-invasive and efficient method of more accurately estimating the meat content of a crab is essential for this application. There are currently many applications of non-invasive technologies for assessing food quality such as chemical composition, internal defects, internal colour, density and other physical properties such muscle and fat content in soft tissue. An analysis of several techniques which could possibly apply to this particular application are investigated below.

2.3.1 Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) are both non-invasive methods of determining internal properties of biologic materials [9]. The nuclei of some atoms such as, ^{1}H, ^{13}C and ^{31}P have a magnetic moment and are capable of absorbing resonance energy when placed in a very strong magnetic field and excited by an appropriate radio frequency. When excited, the magnetic moment of the nuclei will rotate by 90° and after the magnetic field is removed, the relaxation of the excited nuclei will induce a signal characteristic of the environment surrounding the nuclei. Particular compounds have different relaxation profiles and can be identified through analysis of the relaxation response. In complex systems, the magnetic field can be applied in 3 dimensions in order to produce 2 and 3 dimensional images.

NMR and MRI not only has applications in the medical industry but also in the food industry such as identifying internal breakdown in apples and core breakdown of pears. This technology is particularly useful to measure water content and water distribution in many different materials because hydrogen nuclei have a very strong response to magnetic fields [9]. It has been observed that the chemical composition of the muscle in hard shell and soft shell mud crabs are considerably different and it was shown that the moisture content of soft and hard shell mud crabs were averaged to 84.38% and 94.76% respectively [8]. This characteristic makes the application of this technology to mud crabs appear feasible however, the hardware is very complex, expensive and large and would not be suitable for this application.

2.3.2 Electrical Impedance Tomography

Electrical impedance tomography (EIT) is a non-invasive imaging technique in which images of the internal electrical impedance distribution within a material can be generated rapidly using external ECG-type electrodes [10]. Currents are injected into the medium through electrodes positioned on its surface, and the induced voltages are measured. A reconstruction algorithm is applied to the data gathered from the measurements, which uses knowledge of the applied current patterns to compute the electrical permittivity and conductivity distribution throughout an object in the form of a two-dimensional image.

There are two main types of this technology, one of which is 'Applied Potential Tomography' (APT) [10]. This involves sequential application of current to a medium using an adjacent pair of electrodes. Voltages induced between the adjacent non-current carrying electrodes are measured in order to obtain a set of data. The second type is 'Applied Current Tomography' (ACT) in which currents are applied to all electrodes simultaneously while the induced voltages on each of the electrodes is measured. ACT systems are superior to that of APT systems as the can offer greater distinguishability (distinction between impedance changes) of imaging with an increase number of electrodes. However the disadvantage of ACT is their inherent hardware complexity. This technology is used heavily in the medical industry for identifying function of blood flow, screening for breast cancer, internal bleeding monitoring and much more [10]. The resolution achieved by EIT system can be seen in Figure 3 below.

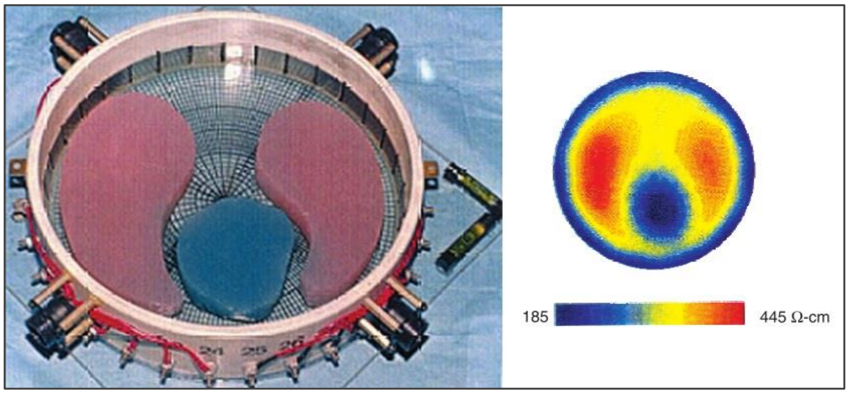

Figure 3 - Tank containing phantom thorax (left) and EIT resistive imagery (right) [10].

However, its applications also extends to geothermal and geophysical surveying. EIT is has the potential to provide very accurate estimates of reservoir saturation, moisture distribution and locate regions of high mineral densities such as metal ores [11]. A typical data set of this can be seen in Figure 4 below.

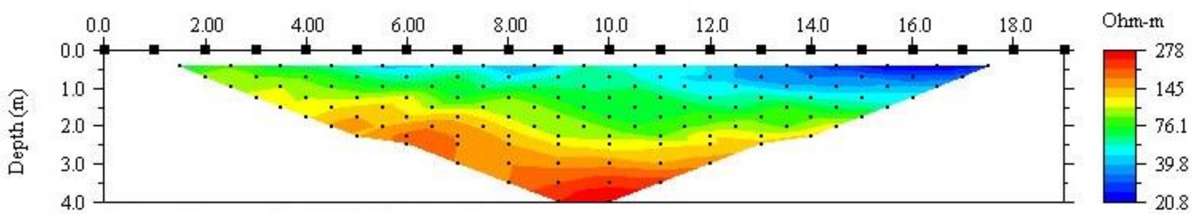

Figure 4 - 2-dimensional image generated from EIT in soil [12].

In the geophysical context, the spacing of the electrodes dictates the resolution of the reconstructed image, and the total length of system dictates the possible depth of penetration into the soil [12]. The disadvantage of this application is that it is partially invasive although non-destructive as the electrodes must be inserted into the soil in order to achieve the contact required for measurements. Furthermore, in order to achieve reasonable accuracy, measurements can be time consuming and extend for hours if many electrodes are used. Unfortunately however, in the context of mud crabs there is little to no existing literature on the electrical properties of mud crabs shell or muscle tissue making it hard to disregard as a possible technique. Nonetheless, the application of such technique is not only invasive but quite impractical. Alternatively, in the medical context, the electrodes a glued to the body with conductive glue in order to achieve a reasonable contact for measurements [10]. Although this is non-invasive and may be applicable to crabs, the practicality of performing a setup of this nature on each individual crab is highly impractical.

2.3.3 Near-Infrared Spectroscopy

Near-Infrared spectroscopy (NIRS) technology has been used for decades as it offers a rapid, repeatable and cost effective method for measuring properties of various materials. NIRS is a non-invasive method of determining information about the chemical composition and physical properties of organic materials by subjecting them to vibrational energy changes in the infrared frequency range of the electromagnetic spectrum [13]. In a material, atoms or a group of atoms sharing a chemical bond vibrate with a fundamental frequency defined by the strength of the bond and the mass of the participating atoms. Overtone bands (harmonic frequencies) and combination bands (combined fundamental frequencies) also exist.

If electromagnetic radiation of a given frequency is capable of providing the exact energy between two of the vibrational energy levels or of their overtones or combinations, it can be absorbed by the molecule and therefore excited to a higher energy state. The absorption or partial absorption of infra-red radiation of different wavelengths can be measured, and this figure of intensity versus wavelength constitutes the infrared spectra of a material [14]. This technology is applied with different apparatuses to measure the reflectance, interactance and transmission spectra of infrared light through material as seen in Figure 5 below.

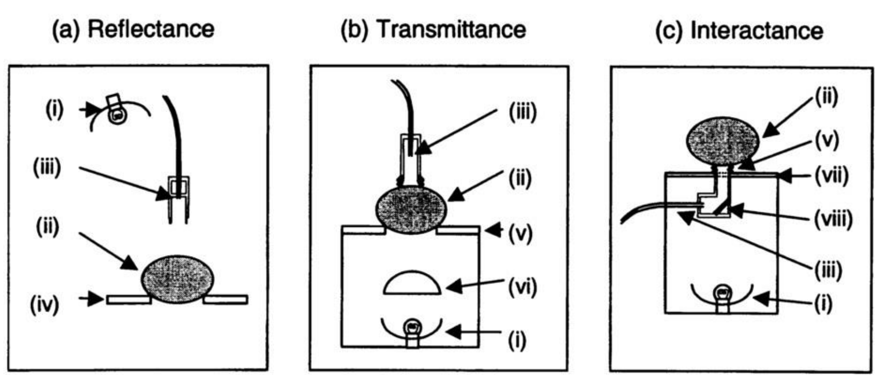

Figure 5 - The apparatus used for measuring (a) reflectance; (b) transmittance; and (c) interactance spectra of a material, showing (i) the infrared light source; (ii) the material; (iii) fibre optic cable; (iv) material holder; (v) light seal; (vi) convex lens; (vii) clear top; (viii) mirror [15].

Near-infrared spectroscopy (NIRS) utilises the spectral range from 780 to 2500 nm and provides much more complex structural information related to the vibration behavior of combinations of bonds than other ranges of the infrared spectrum such as mid-infrared or far-infrared [13]. This ‘near’ region of the electromagnetic spectrum is generally more useful because it can typically penetrate much deeper into samples [16]. Another advantage is that the instrumentation required for near-infrared is more simple and cost effective [14]. This technology already has a wide range of applications in the food industry such as the non-destructive quality analysis of avocados with great accuracy [17]. A more comparable application of NIRS is the ageing of fish based on the chemical attributes of their otoliths (bone located behind the brain in fish) [18]. Otoliths are typically comprised of 90-96% calcium carbonate and 0-10% organic matrix of proteins an approximately 1% of other trace elements. Carbonates have strong NIRS vibrational modes and reasonable correlations exist between the otolith composition and the age of the corresponding fish. However, this analysis has also shown that geographical and seasonal changes correspond to variation in NIRS measurements.

One particular disadvantage of NIRS is that the spectra can be affected by the temperature of the material being tested [18]. In the context of mud crabs, this may offer challenges with correlating measurements due to different water temperatures in different regions and seasons. Nonetheless, these existing uses makes the application of NIRS to measuring meat fullness of mud crabs seem very probable as there may be chemical changes in the shell which correlate to the meat yield.

Looking at the opposite end of the electromagnetic spectrum are X-ray's. This technology is widely used in the medical industry as a non-invasive method of producing two-dimensional imagery of bones within the human body. The effectiveness of this technique of measuring the meat fullness of a mud crab was discussed with people from the Queensland Department of Agriculture, Fisheries and Forestry (QDAFF) and it was concluded that this technology was briefly tested and proved to be incapable of distinguishing muscle tissue from shell. It was also concluded that utilising this technology is highly impractical due to cost and health safety implications.

2.3.4 Ultrasonic / Acoustic Analysis

Ultrasound is defined as an acoustic wave with a frequency higher than the threshold of human hearing, typically greater than 20 kHz [19]. Ultrasonic devices work by sending high frequency sound waves into a material and analysing the response. When a sound wave propagates through a medium, the signal immediately begins to attenuate. If a boundary of two media of different acoustic impedances is encountered, some of the wave is transmitted through the medium and some of the wave is reflected back to the sensor. Both the absorption and the transmission of the sound waves can be measured to provide vital information about the physiochemical properties of a material which include, microstructure, composition, viscosity and physical state [20].

Frequencies ranging from 20 kHz to beyond 100 MHz are used in order to achieve the required penetration and resolution, with most applications using between 500 kHz and 20 MHz [19]. Frequencies on the lower end of the ultrasonic spectrum (i.e. less than 5 MHz) are capable of achieving much greater penetration, consequently this also results in reduced accuracy and lowered resolution. Alternatively, much higher frequencies are capable of much less penetration but can achieve very high resolution measurements.

The three main physical parameters that ultrasound is capable of measuring are ultrasonic velocity, attenuation coefficient, and acoustic impedance [20]. The ultrasonic velocity is the rate at which an ultrasonic wave propagates through a material and is dependent on its elastic modulus (E) and density (ρ):

$$\frac{1}{c^2} = \frac{\rho}{E}. \tag{1}$$

The elastic modulus used is dependent on whether the medium is a liquid, gas or solid [20]. The density and elastic modulus of a material depends on its physical state, composition and structure, and therefore the acoustic velocity can be used to provide information about these properties. The attenuation coefficient (α) however, is a measure of the decrease in amplitude of the sound wave as it propagates through the medium and can be calculated as [20]:

$$A = A_0 e^{-\alpha x}. \tag{2}$$

Here A and A_0 are the applied and attenuated amplitudes respectively and x is the distance the ultrasonic wave has traveled [20]. Attenuation is caused predominantly by absorption and scattering of sound waves. Absorption occurs when the material converts the energy from the ultrasonic wave into heat and the degree to which this occurs is dependent on physical factors such as fluid viscosity, and thermal conduction. Scattering occurs when the incident wave encounters a discontinuity in the material (e.g. a particle or gaseous bubble) and is scattered into many directions. Measurements of the scattering and absorption of ultrasound can provide information about the viscosity and microstructure of a material. The acoustic impedance (Z) however, is the ratio of acoustic pressure (ρ) to the acoustic volume flow (U) [20]:

$$Z = \frac{\rho}{U}. \tag{3}$$

The acoustic impedance of a material is strongly dependent on the applied frequency and also dictates the ratio of an ultrasonic wave that is reflected and transmitted through a boundary of two media [20]. The acoustic impedance is a fundamental characteristic which depends on the composition and microstructure of a material. This measurement can therefore provide information about these properties.

One major disadvantage of ultrasound technology is that the frequencies required to achieve 'good' penetration and resolution in biological materials is strongly attenuated in air, making it difficult to apply [19]. This problem is overcome by the addition of a gel/coupling agent between the sensor and the medium which smoothly allows the ultrasonic signals to pass into and out of the material. Another drawback with ultrasound is the development of heat within tissue as the material absorbs the ultrasonic energy. This can lead to cavitation (bubbles) formation in blood due to the localised heat. However, the extent of heat produced is minimal as non-destructive systems typically have an intensity below 1W/cm^2 [20]. Ultrasonic technology has a major advantage over optical systems such as NIRS as it is applicable to optically opaque materials.

This technology not only has a variety of applications in the medical industry but also in food quality assurance [21]. It has been shown that ultrasound techniques are capable of measuring a variety of physical and chemical properties on biological materials such as measuring the homogenisation of fat within milk and measuring the fat and meat content of live animals [22]. However, seasonal and geographical differences in the specimens can often result in variation in measurements.

2.4 Conclusion

It has been identified that the existing methods of estimating the meat fullness of mud crabs are no longer suitable in the current industry. It was also established that there exists a large knowledge gap in literature with regards to non-invasive techniques for these measurements. Acoustic/ultrasonic analysis and near-infrared spectroscopy appear to have the least limitations of all technologies investigated and also offer the most useful information. On the other hand, MRI and EIT showed to have factors limiting their practicality of implementation into the industry. MRI appeared to be a feasible technique; however, the size, complexity of hardware and cost of this technology renders it an impractical solution to the problem. Similarly, the application of electrodes in EIT technology were concluded to be either impractical or highly invasive.

Chapter 3 – Methodology

It is proposed to carry out testing in order to investigate the feasibility of the application of both ultrasound and near-infrared technology of estimating the meat content of mud crabs. The testing will be done in consultation with QDAFF. Previous literature studies have investigated the practicality of applying each of these technologies in order to establish their feasibility of application. The following section will include a justification of feasibility and suggested implementation methodologies.

This research will be carried out in two stages, a preliminary and a primary testing stage. The preliminary stage is designed to be a proof of concept of the techniques described by using the experimental data to test if an initial correlation can be established. This stage will also investigate how practical the testing methodologies are, measurement time and methods for ensuring repeatable measurements. The primary stage is very dependent on the successfulness of the preliminary stage, nonetheless it will be designed to investigate the potential accuracy of the techniques.

3.1 Near-Infrared Spectroscopy

3.1.1 Justification of Feasibility

Previous literature investigation showed how the chemical composition of mud crab muscle differs quite considerably between hard and soft shell mud crabs. A study conducted in 2009, tabulated the chemical composition of the muscle in the claw and the body (lump) of both soft and hard shell mud crabs which can be see below in Table 1:

Chemical compositions (wet basis)	Hard shell crab lump	Hard shell crab claw	Soft shell crab lump	Soft shell crab claw
Protein (%)	$15.61 \pm 0.01^{*a}$	$14.31 \pm 0.05^{b**}$	12.87 ± 0.05^{c}	3.05 ± 0.02^{d}
Ash (%)	1.59 ± 0.04^{c}	1.67 ± 0.09^{b}	1.56 ± 0.03^{d}	2.17 ± 0.01^{a}
Moisture (%)	78.69 ± 0.06^{d}	84.38 ± 0.39^{b}	82.37 ± 0.17^{c}	94.76 ± 0.06^{a}
Fat (%)	0.28 ± 0.01^{a}	0.18 ± 0.02^{c}	0.24 ± 0.01^{b}	0.12 ± 0.01^{d}
NaCl (%)	0.70 ± 0.03^{d}	1.38 ± 0.09^{b}	1.10 ± 0.03^{c}	1.70 ± 0.06^{a}
Collagen (mg/g)	8.88 ± 0.14^{a}	8.26 ± 0.17^{b}	7.92 ± 0.12^{c}	2.75 ± 0.05^{d}
Ca (mg/kg)	$699.25 \pm 82.72^{*a}$	644.52 ± 52.90^{b}	240.57 ± 25.83^{d}	252.71 ± 98.91^{c}
Mg (mg/kg)	$406.63 \pm 9.89^{c**}$	418.70 ± 14.95^{b}	403.61 ± 5.21^{d}	428.28 ± 58.22^{a}
Cu (mg/kg)	20.43 ± 3.55^{a}	17.82 ± 0.96^{b}	17.68 ± 5.16^{b}	16.38 ± 1.61^{c}
Fe (mg/kg)	13.09 ± 12.96^{a}	10.07 ± 4.77^{b}	4.45 ± 2.56^{c}	5.36 ± 1.00^{c}
Zn (mg/kg)	36.57 ± 8.56^{a}	33.51 ± 14.33^{b}	27.40 ± 3.01^{c}	13.06 ± 5.51^{d}

Table 1 - Composition of claw and lump muscle of hard and soft shell mud crabs [8]

From this table it is evident that three components within the muscle which vary by the greatest extent are moisture, NaCl and protein. NRIS is sensitive to a change in chemical composition and significant variation in muscle composition should yield quite a difference in absorption spectra. Due to the lack of literature on the application of NIRS on mud crabs, it is difficult to determine if this technology is capable of penetrating their dense, optically opaque shell and gathering information about the composition of the muscle. Nonetheless if there are chemical changes in the shell that correlate to its respective muscle development and content, this would eliminate the need to measure the muscle tissue directly.

One possible limitation of this experiment is that the chemical composition of muscle and shell may also be affected by other environmental factors such as salinity, availability of food, water temperature and season making it very difficult to establish a correlation to meat yield. Ideally, a secondary testing stage would involve sourcing mud crabs from different geographical regions with different environmental surroundings and measure the changes in muscle and shell composition; however the investigation of this is not within the scope of the research. Nonetheless, it may be possible to identify a chemical change in the muscle or shell which correlates to meat yield irrespective of other environmental factors.

3.1.2 Proposed Testing Methods and Techniques

The lack of literature on the application of NIRS to mud crabs makes it difficult to establish locations of test sites. However, because the uniqueness of this application, to conduct thorough and comprehensive analysis of the proposed experiment, NIRS spectra measurements will be taken from multiple locations around the mud crab and each of these point will be analysed individually. The 18 individual locations of the NIRS test sites can be seen below in Figure 6:

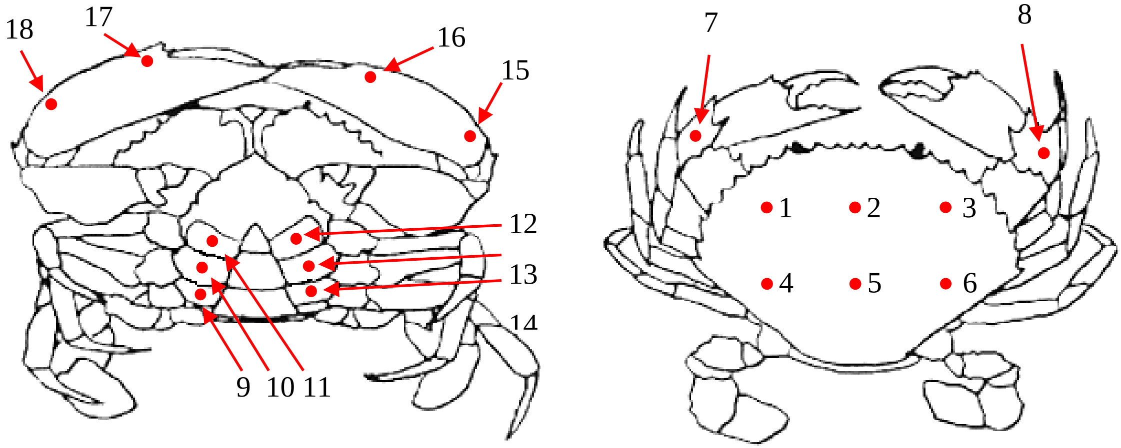

Figure 6 - Test locations for NIRS absorption spectra

As discussed previously, it is possible to measure three different spectra which are reflectance, transmittance and interactance; however due to the nature of the measurement sites, the optical opaqueness of the shell and lack of equipment, it was concluded to be too impractical to measure the interactance and transmittance spectra. Nonetheless, the reflection/absorption spectra is to be measured on each of the test sites using two NIRS machines seen below in (Figure 7 and Figure 8).

Figure 7 - MicroPHASIR NIR Spectrometer

Figure 8 - Brimrose NIR Spectrometer

These two devices both have different spectral ranges and different light intensities. The MicroPHASIR measures an absorption spectrum for wavelengths ranging from 1600nm to 2400nm and the Brimrose, 850nm to 1700nm. This will allow greater coverage across the infra-red spectrum and provide information regarding the importance of light intensity.

3.2 Ultrasound

3.2.1 Justification of Feasibility

A study conducted in 2009 on the physiochemical changes in the muscle of a mud crab at the beginning and end of a molt cycle revealed that there is a significant change in the microstructure of the muscle tissue as this process occurs (as seen in Figure 9 below) [8]. It was found that the claw muscle generally had more partial disintegrations than that observed in lump muscle and that an extremely distinguishable difference exists between the claw muscle of a hard and soft shell crab. The microstructure of a soft shell crab claw can be seen to be almost sponge-like and very porous. This dramatic change in muscle tissue microstructure may also correlate to a change in measurable acoustics properties such as the acoustic velocity and attenuation coefficient.

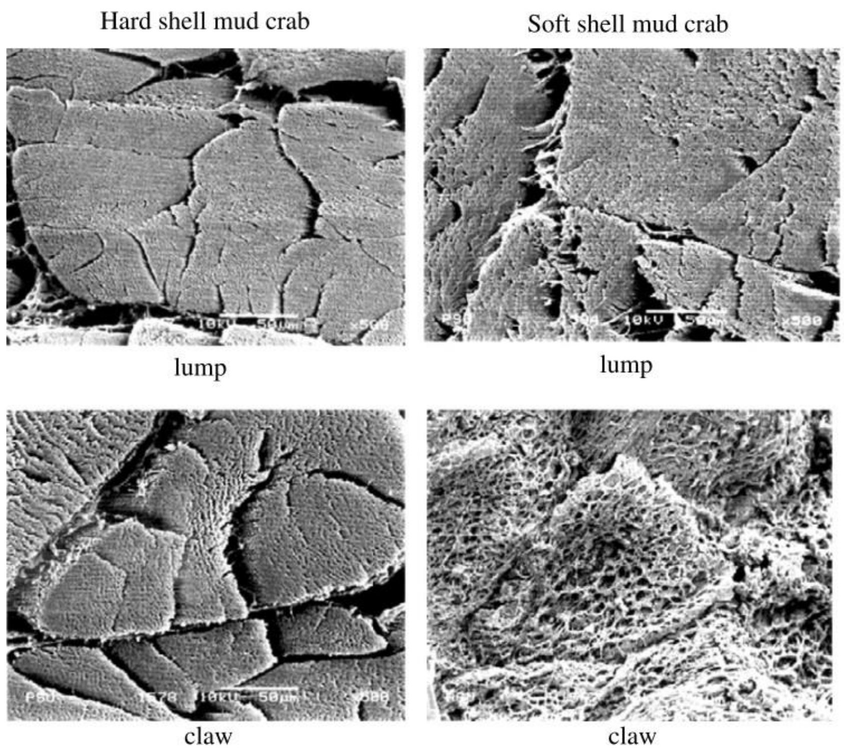

Figure 9 - Microstructure of lump and claw muscle of hard and soft shell mud crabs [8]

Although the acoustic properties of the muscle are very likely to change as the muscle develops, it may be very difficult to measure these properties non-invasively and accurately due to the hard shell. The dense shell will offer quite a considerable acoustic impedance when compared to the muscle tissue. This may make it very difficult/impossible to measure these properties of the muscle tissue directly; nonetheless a correlation may exist between the development stage of muscle and the acoustic properties of the entire claw (shell and muscle). It is also possible that the density of the shell is much greater than that of the muscle tissue such that it has a high enough acoustic velocity for the thickness to be considered negligible. This method of acoustic analysis is slightly more promising that NIRS technology due to range of applications which extend past optically opaque materials.

3.2.2 Proposed Testing Methods and Techniques

Due to the complexity of a mud crab's body and the presence of many variables such as organs, it was concluded that ultrasonic measurements on this segment will not be very effective. The claws however, consist of fewer different materials which give the best chance of finding a correlation between ultrasonic properties and meat yield.

In order to measure ultrasonic properties such as acoustic velocity, attenuation coefficient and acoustic impedance a method of ultrasonic analysis know as *through transmission* must be used. The apparatus shown below in Figure 10 was designed and manufactured specifically for this application; it consists of two ultrasonic transducers facing each other with one configured to transmit ultrasonic pulses, the other, to receive. Different materials are placed between the two sensors and by analysing the difference in amplitude and time between the transmitted and received pulses, these acoustic properties can be calculated.

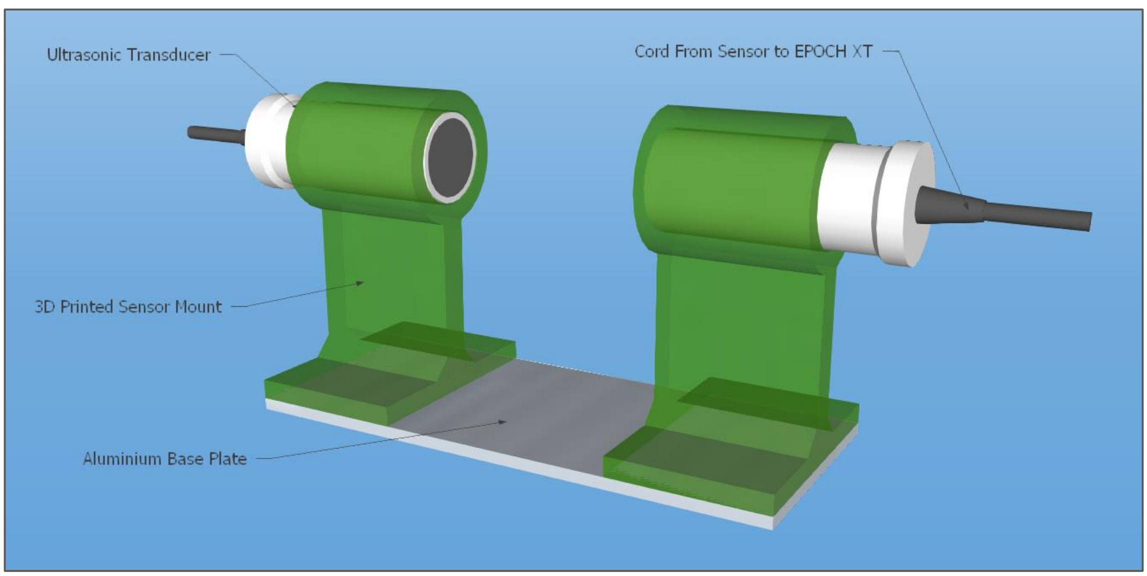

Figure 10 – Ultrasonic 'through transmission' apparatus design

Other measurements such as change in frequency of the pulse through the material can also be measured using this apparatus. The frequency of the transducers that will be used is 5MHz. This will allow reasonable penetrating power of the pulses and also yield an accurate resolution for measurements. The major disadvantage of this method is that the entire apparatus must be submerged in water to enable the pulses to travel between the transducers.

The device that will be used to analyse the signals from the ‘through transmission’ apparatus is an Olympus EPOCH XT show in Figure 12 below. This device is capable of generating a real-time plot of intensity of signal versus time. From this, parameters can be set to measure the time delay between sending and receiving pulses and also the change in amplitude. The apparatus built for through transmission shown below Figure 11 has the transducers placed 63mm apart.

Figure 12 - Olympus EPOCH XT (photo from Olympus)

Figure 11 - Manufactured ultrasound apparatus

When placed in the bath of water, an unobstructed initial measurement is to be taken to calculate the acoustic velocity of the water at its specific temperature. The maximum width of each claw is then measured using vernier calipers and recorded. The claw and the apparatus are then submerged in water and the transmitting transducer is placed flush up against the face of the claw at the maximum width. The time for the acoustic pulse to travel through this obstructed path and the amplitude of the received signal can be measured using the EPOCH XT and these measurements can be used to calculate the acoustic velocity and attenuation coefficient of the each of the claws (refer to Appendix B – Calculation of Claw Acoustic Velocity).

3.3 Experimental Methodology

3.3.1 General Testing Concept

The overall concept of this preliminary testing stage is relatively simple as it only intends to provide a proof of concept of these technologies so the sample size required is small. A sample of size of 15 – 25 mud crabs will be used in order to have a range of meat fullness. In order to limit the variation in data, the mud crabs will be sourced locally from the same region of water at the same time to ensure that environmental factors such as salinity, temperature, season and food supply are kept relatively constant. After the crabs are transported they will be stored in temperature regulated room to ensure they are all equal temperatures for all measurements. Furthermore, as this research is intended to improve the accuracy of the current grading scheme, all samples will be graded using the traditional thumb pressure method and using the blood refractive index method as a basis.

3.3.2 Actual Meat Yield Measurements:

To conduct this step consistently, the crabs will we weighed and steamed for 18 minutes/kilogram. Ideally meat yield measurements would be taken from the claws, body and legs of the crabs; however, simplifying this step by isolating claw meat yield allows the experiment to take place within one day. This will result in more accurate results due to the potential change in chemical and physical characteristics of the crab meat over long periods of time. The percentage yield can be calculated as:

$$\%\, Meat\ Yield = \left(\frac{Mass\ of\ yielded\ meat\ from\ claw(g)}{Total\ mass\ of\ claw\ (g)}\right) \times 100\%. \qquad (4)$$

Chapter 4 – Preliminary Results

The preliminary experiment of 17 mud crabs with a range of meat fullness was completed on the 30th April 2015. During this test, the meat fullness of each crab was assessed using the tradition thumb pressure method and the blood refractive index method. In addition, ultrasonic, NIRS and meat yield measurements were taken.

4.1 Near-Infrared Spectroscopy

To conduct a first pass examination, the absorption spectra measured from the Brimrose and the MicroPHASIR were used to produce the following Figure 13 and Figure 14. Both these figures plot the absorption spectra from all test subjects on test location 10 (see Figure 6).

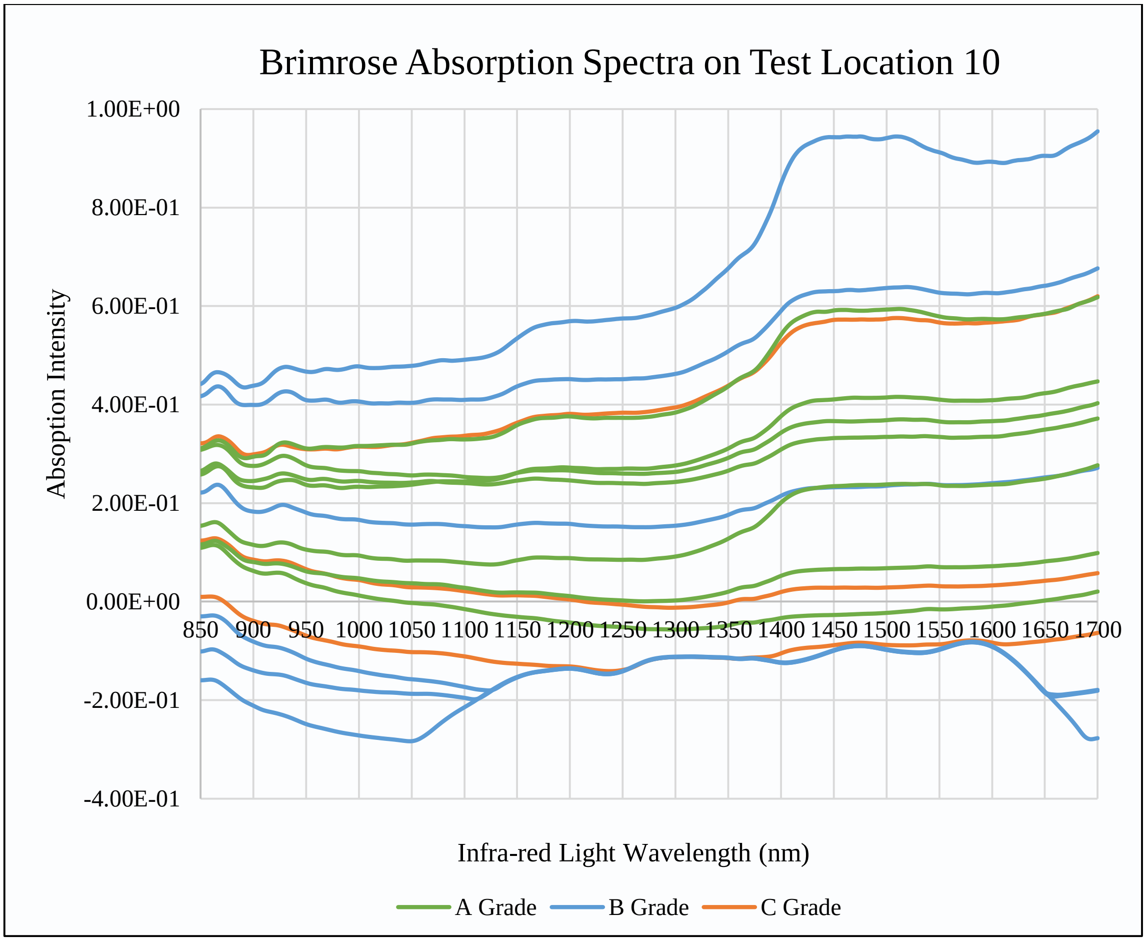

Figure 13 – Brimrose absorption spectra of a variety of grades of crabs

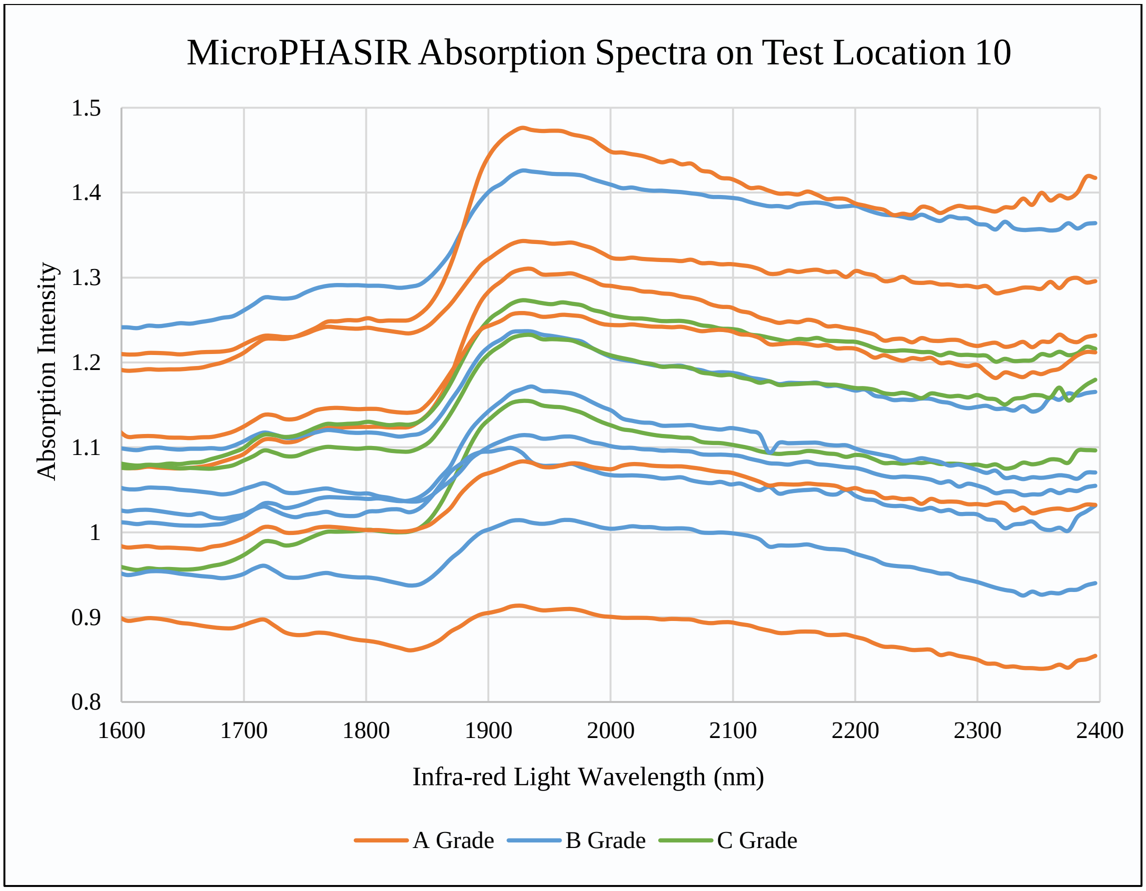

Figure 14 – MicroPHASIR absorption spectra of a variety of grades of crabs

It can be noted that there is very little change in the shape of the spectra for each of the different tests; however, this is the general nature of NIRS spectral analysis. In order to extrapolate any useful information from the raw data and test for any correlation, a statistical procedure known as a *principal component analysis* (PCA) can be performed. Similarly, a *linear discriminant analysis* (LDA) can be performed to test for a possible correlation. However, due to time constraints this was unable to be performed. Although it is probable that a correlation exists, the sample size is quite small which may yield inconclusive results.

4.2 Ultrasound

To establish a base line of existing methods, the RI of each sample's blood was graphed against its corresponding meat yield. The percentage meat yield of each individual crab was calculated by averaging the claw yields (weighted by the size of each claw). It can also be noted that in Figure 15 below, the grade determined by the traditional thumb pressure method is displayed next to each data point.

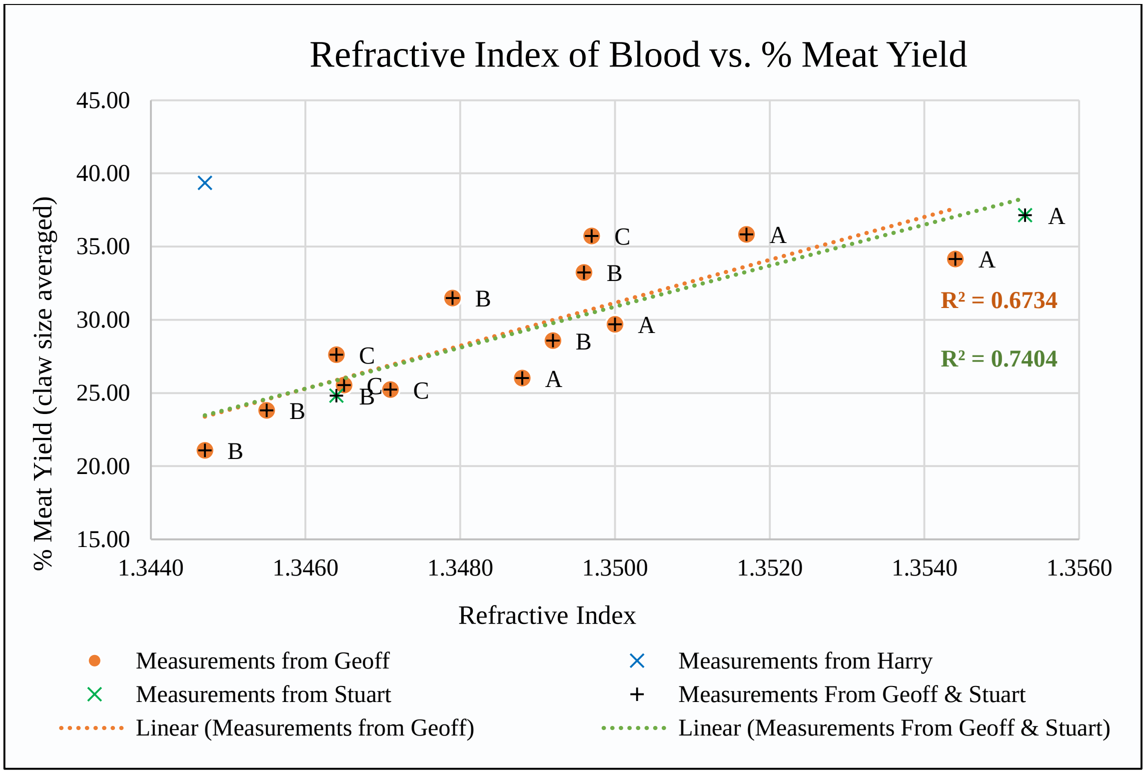

Figure 15 – Experimental results from traditional and refractive index method

It can be noted that the green and blue crosshairs in Figure 15 above refer to measurements of meat yield taken by different people due to experimental time constraints. The one blue value is very inconsistent with other measurements and is considered an outlier. By analysing this data, it is concluded that the traditional thumb pressure method is very inconsistent, inaccurate and unpredictable. On the other hand, there is a very clear relationship with the RI method. Although the data points vary slightly from the trend line with an R^2 value of 0.7404, it is evident that a linear relationship exists.

The acoustic velocity of crabs claws were also averaged and weighted by claw size to give an individual value for each specimen. This averaged acoustic velocity was graphed against the corresponding meat yield producing the following Figure 16 below:

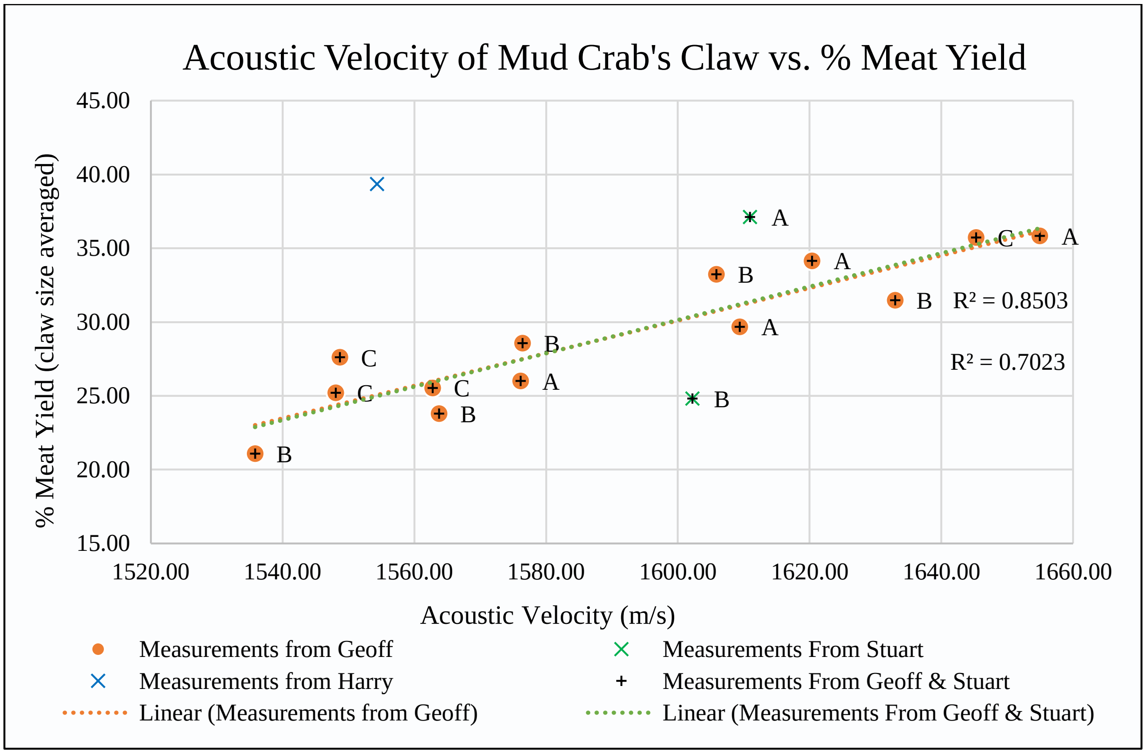

Figure 16 - Relationship between acoustic velocities of claws with meat yield

By analysing this data, it is immediately clear that a linear relationship between acoustic velocity and meat yield exists. The green data points in this graph appear to deviate from the trend line much more; however, this has no effect on the position of the trend line and only reduces the R^2 value from 0.8503 to 0.7023. Nonetheless, a linear correlation evidently does exist and this method achieves roughly the same accuracy as the RI method; however, does so non-invasively.

4.3 Outcomes and Conclusions

Unfortunately, due to software restrictions the amplitude of the transmitted and received signals was unable to be measured. This meant that the acoustic impedance and the attenuation coefficient were therefore not measured in this particular experiment. Nonetheless, it is quite clear from Figure 15 and Figure 16 above that a correlation exists between the averaged acoustic velocity of the claws and the corresponding meat yield. Although the traditional thumb pressure method was shown to be completely inconsistent and unpredictable, the RI method produced reasonable results with a definite correlation. The acoustic method proved to be capable of achieving a very similar accuracy to the RI method. These measurements taken by different people however, show how difficult it is to obtain reproducible measurements of the true meat content in a crab claw, and how important it is to keep experimental factors consistent throughout. Although the intention of this preliminary experiment was to investigate a proof of concept of this method, the practicality of taking measurements of this nature in a large scale fishing industry is unrealistic. Nonetheless, the results achieved from this preliminary experiment are promising and justifies further development of accuracy and practicality of this acoustic method.

For NIRS, at this stage it is impossible to determine the efficacy of this method without further analysis such as PCA or LDA. However, when compared with the acoustic method, it is clear that if this method was shown to work consistently, the application of this technology in the industry which be much more practical.

Chapter 5 – Project Management Plan

5.1 Project Gantt Chart

Required Task	Start Date	End Date	Duration (Days)
Topic allocation	26/02/2015	27/02/2015	2
Proposal/progress report	28/02/2015	8/05/2015	69
Topic research and investigation	28/02/2015	10/04/2015	41
Design and build ultrasonic apparatus	6/04/2015	23/04/2015	17
Place order for ultrasonic transducers	15/04/2015	28/04/2015	13
Partial draft submission	16/04/2015	16/04/2015	1
Conduct risk assessment and sign off	22/04/2015	29/04/2015	7
Pick up equipment from TICS NDT	28/04/2015	30/04/2015	2
Organise for NIRS machines to arrive	29/04/2015	29/04/2015	1
Pick up mud crabs for preliminary test	27/04/2015	27/04/2015	1
Conduct entire preliminary testing	27/04/2015	1/05/2015	4
Finalise progress report	27/04/2015	7/05/2015	10
Submission of proposal report	8/05/2015	8/05/2015	1
Preparation of proposal report seminar	9/05/2015	22/05/2015	13
Presentation of proposal seminar	22/05/2015	22/05/2015	1
Send away NIRS results for full analysis	23/05/2015	19/06/2015	27
Further research on design improvement	17/06/2015	30/06/2015	13
Construction of new ultrasound design	30/06/2015	4/07/2015	4
Pick up crabs & conduct final testing	6/07/2015	10/07/2015	4
Secondary analysis of NIRS results	11/07/2015	7/08/2015	27
Final report writing/drafting and analysis	20/07/2015	8/10/2015	80
Final seminar abstract & poster	9/10/2015	9/10/2015	1
Final seminar presentation with poster	12/10/2015	16/10/2015	4
Preparation of final seminar	28/09/2015	12/10/2015	14
Final submission of Thesis Report	29/10/2015	29/10/2015	1

Table 2 - Project management Gantt Chart

5.2 Contingency Plan

This contingency plan provides procedures to be undertaken if an unforeseen event/setback were to occur. Table 3 below describes these possible events that may result in a project delay and the corresponding necessary actions to mitigate the effect on the total project.

Event	**Contingency Plan**
Failure / breakdown of testing apparatus of equipment	The response is time dependant. If time permits, the failed component of the testing apparatus can be re-manufactured or reordered allowing for shipment time. If repairs are not possible due to time constraints or impracticality, testing and/or other planed events may have to be postponed to adapt to the changes.
Death of a significant portion of test subjects during pre-experiment storage	The response is also very situational. If experiment is not testing for a correlation between data and simply a test of instrumentation, it may be possible for the test to go ahead. However, if a large data set is necessary, more test subject may need to be organised.
Delay of purchases of equipment	In the event that the ordered items are not purchased in time and that the estimated arrival date is much later than planned for, it may be necessary to reorder equipment using an alternative payment method.

Table 3 - Possible project delays and contingency plan

5.3 Resources

The live mud crabs and both the MicroPHASIR and the Brimrose NIR spectrometers were sourced from the Queensland Department of Agriculture Fisheries and Forestry (QDAFF). The ultrasonic analysing equipment (Olympus EPOCH XT) was hired locally from TICS Nondestructive Testing. The ultrasonic transducers were purchased from Shantou Institute of Ultrasonic Instruments (SIUI). This experiment and later experiments are to be conducted at a James Cook University laboratory.

5.4 Cost Analysis

Upon undertaking this thesis, James Cook University provides and budget of $250 on materials for this project. This alone however, will not cover the necessary purchases and hiring of ultrasonic instrumentation. Fortunately, this project also has monetary support from the James

Cook University Rapid Assessment Unit and also funding from QDAFF to enable thorough experimentation for this project.

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Appendices:

Appendix A – Risk Analysis:

Townsville Campus
College of Science,
Technology and Engineering

Risk Assessment Name of Test: Testing feasibility of Ultrasonic and Near-infrared technology of measuring the meat fullness of mud crabs

Purpose: Thesis			
Operator: Stuart Fordyce		**Duration:** 27/04/2015 to 30/04/2015	
SDS Attached: (Tick one)	Yes	No	N/A
Major Hazard Types: (Tick at least one)			
Chemical		Mechanical	
Electrical		Thermal	
Environmental		Other:	

SUMMARY OF RISKS

Specific Task/Activity	Potential Hazards/Consequences	Assessed Risk	Risk Control Measures	Reassessed Risk
Handling of live mud crabs	- Cut of crushed appendages.	MEDIUM	- Ensure all crabs are tied up securely before handing. - Keep fingers out of the claw's crushing zone.	LOW
Use and handling of NIRS machine	- Electric shock. - Eye damage from infrared exposure. - Dropping equipment when moving.	HIGH	- Ensure the equipment and power lead aren't damaged. - Ensure the device is tested and tagged within date. - Do not look into the device's lens during operation. - Wear closed in shoes.	HIGH
Taking blood sample and measuring the refractive index	- Cut or stabbed by needle when taking blood sample.	MEDIUM	- Wear gloves and complete at own pace to reduce the chance of slipping. - Push needle in away from self.	LOW
Cooking of mud crabs	- Physical burns from hot water. - Physical burn from the burner flame. - Slipping on spilt liquid.	MEDIUM	- Use tongs to carefully immerse mud crabs to avoid splashing. - Take caution when lighting the burner and keep hands clear of flame. - If water is spilt, clean up immediately.	LOW
Measuring meat yield of mud crabs	- Crushed body parts when using hammer to break shell. - Blindness from shell shard projectiles while breaking shell.	MEDIUM	- Keep hand well clear of strike zone when breaking shell. -Wear safety glasses to avoid shell shards from entering eyes.	LOW
Post-test clean up	- Physical burns while emptying the pot of boiling water. - Back strain from lifting large pot of water.	MEDIUM	- Wait until the water has cooled before disposing. - Use bucket to bail out majority of water or use two people for lifting and disposing.	LOW

SUMMARY OF REQUIREMENTS

Personal Protective Equipment	Safety glasses, gloves
Is Training Required If YES, please state requirements	Yes / No
Training Manual Location	N/A

SUMMARY OF ACTIVITY

Taking Non-Invasive Measurements of Crabs:

Preparation of Crabs:

1. Ensure all crabs have their claws tied up at all time (except when measuring acoustic properties).
2. Use a permanent marker to mark a unique number on the carapace of each crab. Ensure that this is not writing where and NIRS sample will be taken.

Using the NIRS Machine:

3. Set up apparatus as necessary and measure the reflectance spectra of the claw and body.
4. Repeat step 3 but measuring transmittance.
5. Repeat step 3 but measuring interactance.
6. Repeat for all crabs.

Use of Ultrasonic Camera:

7. Set up apparatus as necessary take images of different locations on the crabs claw and body.
8. Repeat step 7 for all crabs.

Measuring Acoustic Properties:

9. Set up apparatus submerged in a bath of salt water.
10. Measure the acoustic velocity, acoustic impedance and attenuation coefficient of the crab's claw using the apparatus and the EPOCH XL ultrasonic unit.
11. Repeat step 8 for all crabs.

Measuring Refractive Index of Blood Sample:

12. Insert needle under the back left leg of the crab and take a blood sample.
13. Place a drop of the blood on to the face of the refractometer.
14. Hold the refractometer up to a light source and measure and record the refractive index.

Measuring Actual Meat Yield of Crabs:

Set-up:

1. Pour 5 litres of water into large pot.
2. Place pot on portable stove and bring to a boil.

Measuring Meat Yield:

3. Cook all crabs then chill immediately.
4. For each crab the cooked weight of each claw and body will be weighed and recorded.
5. All the meat from the individual parts of each carcase will also be weighed and recorded.

Post-Test Clean Up:

6. Wait until water in pot is room temperature and then dispose of water.
7. Clean all instrumentation used.

ASSESSMENT:

OPERATOR (Student or Technician)**:**

Stuart Fordyce	[signature]	Date: 23/04/15	Contact No: 0406633795
Name	Signature		

SUPERVISOR:

Bronson Philippa	[signature]	Date: 24/4/15	Contact No: 0427795904
Name	Signature		

SAFETY ADVISOR:

Lloyd Baker	[signature]	Date: 24/4/15	Contact No: 14189
Name	Signature		

HEAD OF DISCIPLINE:

Owen Kenny	[signature]	Date: 29/4/15	Contact No: 14279
Name	Signature		

THIS FORM IS TO BE DISPLAYED IN THE IMMEDIATE VICINITY OF THE EXPERIMENT BEING UNDERTAKEN

Appendix B – Calculation of Acoustic Velocity:

So firstly it must be noted that Olympus EPOCH XT returns a measurement of distance ($D_{initial}$) based on an assumed velocity of 1480m/s.

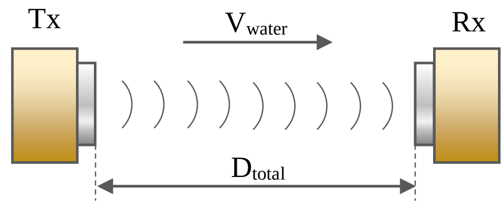


Figure 17 - Ultrasound apparatus initial measurement

So the first step is to calculate the actual velocity of the water. Figure 17 shows how the apparatus was set up for the initial measurement.

Now calculate the actual time for the pulse to travel from transmitter (Tx) to receiver (Rx):

$$t_{total} = \frac{D_{initial}}{V_{assumed}}$$

This corresponds to the actual speed through the water of:

$$V_{water} = \frac{D_{total}}{t_{total}} = \frac{D_{total}}{\left(\frac{D_{initial}}{V_{assumed}}\right)}$$

$$V_{water} = \frac{D_{total}}{D_{initial}} \times V_{assumed}$$

Now referring to Figure 18 for the diagram of how the claw measurement was taken we can note that:

$$T_{measured} = T_{claw} + T_{water}$$

$$\therefore T_{claw} = T_{measured} - T_{water}$$

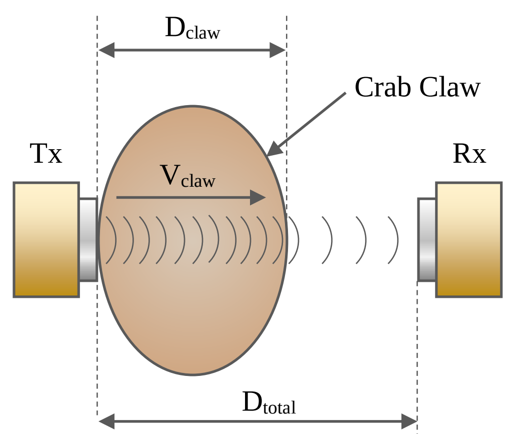


Figure 18 – Ultrasound apparatus claw measurement

Also now labelling the measured distance as $D_{measured}$, we can derive expressions for:

$$T_{measured} = \frac{D_{measured}}{V_{assumed}}$$

$$T_{water} = \frac{D_{water}}{V_{water}} = \frac{D_{total} - D_{claw}}{\frac{D_{total}}{D_{initial}} \times V_{assumed}} = \frac{D_{initial} \times (D_{total} - D_{claw})}{D_{total} \times V_{assumed}}$$

This now gives:

$$T_{claw} = T_{measured} - T_{water} = \frac{D_{measured}}{V_{assumed}} - \frac{D_{initial} \times (D_{total} - D_{claw})}{D_{total} \times V_{assumed}}$$

Rearranging gives:

$$T_{claw} = \frac{D_{measured} \times D_{total}}{V_{assumed} \times D_{total}} - \frac{D_{initial} \times (D_{total} - D_{claw})}{D_{total} \times V_{assumed}}$$

$$T_{claw} = \frac{D_{measured} \times D_{total} - D_{initial} \times (D_{total} - D_{claw})}{V_{assumed} \times D_{total}}$$

Now the velocity through the claw (V_{claw}) can be calculated by:

$$V_{claw} = \frac{D_{claw}}{T_{claw}} = \frac{D_{claw} \times V_{assumed} \times D_{total}}{D_{measured} \times D_{total} - D_{initial} \times (D_{total} - D_{claw})}$$

$$\therefore \boldsymbol{V_{claw}} = \frac{\boldsymbol{D_{claw}} \times \boldsymbol{V_{assumed}} \times \boldsymbol{D_{total}}}{\boldsymbol{D_{measured}} \times \boldsymbol{D_{total}} - \boldsymbol{D_{initial}} \times (\boldsymbol{D_{total}} - \boldsymbol{D_{claw}})}$$

Appendix 5 - Live mud crab grading scheme. Survey on the current status of issues relating to the AILMGS

Scheme questionnaire and results

Live mud crab grading scheme with skip logic instructions

Welcome to Our Survey

Building precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS)

through addressing grading and regional anomalies.

FRDC Project 2014/218

Thank you for participating in our survey. Your feedback is important.

The purpose of this survey is to provide important information to assist us in the FRDC funded project “Building precision into the Australian Industry Live Mud Crab Grading Scheme (AILMCGS) through addressing grading and regional anomalies” (FRDC 2014/218).

This project is a result of concerns expressed by some members of the industry regarding the impact of the Australian Industry Live Mud Crab Grading Scheme. The project was identified as a research priority through the NSW FRAB and has support from various sectors and regions around Australia.

The Queensland Government Department of Agriculture, Fisheries and Forestry (DAFF Qld) and C-AID Consultants led an industry project to establish the AILMCGS. The AILMCGS was developed by the National Mud Crab Industry Reference Group (NMCIRG) representing key sectors and regions of the national industry. The grading scheme was implemented to the entire industry in November 2012 and incorporated in the Sydney Fish Market Seafood Handling Guidelines in December 2012.

Since the introduction of the AILMCGS some sectors of the industry have raised concerns relating to inconsistent use of the scheme. Irregularities and inconsistencies in the application of the thumb pressure grading technique and potential regional and seasonal anomalies have led to some discontent with the scheme.

Following extensive consultation with industry, DAFF Qld was successful in having the FRDC fund the project ‘Building precision into the Australian Industry Live Mud Crab Grading Scheme through addressing grading and regional anomalies’.

<u>This survey is designed to capture the current status of issues for the professional fishing sector relating to the AILMCGS.</u>

The survey consists of multiple choice and free text questions and will only take about 30 minutes to complete. The survey uses skip logic to direct you to questions based on your responses. Just follow the prompts from your selection. There is also an opportunity to raise any issues, ask questions or make additional comments at the end of the survey. All responses are anonymous and strictly confidential.

If you have any questions, please do not hesitate to contact John Mayze at DAFF on 0418 870 488 or via email john.mayze@daff.qld.gov.au
Completed survey return address:
John Mayze
Agri-Science Queensland, DAFF
PO Box 156
Archerfield QLD 4108

Thankyou

DAFF and C-AID

The fine print...

This survey complies with the Information Privacy Act 2009 and is being conducted using SurveyMonkey. Information you provide on this survey will be transferred to their server in the United States of America. By completing this survey, you agree to this transfer.

Live mud crab grading scheme with skip logic instructions

Grading scheme questions

Questions relate to the Australian Industry Live Mud crab Grading Scheme.

1. Do you support the concept of having a national live mud crab grading scheme?

- ◯ Extremely supportive *(skip next question)*
- ◯ Somewhat supportive *(skip next question)*
- ◯ Neither supportive nor unsupportive *(skip next question)*
- ◯ Somewhat unsupportive
- ◯ Extremely unsupportive

Grading scheme questions

2. What are your concerns about having a national live mud crab grading scheme?

Grading scheme questions

3. How aware are you of the Australian Industry Live Mud Crab Grading Scheme (Grading Scheme)?

- ◯ Very aware
- ◯ Slightly aware
- ◯ Not aware at all (go to General Questions #19)

Grading scheme questions

4. Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied with the Grading Scheme?

- ◯ Extremely satisfied *(skip next question)*
- ◯ Quite satisfied *(skip next question)*
- ◯ Somewhat satisfied *(skip next question)*
- ◯ Neither satisfied nor dissatisfied *(skip next question)*
- ◯ Somewhat dissatisfied
- ◯ Quite dissatisfied
- ◯ Extremely dissatisfied

Grading scheme questions

Live mud crab grading scheme with skip logic instructions

5. What are your concerns with the grading scheme?

(select as many as apply)

- ☐ Too complicated
- ☐ Doesn’t suit my crabs
- ☐ Pressure test locations (e.g. top shell of males)
- ☐ Amount of thumb force to apply
- ☐ Effect of repeated pressure tests
- ☐ Types of grades
- ☐ Missing limbs (e.g. limbs dropped in transit)
- ☐ Application of scheme along the distribution chain (e.g. some buyers manipulating the scheme)
- ☐ Variable interpretation of what is ‘lively’
- ☐ Other (please specify)

Grading scheme questions

6. Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied <u>with the attributes used</u> within the Grading Scheme to differentiate grades?

- ◯ Extremely satisfied *(go to question #10)*
- ◯ Quite satisfied *(go to question #10)*
- ◯ Somewhat satisfied *(go to question #10)*
- ◯ Neither satisfied nor dissatisfied *(go to question #10)*
- ◯ Somewhat dissatisfied
- ◯ Quite dissatisfied
- ◯ Extremely dissatisfied

Grading scheme questions

Live mud crab grading scheme with skip logic instructions

7. What are your concerns with the attributes used within the Grading Scheme to differentiate grades?

(select as many as apply)

- ☐ Pressure test locations
- ☐ Amount of thumb force to apply
- ☐ Effect of repeated pressure tests
- ☐ Types of grades
- ☐ Missing limbs
- ☐ Application of scheme along the distribution chain
- ☐ Other (please list additional concerns)

Grading scheme questions

8. Would you like to see modifications made to the Grading Scheme?

- ◯ Yes
- ◯ No *(skip next question)*
- ◯ Don't care *(skip next question)*

Grading scheme questions

9. What modifications do you see necessary?

(select as many as apply)

- ☐ Pressure test locations
- ☐ Amount of thumb force to apply
- ☐ Effect of repeated pressure tests
- ☐ Types of grades
- ☐ Missing limbs
- ☐ Application of scheme along the distribution chain
- ☐ Other (please list additional modifications)

Grading scheme questions

Live mud crab grading scheme with skip logic instructions

10. Before the scheme's implementation, briefly describe what your grading practices were.
For example: What grades did you use? How did you determine grades?

11. Have your grading practices changed since the scheme was implemented in 2012?

- ◯ A great deal
- ◯ A moderate amount
- ◯ A little
- ◯ Not at all *(skip next question)*

Grading Scheme Questions

12. After the scheme's implementation, how did your grading practices change?

- ◯ As per Grading Scheme *(skip next question)*
- ◯ I use some variations to the Grading Scheme
- ◯ I don't use the Grading Scheme at all

Grading scheme questions

13. Describe how you grade crabs different to the scheme.

Grading scheme questions

14. Do you think that any inconsistencies in the way crabs are graded could be addressed by educating graders on the standard grading techniques?

- ◯ Strongly agree
- ◯ Somewhat agree
- ◯ Neither agree nor disagree
- ◯ Somewhat disagree
- ◯ Strongly disagree

Additional comments:

Live mud crab grading scheme with skip logic instructions

15. Have you experienced a change in price/kg for mud crab sales that you directly attribute to the introduction of the Grading Scheme?

- ◯ Price/kg increased (go to question #16)
- ◯ No change (go to question #18)
- ◯ Price/kg decreased (go to question #17)
- ◯ Would prefer not to answer (go to question #18)

Additional comments:

Grading scheme questions

16. How much did it increase?

- ◯ $1 to $2/kg
- ◯ $3 to $5/kg
- ◯ $6 to $9/kg
- ◯ $10 to $15/kg
- ◯ More than $15/kg

Additional comments:

Grading scheme questions

17. How much did it decrease?

- ◯ $1 to $2/kg
- ◯ $3 to $5/kg
- ◯ $6 to $9/kg
- ◯ $10 to $15/kg
- ◯ More than $15/kg

Additional comments:

Grading scheme questions

Live mud crab grading scheme with skip logic instructions

18. Have you received any customer feedback about the quality or consistency of crab grades since the introduction of the grading scheme?

- ◯ Very positive
- ◯ Somewhat positive
- ◯ No feedback
- ◯ Somewhat negative
- ◯ Very negative
- ◯ Not applicable

General questions

General questions about mud crab quality and industry practices

19. Have you experienced <u>seasonal</u> anomalies where crab shells do not become fully hard, yet the crabs appear full?

- ◯ Very often
- ◯ Occasionally
- ◯ Never
- ◯ Not applicable or not sure

Additional comments (e.g. time of year, rainfall related etc.)

20. Have you experienced <u>regional</u> anomalies where crab shells do not become fully hard, yet the crabs appear full?

- ◯ Very often
- ◯ Occasionally
- ◯ Never
- ◯ Not applicable or not sure

Additional comments (e.g. list locations or regions)

Live mud crab grading scheme with skip logic instructions

21. Do you believe that a crab's shell hardness changes from point of capture to market?

- ◯ Shell softens at least one grade
- ◯ Shell softens a little
- ◯ No change
- ◯ Shell hardens a little
- ◯ Shell hardens at least one grade
- ◯ Don't know

Additional comments (e.g. at particular times of the year the shell hardness changes)

22. If a tool or device that grades crabs objectively for you were available today, how likely would you be to use it?

By 'objectively' we mean that the grade can't be disputed. The grade could be determined by either a measure of shell hardness or meat content.

- ◯ Extremely likely *(skip next question)*
- ◯ Somewhat likely *(skip next question)*
- ◯ Neither likely no unlikely *(skip next question)*
- ◯ Somewhat unlikely
- ◯ Extremely unlikely

Additional comments:

General questions

23. Why wouldn't you use a tool or device to help you grade crabs?

General questions

Live mud crab grading scheme with skip logic instructions

24. How important to you is the meat fullness of your mud crab?

- ◯ Extremely important
- ◯ Quite important
- ◯ Neither important nor unimportant
- ◯ Quite unimportant
- ◯ Extremely unimportant

General questions

25. Are you aware that lesser grade crabs often have an increased mortality rate through the transport chain?

- ◯ Very aware
- ◯ Slightly aware
- ◯ Not aware

Additional comments:

26. Are you aware that ‘C’ grade crabs will fatten to become ‘B’ grade within just a few weeks and 'B' into 'A' in a few more?

- ◯ Very aware
- ◯ Slightly aware
- ◯ Not aware

Additional comments:

27. To avoid answering some fisher related questions, are you mud crab fisher?

- ◯ Yes
- ◯ No (go to question #31)

Questions regarding 'C' grade crabs for fishers

Live mud crab grading scheme with skip logic instructions

28. Before the implementation of the Grading Scheme in 2012 did you return ‘C’ grade crabs to the water?

Regional terms for 'C' grade may have been CUC or waterbags.

- ◯ Yes, always
- ◯ Never
- ◯ Sometimes - e.g. recent market prices, other fisher competition, etc.

29. After the implementation of the Grading Scheme do you return ‘C’ grade crabs to the water?

- ◯ Yes, always
- ◯ Never
- ◯ Occasionally - e.g. recent market prices, other fisher competition, etc.

30. Overall, do you believe that revenue or future harvest is improved by releasing 'C' grade crabs to the water?

- ◯ Very much improved
- ◯ Somewhat improved
- ◯ No difference
- ◯ Somewhat reduced
- ◯ Very much reduced

Depends on other factors - e.g. recent market prices, other fisher competition, seasonal variations, etc.

Questions regarding 'C' grade crabs

31. In this last year, have you sold ‘C’ grade crabs that you wouldn’t have previously?

- ◯ Yes, often
- ◯ No
- ◯ Occasionally - e.g. recent market prices, other fisher competition, seasonal variations, etc.

Additional comments:

Live mud crab grading scheme with skip logic instructions

32. Would you agree that all 'C' grade crabs should be returned to the water by both professional and amateur fishers?

- ◯ Agree extremely
- ◯ Very much agree
- ◯ Somewhat agree
- ◯ Neither agree nor disagree
- ◯ Somewhat disagree
- ◯ Very much disagree
- ◯ Disagree extremely

Additional comments:

Demographics

Tell us a bit about your business to help us to understand your role in the mud crab industry.

33. Which of the following categories best describes your principal business sector?

- ◯ Catcher
- ◯ Distributor *(go to question #39*
- ◯ Transport Operator *(go to question #39)*
- ◯ Wholesaler *(go to question #39)*
- ◯ Retailer *(go to question #39)*
- ◯ Restauranteur *(go to question #39)*
- ◯ Other (please specify)

Catcher Demographics

34. How do you receive feedback from markets on any grade variations or downgrades?
(select as many as apply)

- ☐ Directly
- ☐ Pooled through co-operative
- ☐ No feedback

Additional comments:

Live mud crab grading scheme with skip logic instructions

35. Is mud crab harvesting your major fishing activity?

◯ Full time *(skip next question)*

◯ Part time

Catcher Demographics

36. As a part time mud crab fisher, what percentage of your working time is allocated to:

Enter whole numbers only
Total must add up to 100
Values for at least two categories must be entered
For example:
Mud crab fishing 60
Other fishery 40

Mud crab fishing [ ]

Other fishery [ ]

Other industry [ ]

Catcher Demographics

37. What is the maximum number of licenced pots that you use?

◯ Would prefer not to respond

◯ Number of pots:

[ ]

Live mud crab grading scheme with skip logic instructions

38. Please select the approximate percent of your landed catch per your grade.

Your answers should add up to 100% in each month.
In months when you didn't catch any crab, select 0% for each grade.

	'A' grade	'B' grade	'C' grade
Jan			
Feb			
Mar			
Apr			
May			
Jun			
Jul			
Aug			
Sep			
Oct			
Nov			
Dec			

Demographics

39. How many tonne of crab do you handle in a typical year ?

40. From where are your mud crabs originally harvested?
(select as many as apply)

- ☐ Northern Territory
- ☐ Queensland Gulf of Carpentaria
- ☐ Queensland (east coast)
- ☐ New South Wales
- ☐ Western Australia
- ☐ Don't know

Live mud crab grading scheme with skip logic instructions

41. Where do you sell your mud crabs?
(select as many as apply)

- [ ] Northern Territory
- [ ] Queensland
- [ ] New South Wales
- [ ] Victoria
- [ ] Other (please specify)

42. What is your residential postcode?

43. Do you wish to be added to our mailing list and be provided with on-going information regarding this project?

- ( ) Yes
- ( ) No *(skip next question)*

Demographics

44. Please provide your contact details:

Name

Company

Address

Address 2

City

State

Postal Code

Email Address

Phone Number

Do you have any more comments?

Last page!

Your final chance to provide comments.

We value your input you as it will help drive this project with a current industry focus and ultimately assist your industry.

45. Do you have any other comments, questions, or concerns?

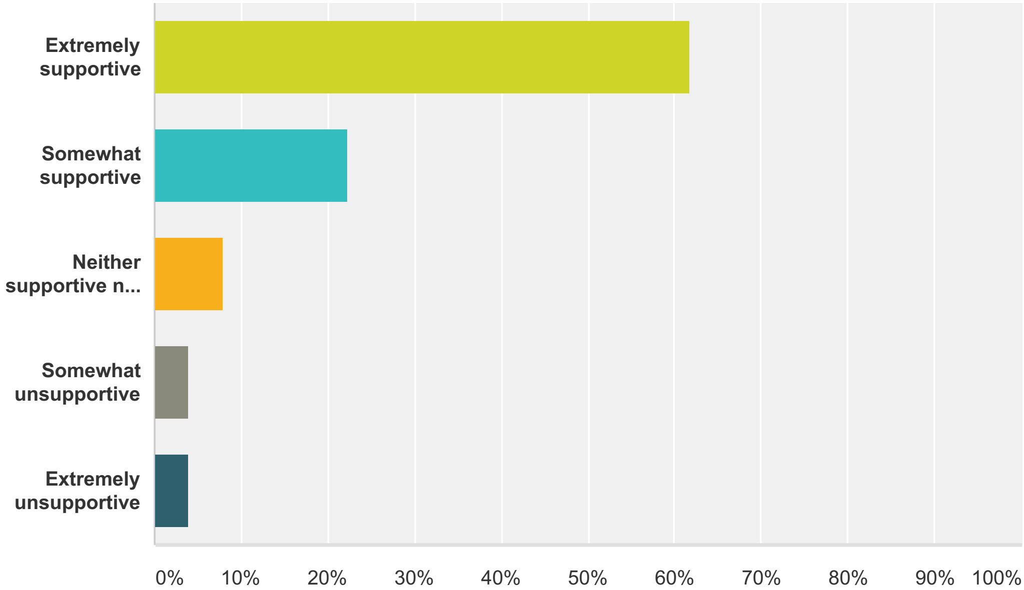
Live mud crab grading scheme with skip logic instructions

Thank you for taking the time to complete this survey.

*Please click "**Done**" to submit your answers.*

Q1 Do you support the concept of having a national live mud crab grading scheme?

Answered: 76 Skipped: 0



Answer Choices	Responses	
Extremely supportive	**61.84%**	47
Somewhat supportive	**22.37%**	17
Neither supportive nor unsupportive	**7.89%**	6
Somewhat unsupportive	**3.95%**	3
Extremely unsupportive	**3.95%**	3
Total		**76**

Q2 What are your concerns about having a national live mud crab grading scheme?

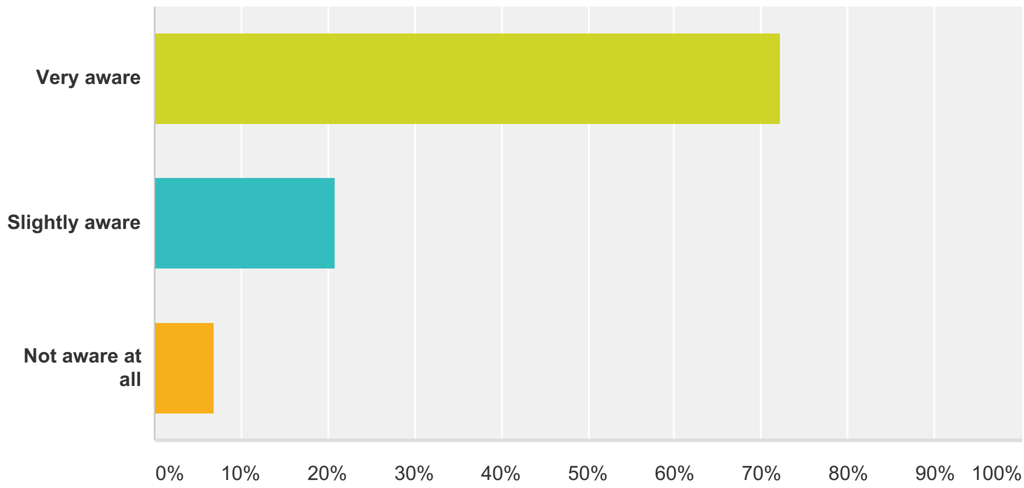
Answered: 4 Skipped: 72

#	Responses	Date
1	Even though it is meant to be a national system everyone does it differently so therefore it does not work	11/5/2014 5:03 PM
2	dont beleive shell hardness is always correct as to the amount of meat !	11/5/2014 9:27 AM
3	the markets are not consistent with their grading	11/4/2014 7:36 PM
4	it has cost our family bussiness over $150,000 so far & this will continue while this scheme	10/29/2014 9:03 PM

Q3 How aware are you of the Australian Industry Live Mud Crab Grading Scheme (Grading Scheme)?

Answered: 72 Skipped: 4

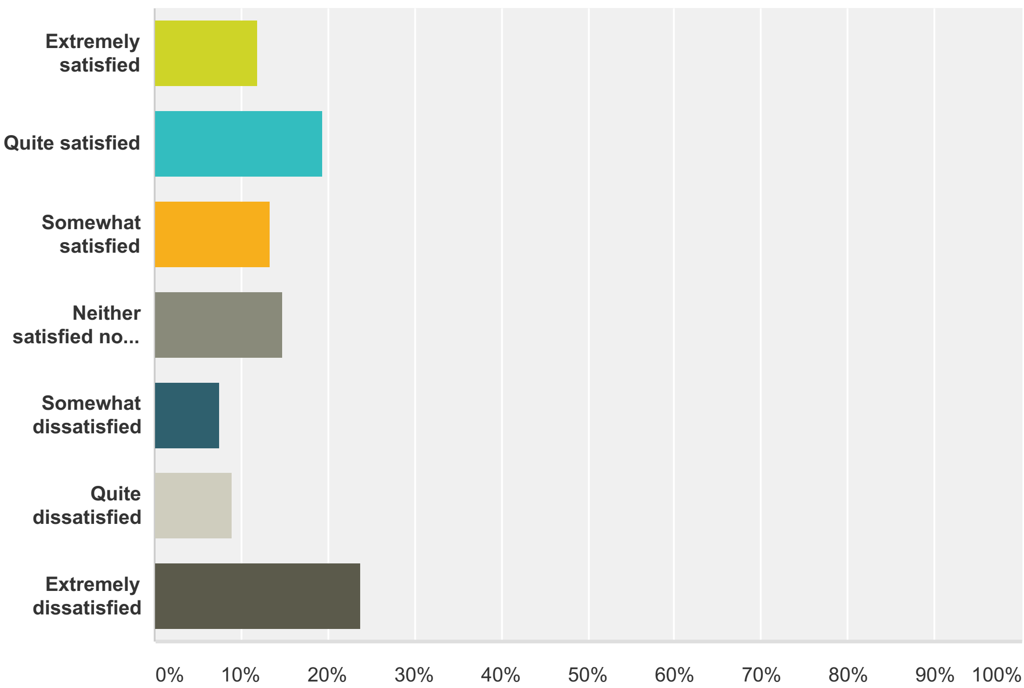
Live mud crab grading scheme



Answer Choices	Responses	
Very aware	**72.22%**	52
Slightly aware	**20.83%**	15
Not aware at all	**6.94%**	5
Total		**72**

Q4 Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied with the Grading Scheme?

Answered: 67 Skipped: 9

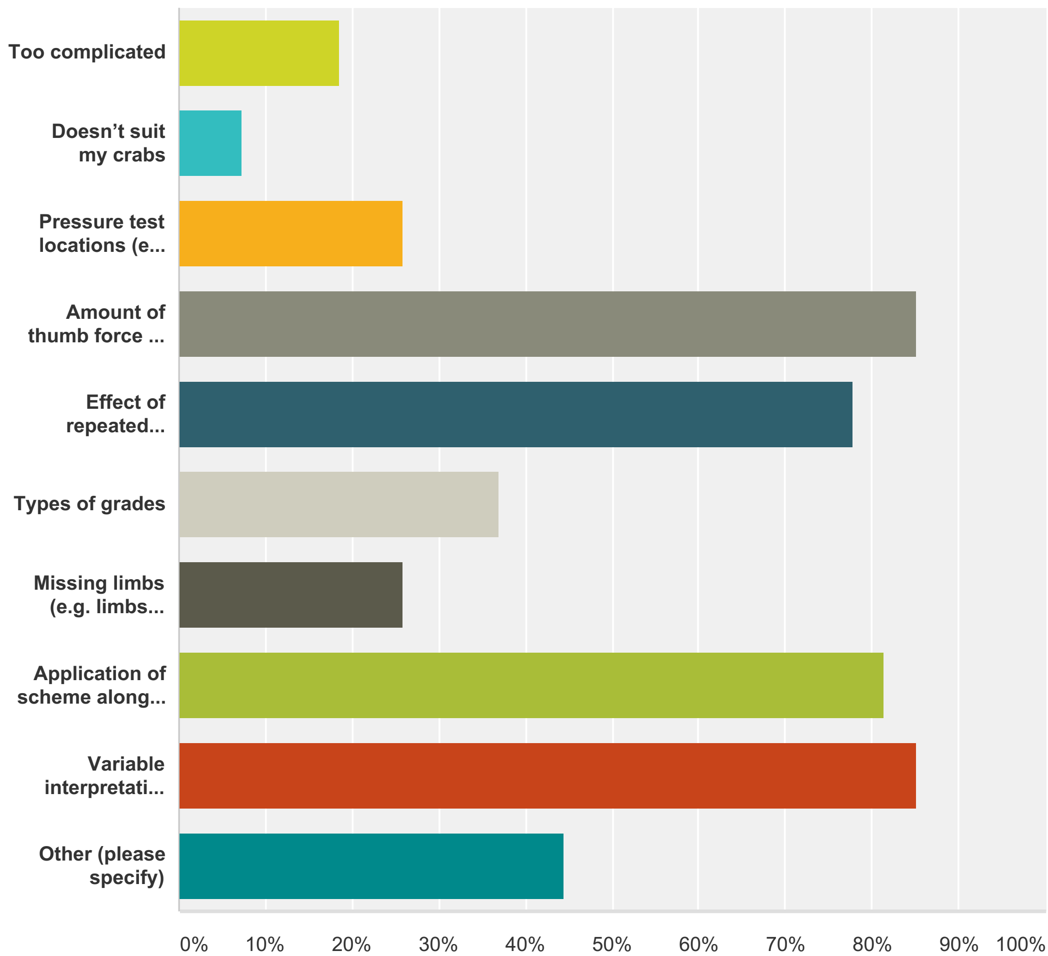


Answer Choices	Responses	
Extremely satisfied	**11.94%**	8
Quite satisfied	**19.40%**	13

Somewhat satisfied	**13.43%**	9
Neither satisfied nor dissatisfied	**14.93%**	10
Somewhat dissatisfied	**7.46%**	5
Quite dissatisfied	**8.96%**	6
Extremely dissatisfied	**23.88%**	16
Total		**67**

Q5 What are your concerns with the grading scheme?(select as many as apply)

Answered: 27 Skipped: 49



Answer Choices	Responses	
Too complicated	**18.52%**	5
Doesn't suit my crabs	**7.41%**	2
Pressure test locations (e.g. top shell of males)	**25.93%**	7
Amount of thumb force to apply	**85.19%**	23
Effect of repeated pressure tests	**77.78%**	21
Types of grades	**37.04%**	10

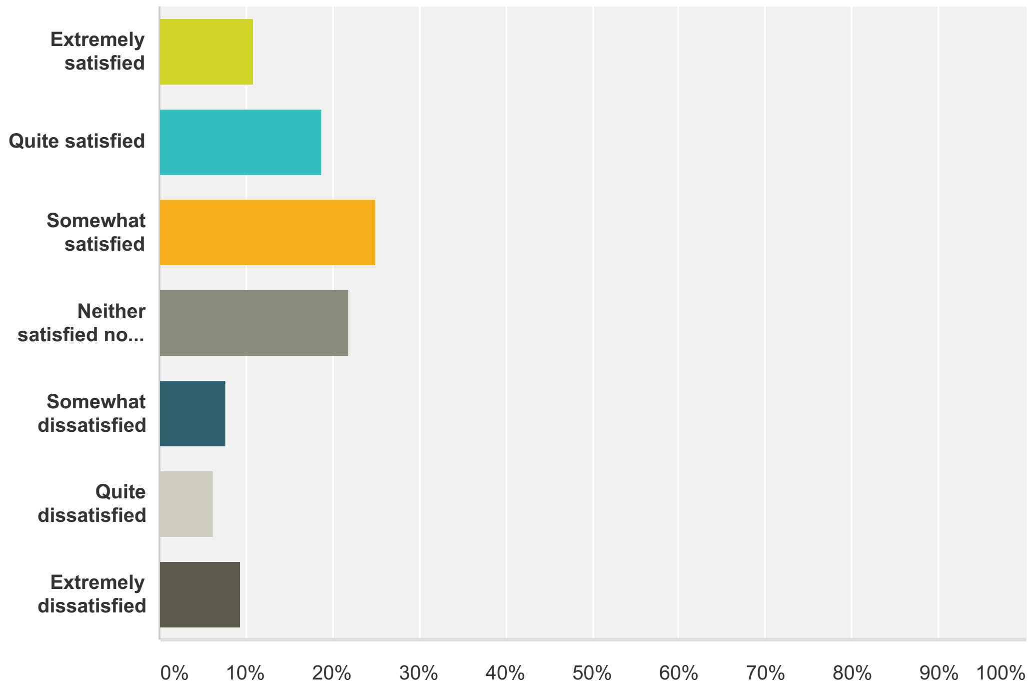
Missing limbs (e.g. limbs dropped in transit)	**25.93%**	7
Application of scheme along the distribution chain (e.g. some buyers manipulating the scheme)	**81.48%**	22
Variable interpretation of what is 'lively'	**85.19%**	23
Other (please specify)	**44.44%**	12
Total Respondents: 27		

#	Other (please specify)	Date
1	too many people pressure testing crabs before sale . this happens a least 4 times before the buyer has his go at testing & then the crab is down graded because of excessive handeling	11/7/2014 12:01 PM
2	C Grade should be banned from taking from the water by recreational and commercial fisherman as they are the future income for commercial fisherman and make it near impossible to make a living if everybody takes them .	11/6/2014 12:38 PM
3	Should be a national scheme	11/6/2014 11:19 AM
4	Variable interpretation of thumb pressure.Every creek has different shell thicknesses and dosen't mean the crab is always a certain grade.	11/5/2014 7:17 PM
5	Top of shell for male is not acceptable. Repetitive pressure testing in the same spot can result in softening. "Lively" in winter is different to summer.	11/5/2014 3:31 PM
6	The taking of any c grade or empty crabs should be made illegal, the only good crab to be fair to the consumer and to protect the integrity of the supplier is a full crab, SFM should be in the forefront to abolish this practice , seeing as how they supposedly pride themselves on enviromental sustainability. SFM grading system is extremely poor and evasive.g	11/5/2014 7:17 AM
7	the concept of taking C grade crabs is the worst decision ever it is extremly hard to even get a marketable crab in my area the Hinchinbrook channel as they are caught before the get a chance to grow out ,This matter is not helped by blaytent disregard for the viability and sustainability of our crab fishery as one family have basically taken over and running far in excess of the recomended allowable 50 pots this is no joke and fishery,s put this in the to hard basket please have something done as i was born and bred here my family settled here approx 1879 and i can no longer make a living	11/4/2014 9:48 PM
8	buyers have control over staff on gradings	11/4/2014 7:38 PM
9	How can a hard crab with no legs missing be downgraded because of worn nipper teeth? Not all crabs with shell damage, even severe,are inedible after cleaning and cooking. Damage MAY be in gill area. At the moment grading is completely inconsistent. Who trains the graders??	10/30/2014 4:16 PM
10	our extremely large size female mud crabs are very rarely fully hard shelled but are full of meat so we are downgraded from A to B decreasing our prices. I think that buyers take advantage of this knowing that the Chinese market prefer females.	10/30/2014 10:48 AM
11	Incredibly poor take-up of the scheme by suppliers and buyers.	10/30/2014 6:13 AM
12	this scheme only aids the buyer as it definately increases (there) bottom line eg the more they pressure test the segments the more it will start to give. the buyers have several ways to down grade a crab which all atracts a 20% reduction in it's price.when we down grade an (a) crab to a (b) grade because it has 3 missing legs or a damaged shell they down grade it again	10/29/2014 9:55 PM

Q6 Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied with the attributes used within the Grading Scheme to differentiate grades?

Answered: 64 Skipped: 12

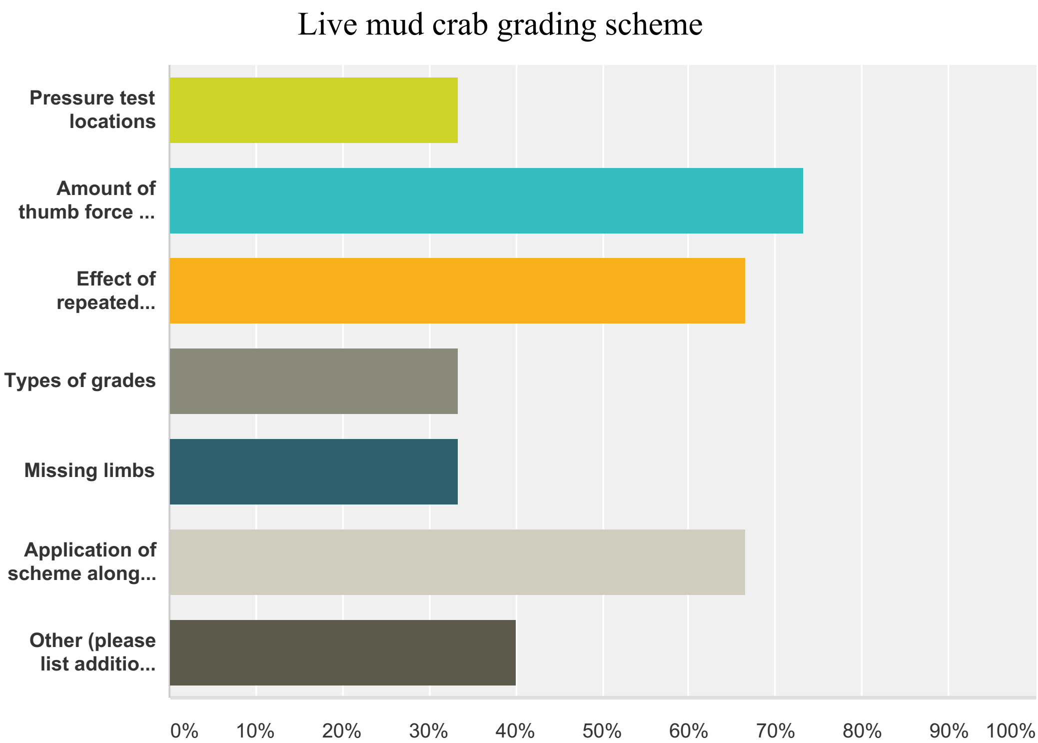
Live mud crab grading scheme



Answer Choices	Responses	
Extremely satisfied	**10.94%**	7
Quite satisfied	**18.75%**	12
Somewhat satisfied	**25.00%**	16
Neither satisfied nor dissatisfied	**21.88%**	14
Somewhat dissatisfied	**7.81%**	5
Quite dissatisfied	**6.25%**	4
Extremely dissatisfied	**9.38%**	6
Total		**64**

Q7 What are your concerns with the attributes used within the Grading Scheme to differentiate grades?(select as many as apply)

Answered: 15 Skipped: 61



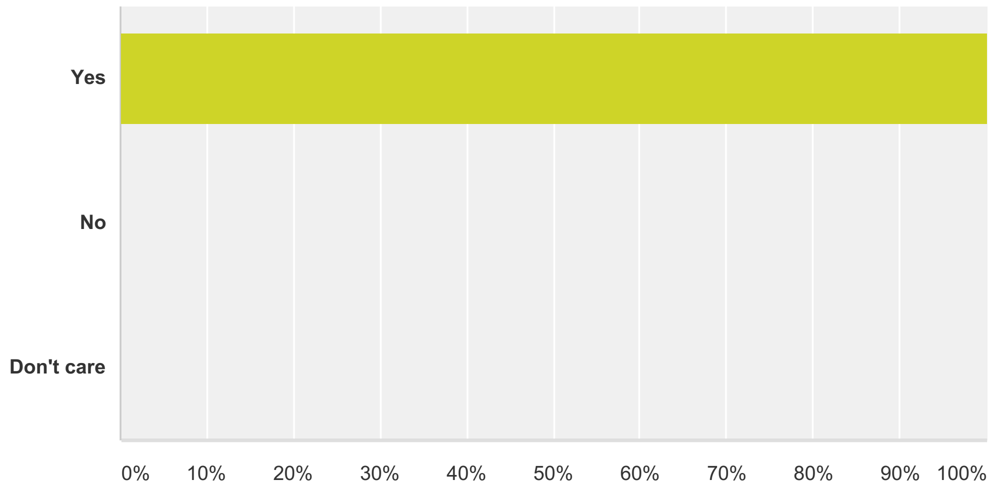
Answer Choices	Responses	
Pressure test locations	**33.33%**	5
Amount of thumb force to apply	**73.33%**	11
Effect of repeated pressure tests	**66.67%**	10
Types of grades	**33.33%**	5
Missing limbs	**33.33%**	5
Application of scheme along the distribution chain	**66.67%**	10
Other (please list additional concerns)	**40.00%**	6
Total Respondents: 15		

#	Other (please list additional concerns)	Date
1	repeated pressure testing too much handeling	11/7/2014 12:04 PM
2	Very happy with the grading scheme except for the C Grade not be illegal to take .	11/6/2014 12:40 PM
3	depends on the person that applies the pressure and once pressed the shell is then softened and can down grade a good crab which is happening in our situation. we have done tests on them and there are about 20% of our product that is getting down graded. there are starting to be alot of dollars lost by this scheme by suppliers down the chain.	11/5/2014 7:30 PM
4	Buyers say they are less grade crabs at market and pay sometimes up to 20 dollars a kg less for them	11/5/2014 5:11 PM
5	buyer manlpulation subjective intereptation	10/30/2014 10:38 PM
6	As described in previous question.	10/30/2014 4:18 PM

Q8 Would you like to see modifications made to the Grading Scheme?

Answered: 15 Skipped: 61

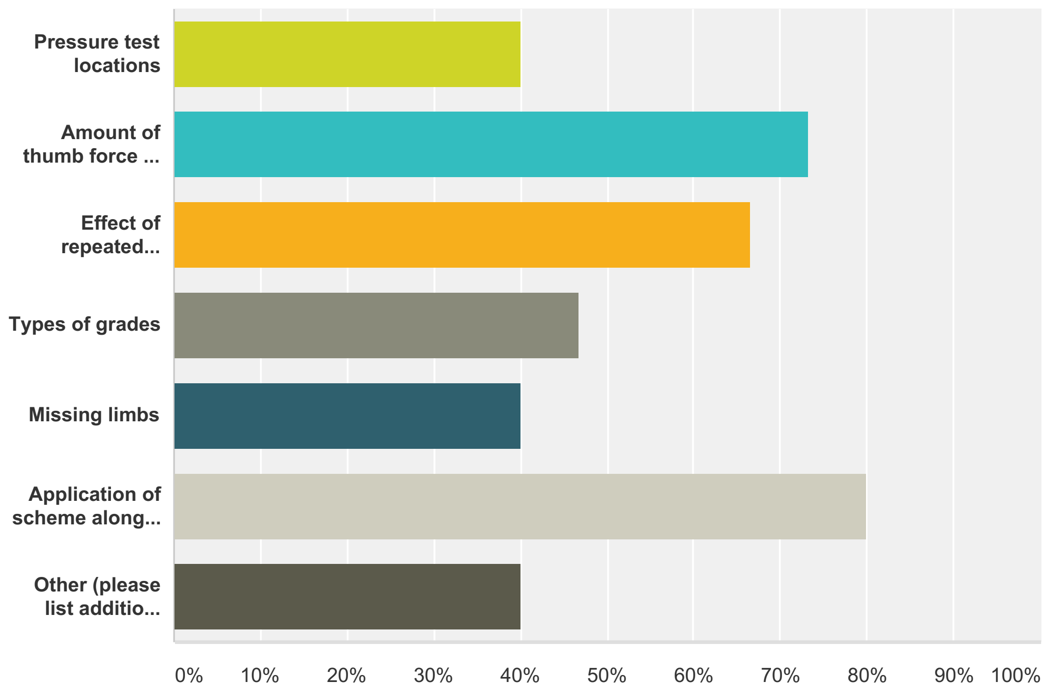
Live mud crab grading scheme



Answer Choices	Responses	
Yes	100.00%	15
No	0.00%	0
Don't care	0.00%	0
Total		**15**

Q9 What modifications do you see necessary?(select as many as apply)

Answered: 15 Skipped: 61



Answer Choices	Responses	
Pressure test locations	40.00%	6
Amount of thumb force to apply	73.33%	11

Effect of repeated pressure tests	**66.67%**	10
Types of grades	**46.67%**	7
Missing limbs	**40.00%**	6
Application of scheme along the distribution chain	**80.00%**	12
Other (please list additional modifications)	**40.00%**	6
Total Respondents: 15		

#	Other (please list additional modifications)	Date
1	Please Ban C Grade it is destroying the mudcrab industry.	11/6/2014 12:41 PM
2	In the grading system it should be made compulsory that the buyer when reselling the crabs must advertise the grade as this would stop alot of the downgrade in the market for no reason as most of the time they apply far to much pressure so they get them at a cheaper rate when they get downgraded	11/5/2014 5:16 PM
3	I wood like to see more scientific means to test the grade of the crabs	11/5/2014 3:51 PM
4	Stop the taking of soft shell crab	11/4/2014 9:00 PM
5	not let the buyers control what grade they think the crab is and then get it knocked down to a lower price	11/4/2014 7:43 PM
6	down grading crabs purely because of colour	10/29/2014 9:57 PM

Q10 Before the scheme’s implementation, briefly describe what your grading practices were. For example: What grades did you use? How did you determine grades?

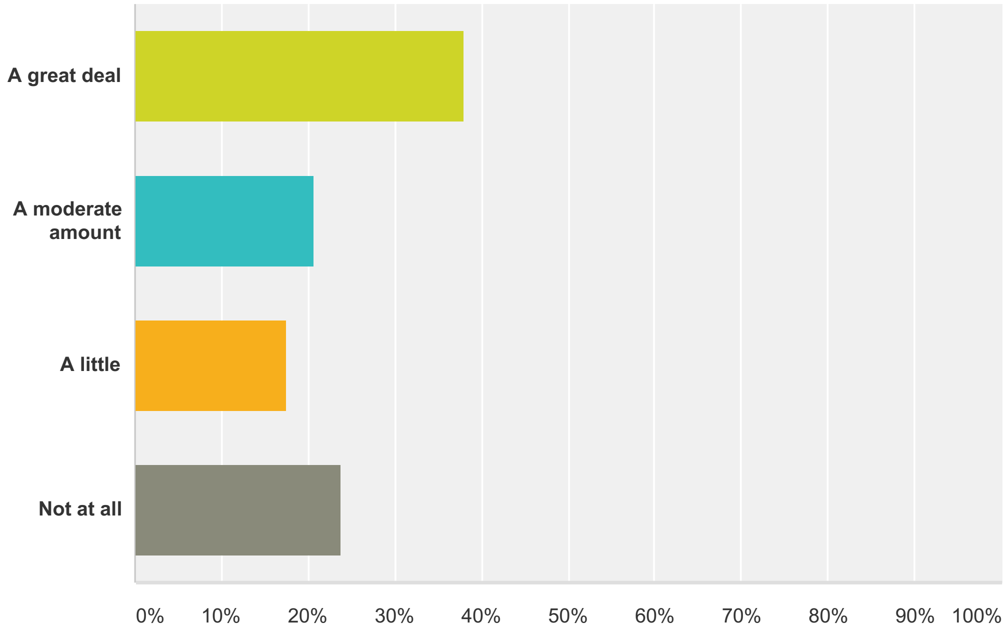
Answered: 15 Skipped: 61

#	Responses	Date
1	sent a dvd on how grade crabs. stuck to the way the dvd showed & then the gradeing became worse when sent to market	11/7/2014 12:07 PM
2	A Grade - Hard shell alround when pressed as hard as possible B Grade- Hard shell on top with good colour and small movement in the middle carapace underneath when pressed as hard as possible .	11/6/2014 12:43 PM
3	Same as it is now. A, B and no C grade	11/6/2014 11:22 AM
4	the same locations for pressure test but no c grades where taken	11/5/2014 7:32 PM
5	B grade	11/5/2014 5:28 PM
6	No grade and told customers if shell was not firm shorten the cook time	11/5/2014 5:18 PM
7	if you could press the second segment down underneath the crab and it didn't move it was an a grade if it moved it was a b grade that was the only two grade there was	11/5/2014 3:56 PM
8	By pressure test under carapice behind the claw and the segment test ,also pincer condition as to if the crab has been feeding,color and weight	11/5/2014 7:22 AM
9	A grade only and A/OL A grade was a complete crab with all legs and claws no shell damage and A/OL was wingies	11/4/2014 9:02 PM
10	a grade male look for no movement in middle rib when pressing with thumb	11/4/2014 7:45 PM
11	crabs was a grade be for 2012 now is don a grade	11/4/2014 6:23 PM
12	weight	10/30/2014 10:39 PM
13	A grade crab was a full crab. Could have missing legs. B grade crab was a soft crab.	10/30/2014 4:21 PM
14	A/ firm on one side & may have slight give on the other side B/ will give on both sides all crab must have no more than 2 legs & 1 flipper missing B grade to be 70% +	10/29/2014 10:03 PM

15	Claw where and pressure test under. Ribs on bottom of crab	10/29/2014 9:52 PM

Q11 Have your grading practices changed since the scheme was implemented in 2012?

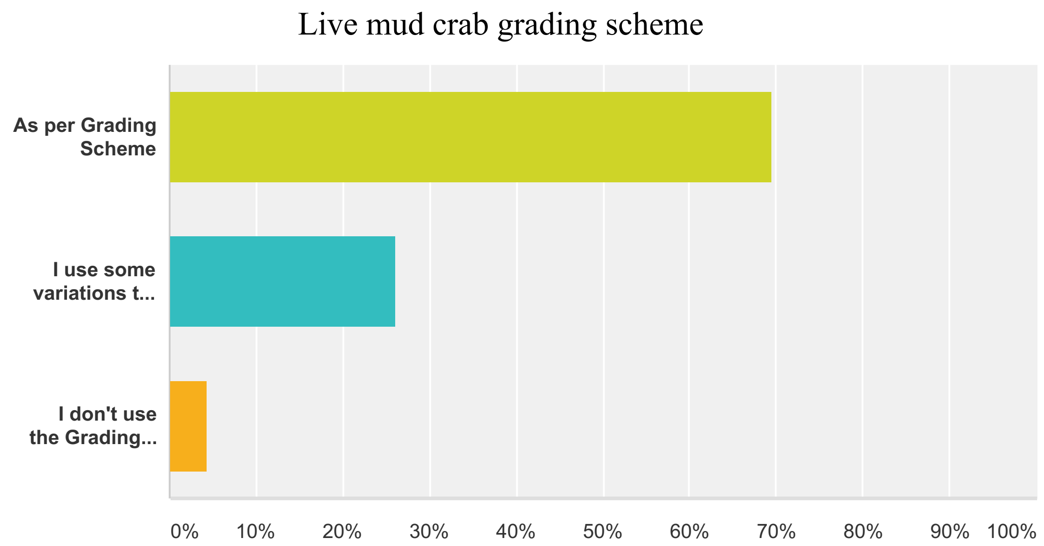
Answered: 63 Skipped: 13



Answer Choices	Responses	
A great deal	38.10%	24
A moderate amount	20.63%	13
A little	17.46%	11
Not at all	23.81%	15
Total		63

Q12 After the scheme's implementation, how did your grading practices change?

Answered: 46 Skipped: 30



Answer Choices	Responses	
As per Grading Scheme	**69.57%**	32
I use some variations to the Grading Scheme	**26.09%**	12
I don't use the Grading Scheme at all	**4.35%**	2
Total		**46**

Q13 Describe how you grade crabs different to the scheme.

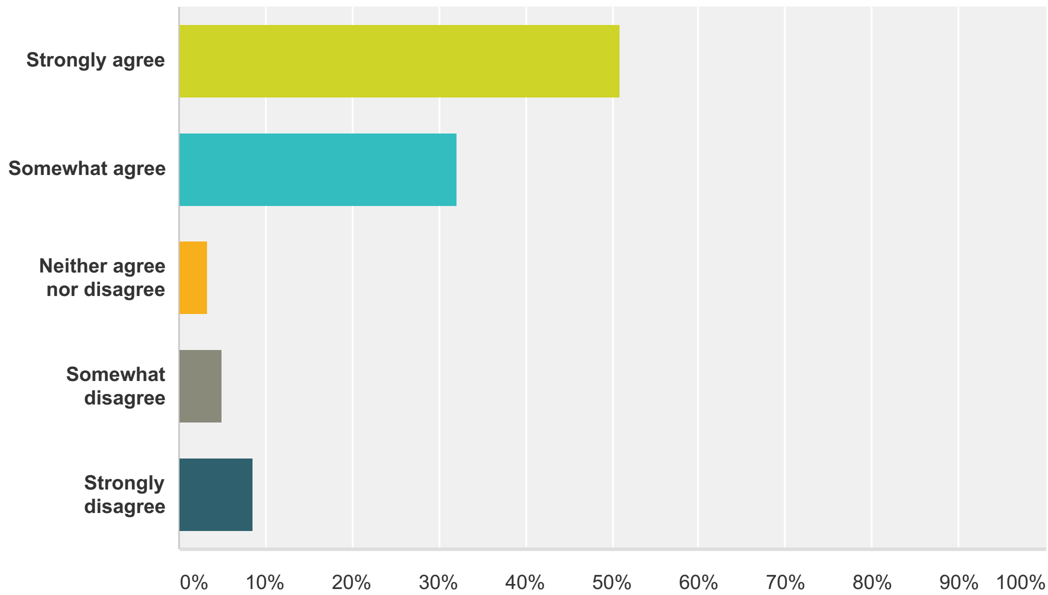
Answered: 27 Skipped: 49

#	Responses	Date
1	We are ahead of the grading system. We have done the practices for 5 years now	11/10/2014 3:16 PM
2	place males & females into different boxes. when the crab was graded A B C most of them were down graded on arriving at market	11/7/2014 12:10 PM
3	C GRADE CRAB WE DONOT BRING IN ANYMORE	11/7/2014 10:17 AM
4	downgrade a too b	11/7/2014 6:37 AM
5	There is no financial benefit in grading crabs	11/6/2014 4:28 PM
6	Grade the same . i have to take CGrade now because everyone else takes them and i cannot survive if i dont . Income has halved	11/6/2014 12:44 PM
7	Properly!	11/6/2014 11:22 AM
8	I dont	11/6/2014 9:23 AM
9	.	11/6/2014 7:21 AM
10	colour of crab and nippers and then the pressure test	11/5/2014 7:34 PM
11	The heaviness of crab	11/5/2014 5:29 PM
12	Male crabs only get graded underneath if i cannot flex any of the segments underneath i class as a grade if i can only flex the 3rd segment up b grade and more than 1 c grade female only top and small amount of pressure no movement a movement only 1 side of shell b and both sides of shell c	11/5/2014 5:25 PM
13	similar to the scheme	11/5/2014 4:08 PM
14	We have watched DVD and read book. We have never pushed on the backs of bucks only underneath.	11/5/2014 3:31 PM
15	There are to many interpretations of what denotes a good or bad crab and too many uneducated persons implementing the scheme,	11/5/2014 7:24 AM

16	i grade my A/G crabs only based on body weight for size i dont take C/GRADE and only take a B/GRADE thats on the verge of an A/G quality crab [Please bann the taking of C grade crabs Sydney fish market has got to stop the practice	11/5/2014 6:16 AM
17	No real different only take A grade crab	11/4/2014 9:03 PM
18	Large,med,small Female, male, and C grade and o/l crabs the more I grade crabs say A grade B grade C grade the worst the prices are especially after they get graded at the markets, Been crabing for 30yrs and know what a A grade crab is meant to be but some how they are different crabs 18hrs after being caught,graded and sold at SFM so now I grade as stated above and still they resell crabs saying they arent A grade I don't send A grade they are sent as male or female ? Only,	11/4/2014 8:44 PM
19	N/A	11/4/2014 7:06 PM
20	n/a	11/4/2014 6:27 PM
21	My grading is done the same and the end result is that only A grade crab is forwarded to wholesalers.	11/4/2014 5:41 PM
22	N/A	11/1/2014 10:37 PM
23	I can't be too hard grading or else suppliers hesitant to send crab . They prefer customers whom not too fussy.	11/1/2014 10:26 PM
24	have always had a high standard	10/31/2014 10:30 AM
25	as per scheme	10/31/2014 9:36 AM
26	I do not. But if I have only three crabs with more than two legs missing, I cannot put them in a separate box. So they are included with the others. Boxes cost $9.00 to buy and get to me here	10/30/2014 4:24 PM
27	NT crab is more strictly graded - on the male if you can push a segment in on both sides then it would be illegal and rejected ie C grade	10/29/2014 5:17 PM

Q14 Do you think that any inconsistencies in the way crabs are graded could be addressed by educating graders on the standard grading techniques?

Answered: 59 Skipped: 17



Answer Choices	Responses	
Strongly agree	**50.85%**	30
Somewhat agree	**32.20%**	19
Neither agree nor disagree	**3.39%**	2

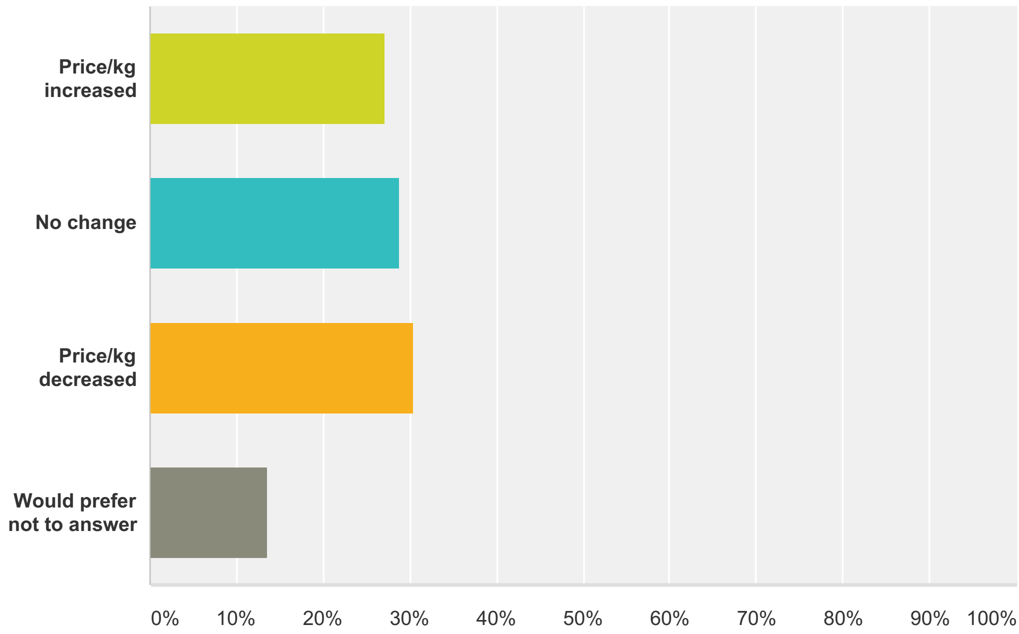
Somewhat disagree	**5.08%**	3
Strongly disagree	**8.47%**	5
Total		**59**

#	Additional comments:	Date
1	I think some fisherman might have "soft pressing"	11/10/2014 3:17 PM
2	nil	11/7/2014 6:39 AM
3	Using the current grading system it is all dependent on the pressure used in the grading. I don't see that there will ever be consistency in grading of mud crabs as individuals will always apply different pressure. In staying this however i don't know of any other method that would work any better.	11/6/2014 6:20 PM
4	graders need to be shown by experienced people with a knownledge of mud crabs	11/5/2014 7:39 PM
5	Crabs seem to be severly downgraded when there is more crab on the floor and when there is not alot of crab being caught they magicly all are the grade they were sent as	11/5/2014 5:29 PM
6	Are you referring to the fisherman or the Sydney Fish Market employee? Their grading varies enormously between shipments with no apparent consistency. Our grading has remained unchanged for over 20 years and we have no issues with private buyer sales who do not downgrade our crab like SFM does.	11/5/2014 3:31 PM
7	i beleive the graders at the markets presure test to hard!	11/5/2014 9:33 AM
8	First you have to have a national scheme that is standardized through out the whole industry, and not a scheme open to the interpretation of a few uneducated or greedy persons or markets.	11/5/2014 7:28 AM
9	If people are willing to listen and modify their practices.	11/5/2014 6:55 AM
10	Should only be one grade of crab and this is A grade and A/OL	11/4/2014 9:04 PM
11	The soft shell when it's pushed is a guide to the crabs condition and isn't the only way a crab should be graded	11/4/2014 8:47 PM
12	Grading scheme seems to be suiting the buyer at the present instead of helpIng the industry eg c grade crab should be illegal in qld!!!!	11/4/2014 8:12 PM
13	buyers in sydney markets have final say	11/4/2014 7:47 PM
14	If graders at wholesalers adhered to the guidelines there would be no C grade crab accepted for sale. Educating graders (commercial fishers) is a waste of time if buyers will purchase anything.	11/4/2014 5:49 PM
15	Concentration and honesty are a big problem. Some supplier lose concentration and grading is everywhere Others whom don't grade properly I just don't reorder.	11/1/2014 10:58 PM
16	Its your business name and reputation which is affected by how you grade your product	11/1/2014 10:40 PM
17	If there are many crab on the market, the grading is harder. The less crab, the grading is less harsh.	10/30/2014 4:29 PM
18	I think that buyers manipulate the market and that SFM should not source so much crab from QLD and the NT which affects our sales and prices	10/30/2014 10:55 AM
19	We found that it was not consistent, so yes it would make a huge impact for us	10/30/2014 4:37 AM
20	A grade unrealistic. most B grade are now the old A grade, everything else is C grade. buyers are now buying B grade & now selling it on as A grade at the supplers expence	10/29/2014 10:17 PM
21	Each person will have a different interpretation that is the problem. I have been to syd fish markets a witnessed how the Byers influence the QA people this needs to be addressed if the problem is to be sorted	10/29/2014 9:58 PM
22	most of the Asian restaurants still not familiar with the grading scheme - I have shown a number of customers and they thank me	10/29/2014 5:26 PM

Q15 Have you experienced a change in price/kg for mud crab sales that you directly attribute to the introduction of the Grading Scheme?

Answered: 59 Skipped: 17

Live mud crab grading scheme



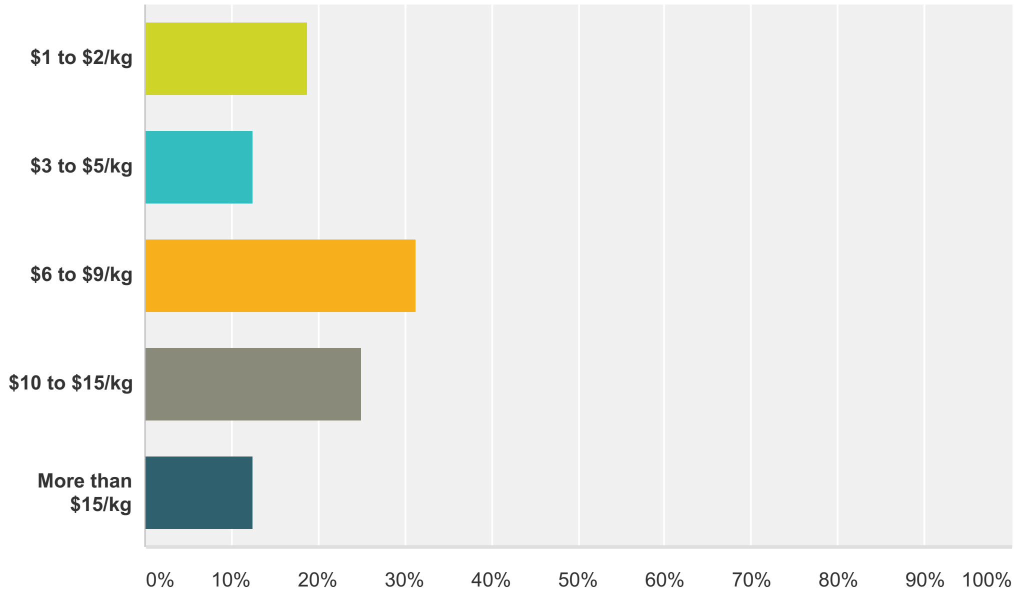
Answer Choices	Responses	
Price/kg increased	**27.12%**	16
No change	**28.81%**	17
Price/kg decreased	**30.51%**	18
Would prefer not to answer	**13.56%**	8
Total		**59**

#	Additional comments:	Date
1	SFM look after the buyers the fishermen are not represented	11/8/2014 9:52 AM
2	depends on the ammount of boxes for sale on the day	11/7/2014 12:12 PM
3	Some that we classed as A grade are now classed as B grade and some B grade now C grade.	11/6/2014 6:20 PM
4	C Grade crabs are glutting the market and bringing the prices of a grade down	11/6/2014 12:45 PM
5	a decrease because of the sale of c grades they are simply not worth taken and in 2/3 weeks they are a grades	11/5/2014 7:39 PM
6	Price isn't changed, but get trust from customers, and sold more mud crabs.	11/5/2014 4:11 PM
7	most of my crabs meet the a grade when I test the protein in the blood but I can move the shell when I press it with my thumb so I get a down graded price because the blood test isn't in the grading scheme	11/5/2014 4:07 PM
8	avg price A B C grade = ungraded price	11/5/2014 8:17 AM
9	More of a volume effect after accepting C grades for sale.	11/5/2014 6:55 AM
10	there is no change the price is determined by the Sydney Fish Market buyers its all about volume of supply, at the moment they are paying $40 plus dollars per kg for C grade mud crabs i wont take them on principal even though i should as i cant make a living at moment BANN THE TAKING OF C GRADE AND POOR QUALITY B GRADE AND INVESTIGATE THE CRABBING PRACTICES OF MISSIONARY BAY AND THE HINCHINBROOB CHANNEL	11/5/2014 6:23 AM
11	When the grading system was adhered to my price per kg increased. when the grading system was thrown out the door by SFM my price reduced as a supplier of A grade crab only.	11/4/2014 5:49 PM
12	Not sure where the there's not much crab available or just less bad crab on the market . But prices have been on a very high average for a few years now .	11/1/2014 10:58 PM
13	The end user now expects a perfect looking crab when it is after all a wild creature and often has one of mother nature's imperfections. Is this the work of the multinationals again??	10/30/2014 4:29 PM

14	prices never increased. buyers complain and manipulate prices by requesting that crabs get graded down for reasons that are unreasonable.	10/30/2014 10:55 AM
15	our overall price per kg hasn't increased.due to the new scheme we now only send app 1/3 of our crab to the sfm	10/29/2014 10:17 PM
16	The buyers are using the grading program to get cheaper prices	10/29/2014 9:58 PM
17	restaurants are more conscious of quality and are not as inclined to buy from' part-timers'	10/29/2014 5:26 PM

Q16 How much did it increase?

Answered: 16 Skipped: 60



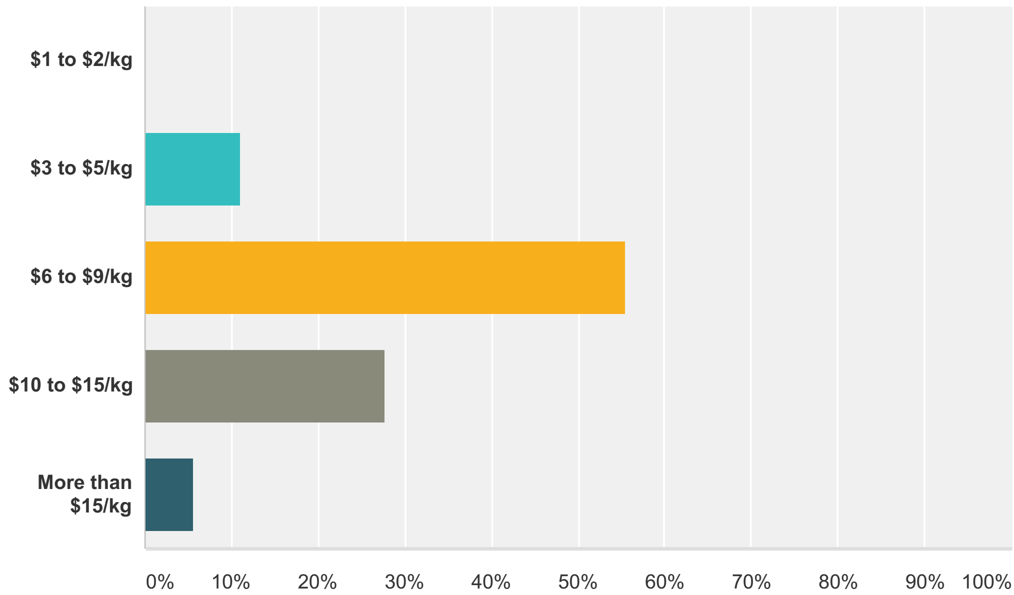
Answer Choices	Responses	
$1 to $2/kg	**18.75%**	3
$3 to $5/kg	**12.50%**	2
$6 to $9/kg	**31.25%**	5
$10 to $15/kg	**25.00%**	4
More than $15/kg	**12.50%**	2
Total		**16**

#	Additional comments:	Date
1	and at times more than 15 . i think the price is still slightly increasing as time goes on due to the grading scheme	11/7/2014 6:54 PM
2	Not as much as the fees to catch did	11/4/2014 8:48 PM
3	This only occured when grading system was followed.	11/4/2014 5:49 PM
4	Although $1 to $2 was nominated, the actual price range varies depending on the grade of crab	10/30/2014 9:50 AM
5	already gettig a fair premium before becaues of Darwin's grading	10/29/2014 5:27 PM

Q17 How much did it decrease?

Answered: 18 Skipped: 58

Live mud crab grading scheme



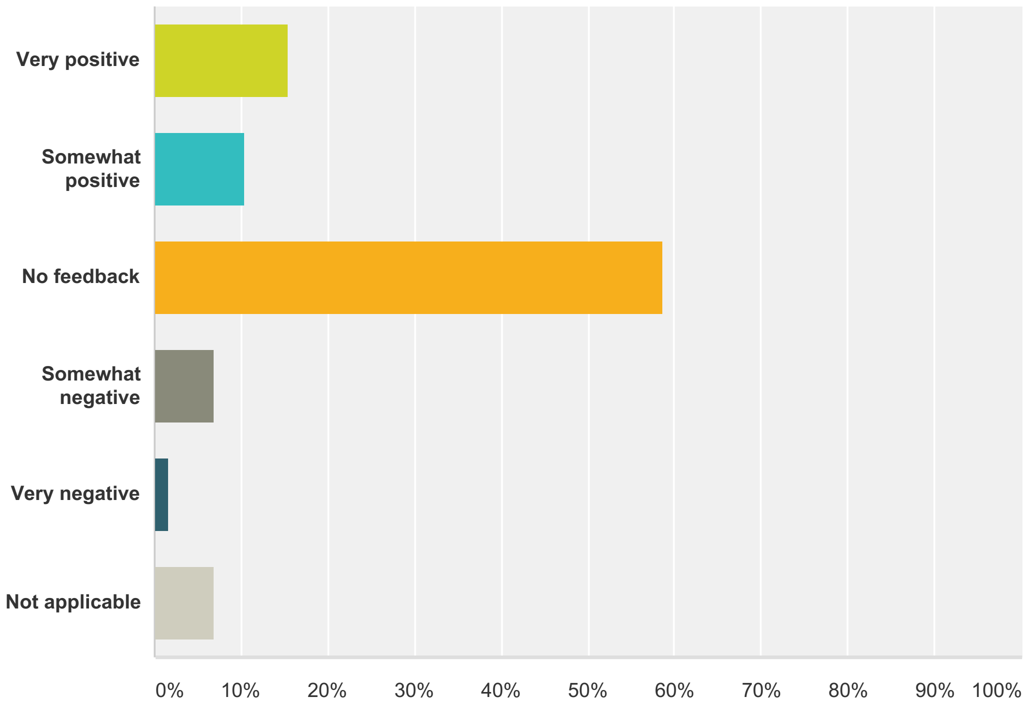
Answer Choices	Responses	
$1 to $2/kg	**0.00%**	0
$3 to $5/kg	**11.11%**	2
$6 to $9/kg	**55.56%**	10
$10 to $15/kg	**27.78%**	5
More than $15/kg	**5.56%**	1
Total		**18**

#	Additional comments:	Date
1	Crabs that I would've thought to be A grade, were downgraded to B Grade	11/5/2014 7:40 PM
2	depents on the buyer on the day	11/5/2014 4:08 PM
3	Needed to be a percentage choice because prices vary so much during year. Estimate 25%	11/5/2014 3:31 PM
4	this is estimate on what i am losing after my grades are changed	11/4/2014 7:49 PM
5	This is an unanswerable question	10/30/2014 4:30 PM
6	prices remain stable at the beginning of the season but decrease significantly once there is more product in the market. NSW product should be sold first at good prices before SFM sources seafood from other states that causes decreases in our prices.	10/30/2014 10:59 AM

Q18 Have you received any customer feedback about the quality or consistency of crab grades since the introduction of the grading scheme?

Answered: 58 Skipped: 18

Live mud crab grading scheme

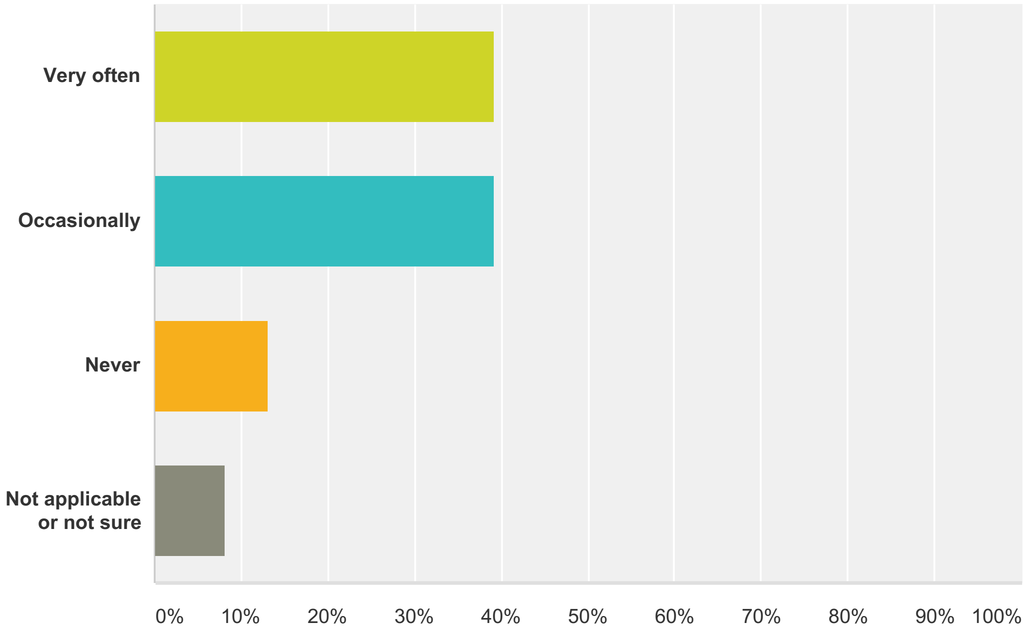


Answer Choices	Responses	
Very positive	**15.52%**	9
Somewhat positive	**10.34%**	6
No feedback	**58.62%**	34
Somewhat negative	**6.90%**	4
Very negative	**1.72%**	1
Not applicable	**6.90%**	4
Total		**58**

Q19 Have you experienced seasonal anomalies where crab shells do not become fully hard, yet the crabs appear full?

Answered: 61 Skipped: 15

Live mud crab grading scheme

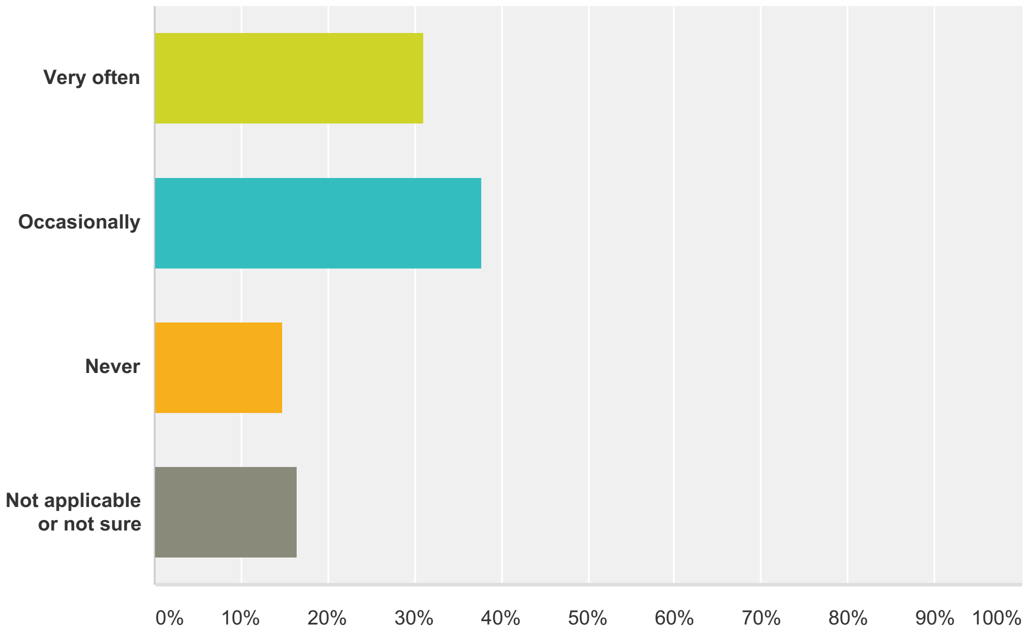


Answer Choices	Responses	
Very often	**39.34%**	24
Occasionally	**39.34%**	24
Never	**13.11%**	8
Not applicable or not sure	**8.20%**	5
Total		**61**

#	Additional comments (e.g. time of year, rainfall related etc.)	Date
1	It seems to be a water salinity problem	11/10/2014 3:19 PM
2	nov to feb	11/7/2014 6:58 PM
3	crabs that you can just press in on the lefthand underside with crab on its back with the right-side not being able to press in are just as full as a crab that has no movement either side. This is where we have lost a great deal of money.	11/6/2014 6:30 PM
4	In the cooler months of the year they are genarally harder as they are last seasons crabs that have not buried and had plenty of time to harden since reshelling	11/5/2014 5:34 PM
5	but sometimes the other way around, hard shell but empty.	11/5/2014 4:20 PM
6	ive eaten these crabs myself and found the softer the crab the less cooking time is required then found to be very consumable contrary to SFM opinion	11/5/2014 9:40 AM
7	As you know my QA staff see this often.	11/5/2014 6:56 AM
8	YES appear full due to weight only and thats only water def a poor B/G OR A C/G	11/5/2014 6:32 AM
9	The soft shell crab is mainly around during and after the wet season.	11/4/2014 9:09 PM
10	Time of year,dry periods especially with hot water and shallow water.	11/4/2014 8:52 PM
11	This is completely normal at different times of year	11/4/2014 8:14 PM
12	Season has nothing to do with it. Either a crab is hard or soft!!!	10/30/2014 4:34 PM
13	over the last two years when there has been a lot of fresh water in the lakes.	10/30/2014 11:04 AM
14	I have cooked this crab many times it is perfect new shell full crab the buyers are simply manipulating the system to get cheap crab who regulates the buyers when they on sell it jan to April gulf of carpentaria	10/29/2014 10:07 PM
15	sometimes B grade females have turned out to be full	10/29/2014 5:35 PM

Q20 Have you experienced regional anomalies where crab shells do not become fully hard, yet the crabs appear full?

Answered: 61 Skipped: 15



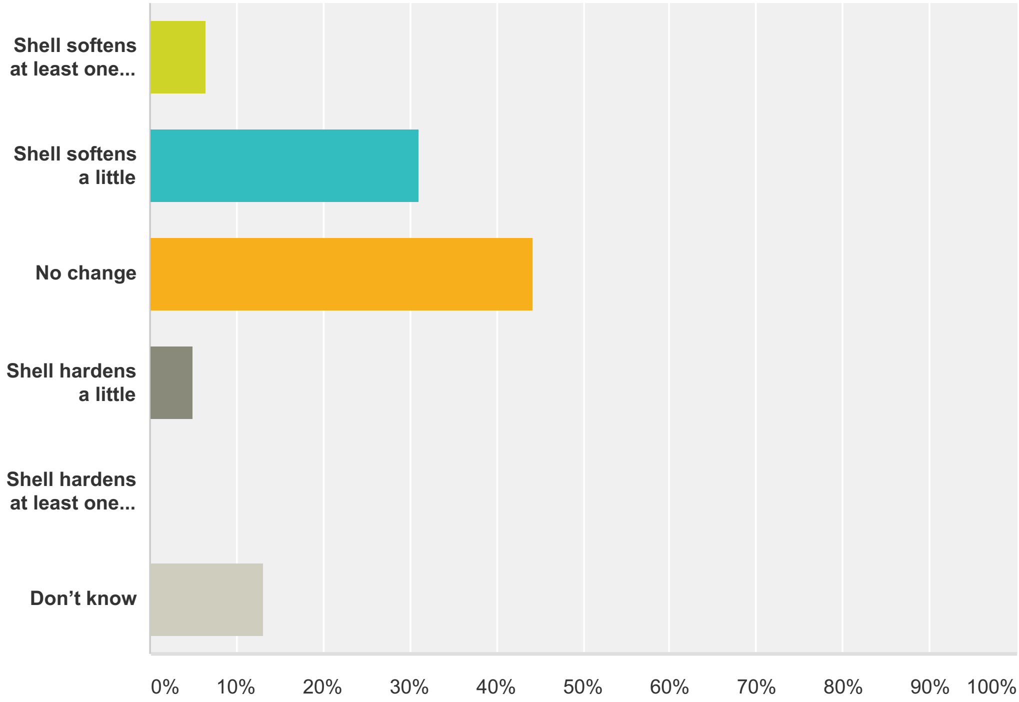
Answer Choices	Responses	
Very often	**31.15%**	19
Occasionally	**37.70%**	23
Never	**14.75%**	9
Not applicable or not sure	**16.39%**	10
Total		**61**

#	Additional comments (e.g. list locations or regions)	Date
1	only talking about our region which is Moreton Bay	11/10/2014 3:19 PM
2	clarence river	11/7/2014 6:58 PM
3	Region 2	11/6/2014 8:33 PM
4	as above	11/6/2014 6:30 PM
5	I do not move from area to area	11/5/2014 4:21 PM
6	AS ABOVE	11/5/2014 6:32 AM
7	I fish in 2 arms of the river when 1 side is soft the other has good crabs	11/4/2014 8:36 PM
8	female crabs in Wallis Lake seem to have softer shells but are always full of meat	10/30/2014 11:04 AM
9	Gulf of carpentaria	10/29/2014 10:07 PM
10	cannot recall this happening	10/29/2014 5:35 PM

Q21 Do you believe that a crab’s shell hardness changes from point of capture to market?

Live mud crab grading scheme

Answered: 61   Skipped: 15



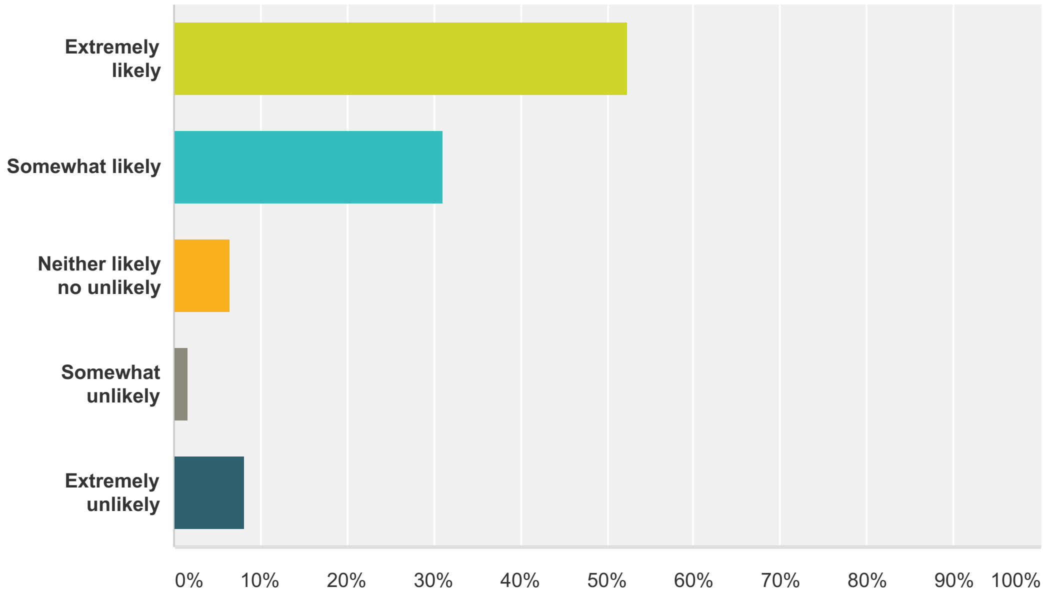
Answer Choices	Responses	
Shell softens at least one grade	**6.56%**	4
Shell softens a little	**31.15%**	19
No change	**44.26%**	27
Shell hardens a little	**4.92%**	3
Shell hardens at least one grade	**0.00%**	0
Don't know	**13.11%**	8
Total		**61**

#	Additional comments (e.g. at particular times of the year the shell hardness changes)	Date
1	this is when kept in tubes with hession	11/7/2014 6:58 PM
2	if the shell strays moist the shell dosen't change	11/7/2014 12:17 PM
3	Shell softens due to being pressed on so many times	11/5/2014 5:34 PM
4	due to continually presure testing	11/5/2014 9:40 AM
5	NO CHANGE	11/5/2014 6:32 AM
6	More pushing softens the shell	11/4/2014 8:36 PM
7	All depends on how long crabs are held and how they are handled	11/4/2014 8:14 PM
8	WHEN THE BUYERS CONSISTANTLY SQUEEZE THE SEGMENTS	10/29/2014 10:24 PM
9	hard to say from the wholesaler's point of view would have to follow crab from beginning to end of chain	10/29/2014 5:35 PM

Q22 If a tool or device that grades crabs objectively for you were available today, how likely would you be to use it?By

'objectively' we mean that the grade can't be disputed. The grade could be determined by either a measure of shell hardness or meat content.

Answered: 61 Skipped: 15



Answer Choices	Responses	
Extremely likely	**52.46%**	32
Somewhat likely	**31.15%**	19
Neither likely no unlikely	**6.56%**	4
Somewhat unlikely	**1.64%**	1
Extremely unlikely	**8.20%**	5
Total		**61**

#	Additional comments:	Date
1	It woutld be better for the whole industry as grading would then be consistent	11/10/2014 3:19 PM
2	dedepending on how easy it is to implement into every day work e.g. time involved, practicality, cost ext	11/7/2014 6:58 PM
3	a weight system would be better than pressure testing as pressure testing breaks the membrane in the shell	11/7/2014 12:17 PM
4	it would be very much dependant on how user friendly it was and how time consuming it was.	11/6/2014 6:30 PM
5	I think the crab should only be graded on meat content not on how hard the shell is	11/5/2014 4:21 PM
6	The tool would have to be easy to use and give a foolproof and consistent result accepted by all in the industry	11/5/2014 7:32 AM
7	depending on the cost but i take pride in grading my crabs and when a good crab comes on my boat i can tell as soon as i pick it up it must have at least some colour on the underside as well as being hard but the weight tells it all not all rusty crabs are necesseraly full	11/5/2014 6:32 AM
8	The taking of the soft shell crab is killing the mud crab industry as it makes other crabbers take the soft crab you throw it back and they come behind and pick it up.	11/4/2014 9:09 PM
9	I know when a crab is hard or soft. After 40 years experience, it is not rocket science.	10/30/2014 4:34 PM
10	I would be happier if meat content was used to judge the quality of crabs rather than shell hardness.	10/30/2014 11:04 AM

11	IF THE GRADING TOOL WAS NOT INVASIVE TO THE CRAB I WOULD MOST LIKELY USE IT. WHEN KEEPING LIVE PRODUCT ANYTHING INVASIVE TO THE CRAB (NEEDLE ETC) IS GOING TO INCREASE THE CHANCE DEATH 3 FOLD CRABS BLEED VERY EASILY.	10/30/2014 10:57 AM
12	As long as it is practical for fisher to use in the boat directly and not damage the crab taking blood samples of each crab is simply not a option	10/29/2014 10:07 PM
13	note - when I receive the crabs they have already been graded	10/29/2014 5:35 PM

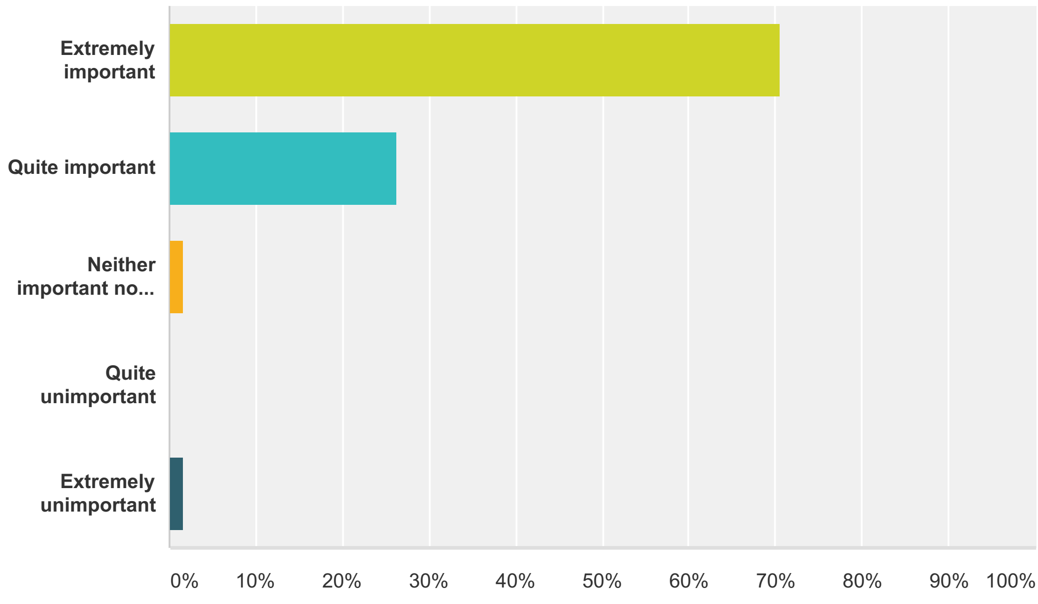
Q23 Why wouldn’t you use a tool or device to help you grade crabs?

Answered: 6 Skipped: 70

#	Responses	Date
1	It is all about the feel and common sense	11/6/2014 11:25 AM
2	I use my brain better than any crap you could ever make	11/6/2014 7:24 AM
3	I would takes all the guess work out of the industry as there would be a standard.	11/4/2014 9:10 PM
4	Because there is no such thing and I cannot see one being invented in the next 10 years	10/30/2014 4:35 PM
5	Time from recieval to sale	10/30/2014 9:42 AM
6	because a device can't feel, look & dudge the weight	10/29/2014 10:26 PM

Q24 How important to you is the meat fullness of your mud crab?

Answered: 61 Skipped: 15

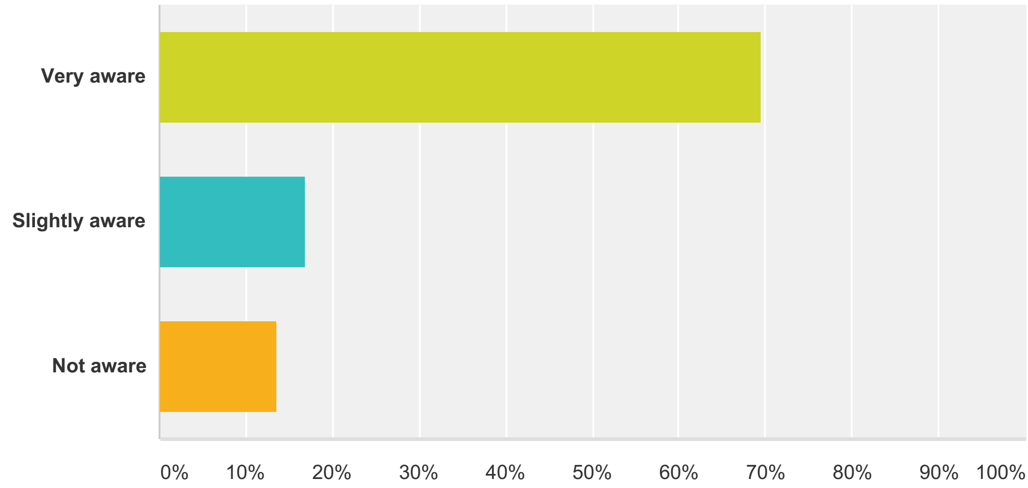


Answer Choices	Responses	
Extremely important	70.49%	43
Quite important	26.23%	16
Neither important nor unimportant	1.64%	1
Quite unimportant	0.00%	0

Extremely unimportant	1.64%	1
Total		**61**

Q25 Are you aware that lesser grade crabs often have an increased mortality rate through the transport chain?

Answered: 59   Skipped: 17

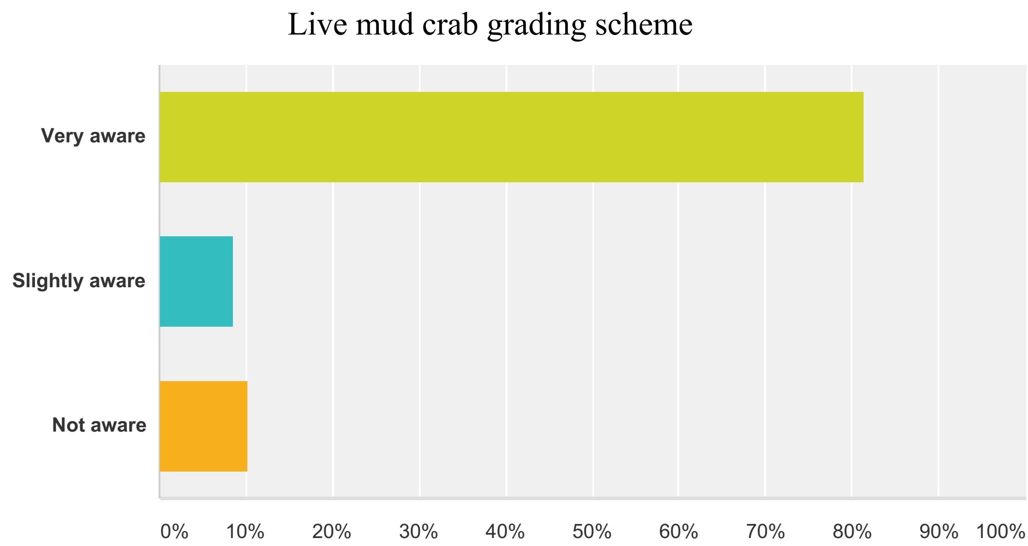


Answer Choices	Responses	
Very aware	69.49%	41
Slightly aware	16.95%	10
Not aware	13.56%	8
Total		**59**

#	Additional comments:	Date
1	due to transport distance	11/7/2014 12:19 PM
2	not true we have sent crab to various places and most times it has been A grade that have died not other grades.i have been in the crabbing industry for 36 years.	11/6/2014 6:33 PM
3	Yes this is quite true and this is the reason c grade should be illegal Both commercially and recreationally	11/4/2014 8:16 PM
4	i have found the opposite	11/4/2014 7:39 PM
5	no of days keppt	11/4/2014 6:36 PM
6	A waste of a resource that would be worth considerably more when reaching A grade quality.	11/4/2014 5:58 PM
7	results dont show this "A" grade mortality is on par with "C" grade	10/30/2014 10:46 PM
8	but isn't it funny at the sfm more A grade crab then C grade	10/29/2014 10:35 PM
9	this mortality is a shocking waste of the resource and gives the crab a bad name	10/29/2014 5:40 PM

Q26 Are you aware that ‘C’ grade crabs will fatten to become ‘B’ grade within just a few weeks and 'B' into 'A' in a few more?

Answered: 59   Skipped: 17



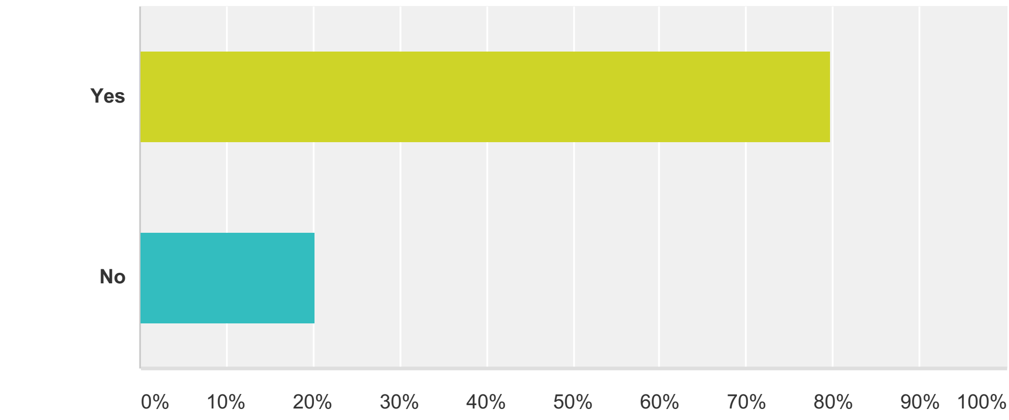
Answer Choices	Responses	
Very aware	**81.36%**	48
Slightly aware	**8.47%**	5
Not aware	**10.17%**	6
Total		**59**

#	Additional comments:	Date
1	i think it may be tacking longer on the clarence	11/7/2014 6:59 PM
2	there is a market for C grade crabs.	11/6/2014 6:33 PM
3	i have kept soft crabs for 6 weeks penned up and there was no change	11/6/2014 4:33 PM
4	there should not be a C Grade they should be rejected	11/5/2014 7:45 PM
5	Although not all crabs harden as i have stored them for up to 3 months trying to harden 50 percent go a 30 percent b and 20 percent never become harder than c	11/5/2014 5:38 PM
6	but not all crabs harden have done my own study ,have kept and feed crabs for months with no change !	11/5/2014 9:42 AM
7	cant catch them due to crabbing practice in our region due to greed	11/5/2014 6:35 AM
8	You can not tell some of the crabbers this as they have a very bad attitude and will take every thing due to greed.	11/4/2014 9:11 PM
9	don t sell c grade i sell some b grade and a grade	11/4/2014 6:36 PM
10	Now they do not get the chance. Will the continual taking of inferior quality male crab upset the natural male female balance and lead to sustainability issues in the future.	11/4/2014 5:58 PM
11	Bull shit no prof of statement crabs kept in holding cages in river and fed no increase in quality no data on "C" grade tagged and recaptured has been cited	10/30/2014 10:46 PM
12	we have done test ourselves on 100 non A grade crabs, put date on the shell & returned to the water, we are the only boat working in this area & have only recaught 15 of these back	10/29/2014 10:35 PM
13	that is why C grade crabs should be banned and the grading of the B grade should be stricter in line with Darwin standards	10/29/2014 5:40 PM

Q27 To avoid answering some fisher related questions, are you mud crab fisher?

Answered: 59 Skipped: 17

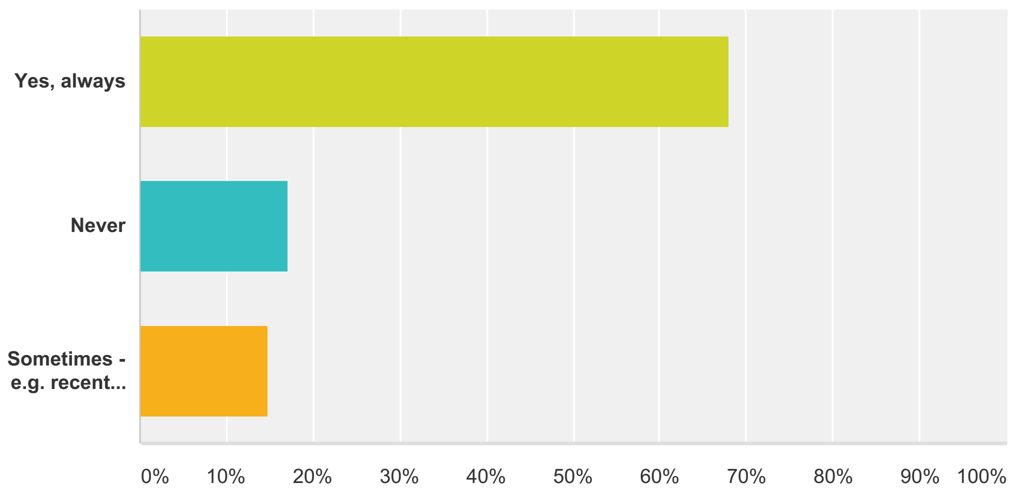
Live mud crab grading scheme



Answer Choices	Responses	
Yes	**79.66%**	47
No	**20.34%**	12
Total		**59**

Q28 Before the implementation of the Grading Scheme in 2012 did you return ‘C’ grade crabs to the water?Regional terms for 'C' grade may have been CUC or waterbags.

Answered: 47 Skipped: 29

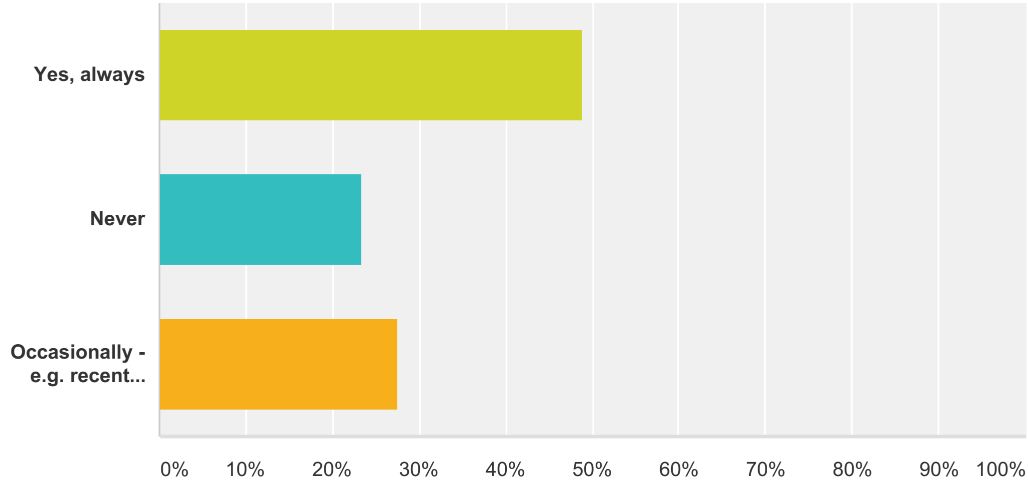


Answer Choices	Responses	
Yes, always	**68.09%**	32
Never	**17.02%**	8
Sometimes - e.g. recent market prices, other fisher competition, etc.	**14.89%**	7
Total		**47**

Q29 After the implementation of the Grading Scheme do you return ‘C’ grade crabs to the water?

Live mud crab grading scheme

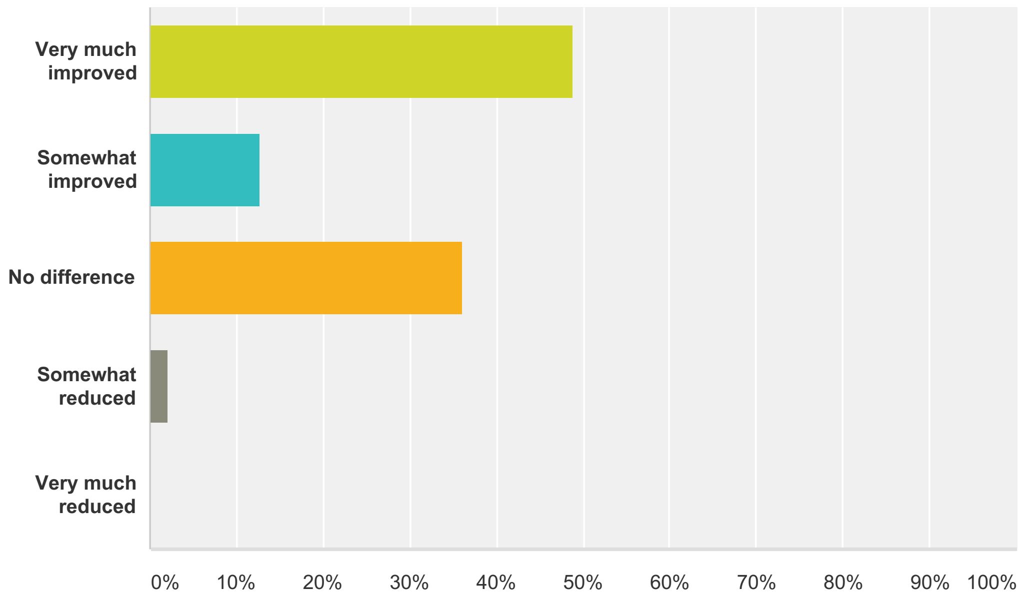
Answered: 47   Skipped: 29



Answer Choices	Responses	
Yes, always	**48.94%**	23
Never	**23.40%**	11
Occasionally - e.g. recent market prices, other fisher competition, etc.	**27.66%**	13
Total		**47**

Q30 Overall, do you believe that revenue or future harvest is improved by releasing 'C' grade crabs to the water?

Answered: 47   Skipped: 29



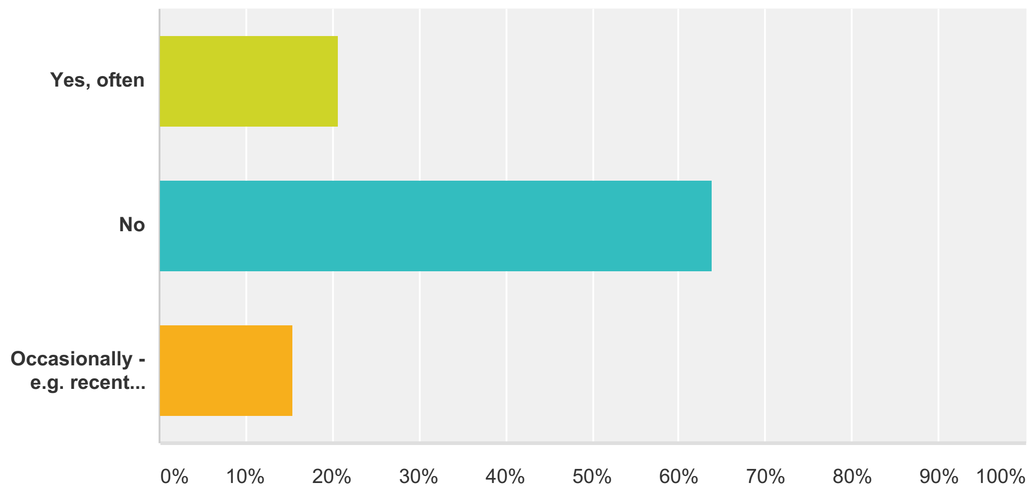
Answer Choices	Responses	
Very much improved	**48.94%**	23
Somewhat improved	**12.77%**	6

No difference	**36.17%**	17
Somewhat reduced	**2.13%**	1
Very much reduced	**0.00%**	0
Total		**47**

#	Depends on other factors - e.g. recent market prices, other fisher competition, seasonal variations, etc.	Date
1	to g hard to answer that question at the moment. depends on how well certain things are managed e.g. fisher competition . recreational issues with there effort capacity more than doubling at the moment.	11/7/2014 7:03 PM
2	as long as everyone is doing the same	11/7/2014 12:20 PM
3	it is maybe to early to tell but currently over the last 2 years we have notice no change. weather plays a far more important role then the release of C grade. a good wet season or flood give us 2 to 3 years of increased yield by at least 50%.	11/6/2014 6:39 PM
4	crabers not sending sfm take them and are sold as b grade to other markets	11/5/2014 8:14 AM
5	You have to take into consideration the breeding cycle is compromised by the taking of c grade crabs	11/5/2014 7:35 AM
6	its crippling our catch due to greed $$$$$$$$$$$$$$$$	11/5/2014 6:37 AM
7	There should be no market for the soft crab this would greatly improve the crab fishery.	11/4/2014 9:13 PM
8	Keeping c grade crab only makes your season shorter and less profitable	11/4/2014 8:17 PM
9	released crabs are caught by other fishers. also uncaught crabs have less competition for food if more crabs are taken.	11/4/2014 7:43 PM
10	As above for depending factors	11/1/2014 10:50 PM
11	wrong question number 25 we were obliged to return "C" grade when market would not sell them no improvement in catch after returns	10/30/2014 10:49 PM
12	no as other fishermen will take them anyway and the buyers would again move to out of state product to decrease our prices	10/30/2014 11:07 AM
13	They all take c grade crabs as all the Asian restaurants will by it directly of the fisher this contributes to over heads ie pays there fuel bill	10/29/2014 10:12 PM

Q31 In this last year, have you sold ‘C’ grade crabs that you wouldn’t have previously?

Answered: 58 Skipped: 18

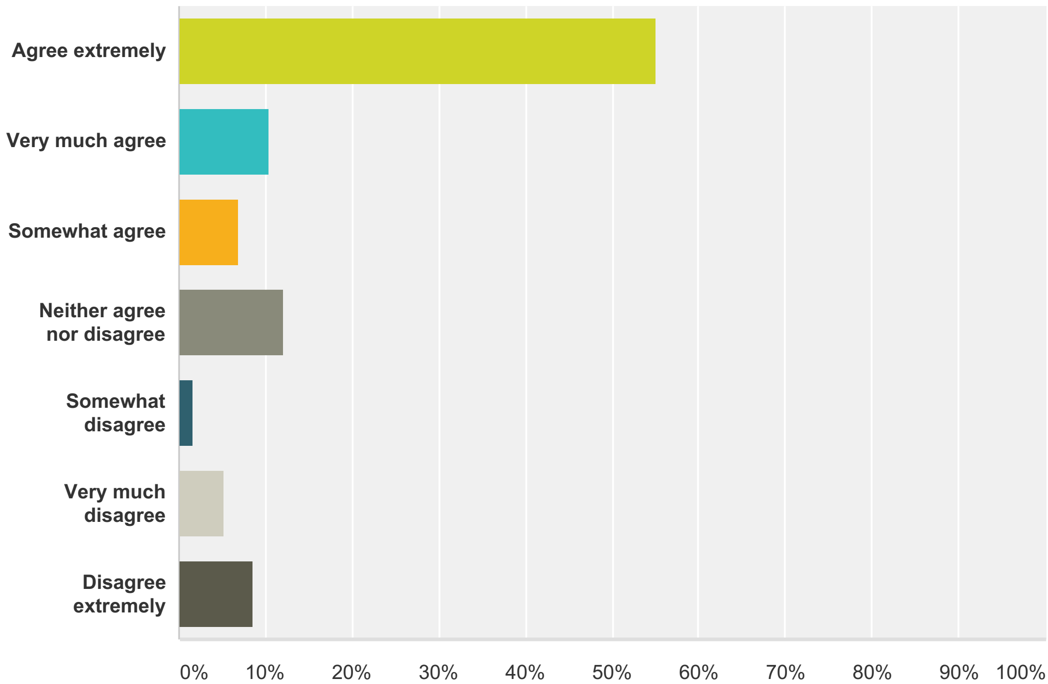


Answer Choices	Responses	
Yes, often	**20.69%**	12
No	**63.79%**	37
Occasionally - e.g. recent market prices, other fisher competition, seasonal variations, etc.	**15.52%**	9
Total		**58**

#	Additional comments:	Date
1	no but have been graded back too c	11/7/2014 6:46 AM
2	have had lots of crabs been down graded to b or c grade because of movement in the shell	11/5/2014 4:26 PM
3	Nsw fisheries fees have gone mad? I now measure all crab and sell anything thats legal. Never measured crabs before if they didn't look legal they when back. C grade straight ove,r the Nsw fisheries fees have gone mad? I now keep every crab which is legal to sell and aren't proud to admit it.	11/4/2014 9:01 PM
4	Fisher completion forces this	11/4/2014 8:18 PM
5	bay be 5 crabs	11/4/2014 6:39 PM
6	$35 per kg do you need to say any more	10/29/2014 10:13 PM
7	Asians who are the main consumers don't want them - the only people that buy them in my experience are those that don't know anything about crabs	10/29/2014 5:47 PM

Q32 Would you agree that all ‘C’ grade crabs should be returned to the water by both professional and amateur fishers?

Answered: 58 Skipped: 18



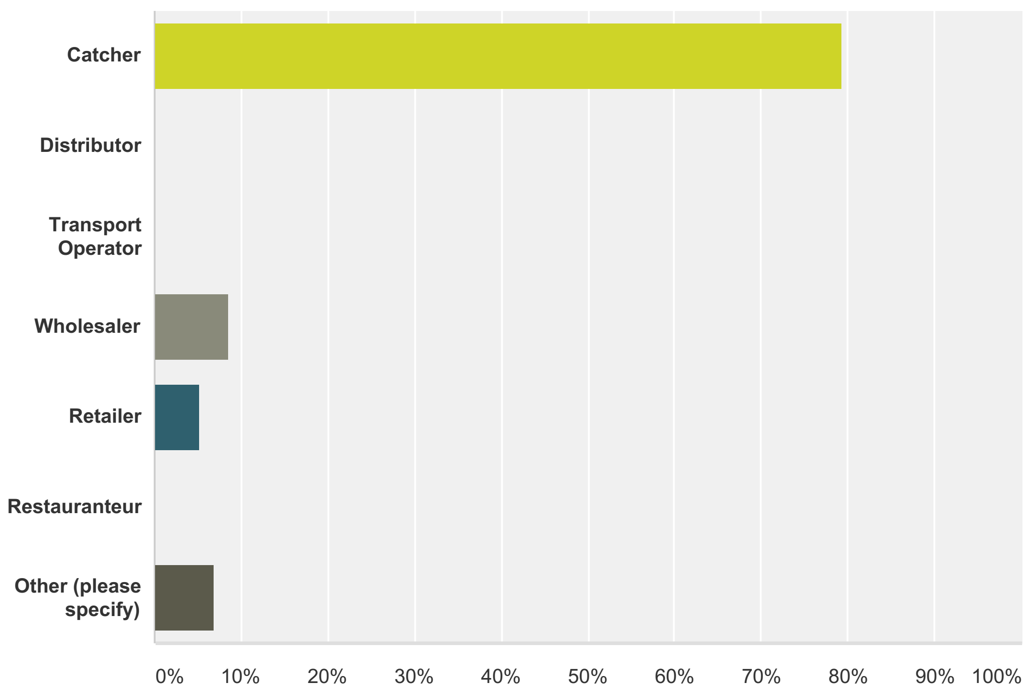
Answer Choices	Responses	
Agree extremely	**55.17%**	32
Very much agree	**10.34%**	6

Somewhat agree	**6.90%**	4
Neither agree nor disagree	**12.07%**	7
Somewhat disagree	**1.72%**	1
Very much disagree	**5.17%**	3
Disagree extremely	**8.62%**	5
Total		**58**

#	Additional comments:	Date
1	If i was to catch what i class a b grade crab then send it to market and it was deemed to be a c grade crab when it got there from repeatedly being pushed on with force i would then be commiting aoffence because someone could not grade a crab without using excessive force	11/5/2014 5:45 PM
2	if the grading was the right method is used	11/5/2014 4:26 PM
3	I agree only on the basis that it was carried out by ALL which i feel is unlikely to happen.	11/5/2014 6:58 AM
4	This should have been done years ago, it's a no brainer	11/4/2014 8:18 PM
5	I Think it is a waste of mud crabs for the quality and prices it worth in the market today. most of it end up in the bin any way.	11/4/2014 4:55 PM
6	grading is to open to a subjective decision my "B-" might be your "C" grade	10/30/2014 10:52 PM
7	no as its another restriction on us and will only lead to black marketing	10/30/2014 11:09 AM
8	This will purely bedpans on the interpretation of what is "c" grade	10/30/2014 4:41 AM
9	these are mature crabs they are purely at a stage of moult & the meat is much sweeter than a full crab	10/29/2014 10:39 PM
10	That would fix the problem and no one can argue	10/29/2014 10:13 PM
11	Leave them alone as they fatten up quickly should have the legislatures ban them like Darwin	10/29/2014 5:47 PM

Q33 Which of the following categories best describes your principal business sector?

Answered: 58 Skipped: 18



Answer Choices	Responses	
Catcher	79.31%	46
Distributor	0.00%	0
Transport Operator	0.00%	0
Wholesaler	8.62%	5
Retailer	5.17%	3
Restauranteur	0.00%	0
Other (please specify)	6.90%	4
Total		**58**

#	Other (please specify)	Date
1	All of the above	11/6/2014 7:26 AM
2	Fishermen's Co-operative	11/5/2014 8:21 AM
3	both wholesale and retail	11/1/2014 11:06 PM
4	fish market	10/30/2014 9:44 AM

Q34 How do you receive feedback from markets on any grade variations or downgrades? (select as many as apply)

Answered: 0 Skipped: 76

! No matching responses.

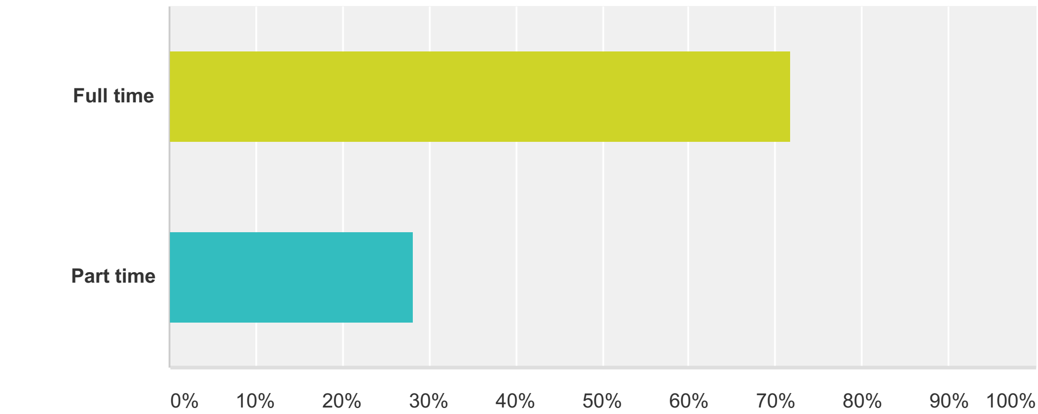
Answer Choices	Responses	
Directly	0.00%	0
Pooled through co-operative	0.00%	0
No feedback	0.00%	0
Total Respondents: 0		

#	Additional comments:	Date
	There are no responses.	

Q35 Is mud crab harvesting your major fishing activity?

Answered: 46 Skipped: 30

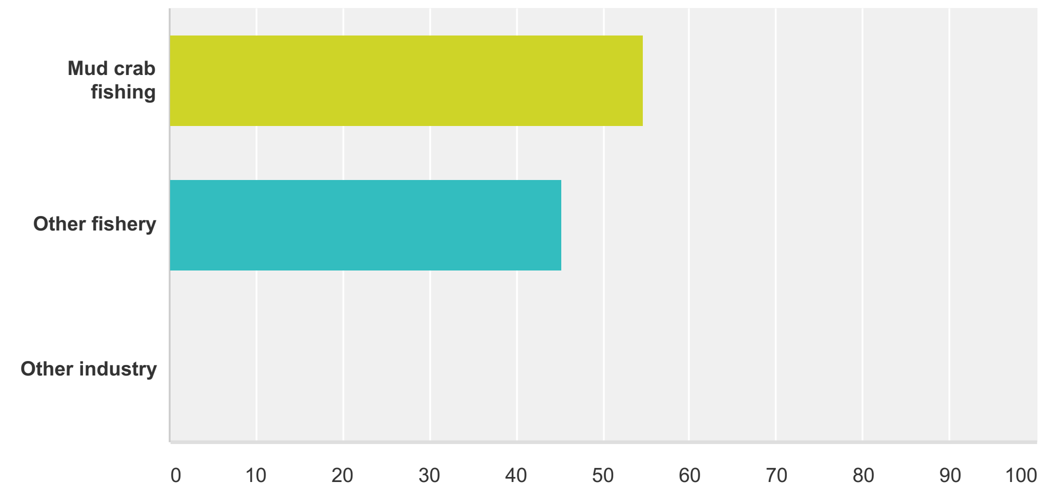
Live mud crab grading scheme



Answer Choices	Responses	
Full time	**71.74%**	33
Part time	**28.26%**	13
Total		**46**

Q36 As a part time mud crab fisher, what percentage of your working time is allocated to:Enter whole numbers onlyTotal must add up to 100Values for at least two categories must be enteredFor example: Mud crab fishing 60Other fishery 40

Answered: 13 Skipped: 63



Answer Choices	Average Number	Total Number	Responses
Mud crab fishing	55	710	13
Other fishery	45	590	13
Other industry	0	0	0
Total Respondents: 13			

#	Mud crab fishing	Date

1	30	11/10/2014 12:21 PM
2	60	11/8/2014 6:27 PM
3	100	11/7/2014 6:48 AM
4	70	11/6/2014 8:37 PM
5	50	11/5/2014 5:44 PM
6	55	11/4/2014 9:05 PM
7	60	11/4/2014 7:55 PM
8	30	11/4/2014 1:16 PM
9	40	11/1/2014 10:54 PM
10	5	10/31/2014 10:34 AM
11	80	10/30/2014 10:53 PM
12	50	10/30/2014 11:03 AM
13	80	10/30/2014 4:42 AM

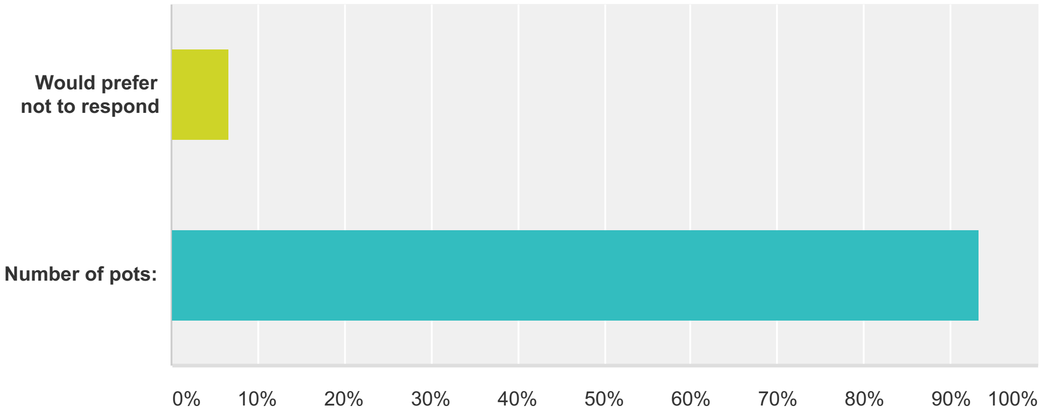
#	Other fishery	Date
1	70	11/10/2014 12:21 PM
2	40	11/8/2014 6:27 PM
3	0	11/7/2014 6:48 AM
4	30	11/6/2014 8:37 PM
5	50	11/5/2014 5:44 PM
6	45	11/4/2014 9:05 PM
7	40	11/4/2014 7:55 PM
8	70	11/4/2014 1:16 PM
9	60	11/1/2014 10:54 PM
10	95	10/31/2014 10:34 AM
11	20	10/30/2014 10:53 PM
12	50	10/30/2014 11:03 AM
13	20	10/30/2014 4:42 AM

#	Other industry	Date
	There are no responses.	

Q37 What is the maximum number of licenced pots that you use?

Answered: 45 Skipped: 31

Live mud crab grading scheme



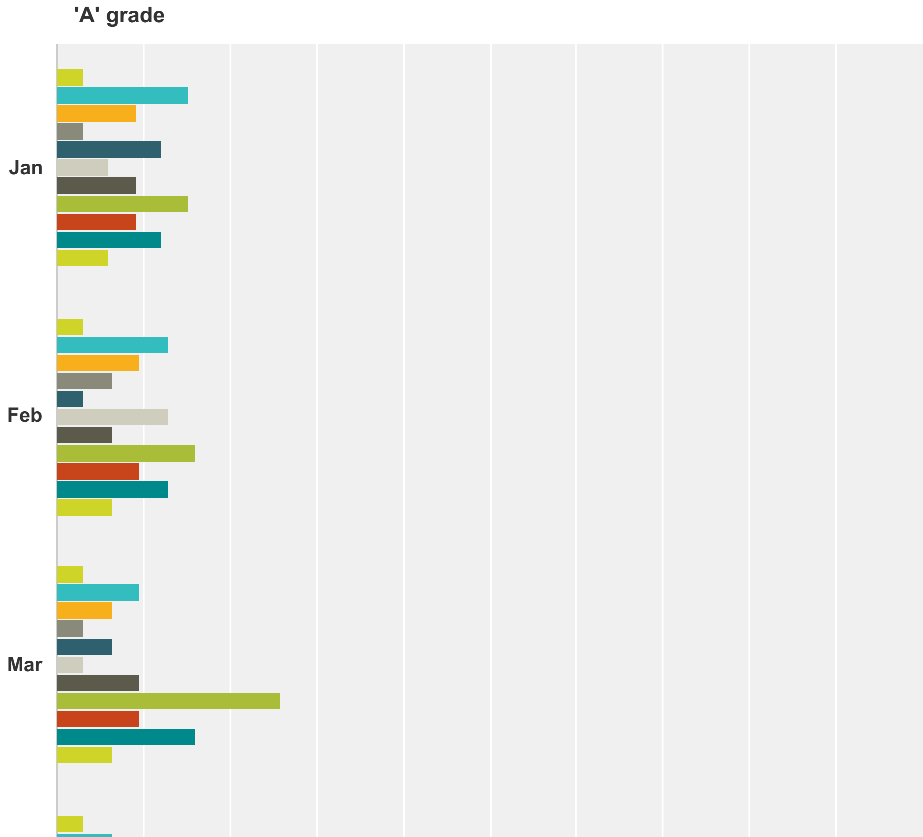
Answer Choices	Responses	
Would prefer not to respond	**6.67%**	3
Number of pots:	**93.33%**	42
Total		**45**

#	Number of pots:	Date
1	50	11/10/2014 3:24 PM
2	10	11/8/2014 6:28 PM
3	50	11/8/2014 10:01 AM
4	10	11/7/2014 8:00 PM
5	10	11/7/2014 12:22 PM
6	100	11/7/2014 10:38 AM
7	100	11/7/2014 10:22 AM
8	40	11/7/2014 6:49 AM
9	10	11/6/2014 8:40 PM
10	100	11/6/2014 6:41 PM
11	10	11/6/2014 4:38 PM
12	100	11/6/2014 1:21 PM
13	50	11/6/2014 11:27 AM
14	10	11/6/2014 9:33 AM
15	10	11/6/2014 2:11 AM
16	50	11/5/2014 7:50 PM
17	10	11/5/2014 5:51 PM
18	10	11/5/2014 5:44 PM
19	45	11/5/2014 4:30 PM
20	50	11/5/2014 3:32 PM
21	50	11/5/2014 12:05 PM
22	10	11/5/2014 9:44 AM
23	100	11/5/2014 8:21 AM
24	50	11/5/2014 7:41 AM
25	50	11/5/2014 6:48 AM

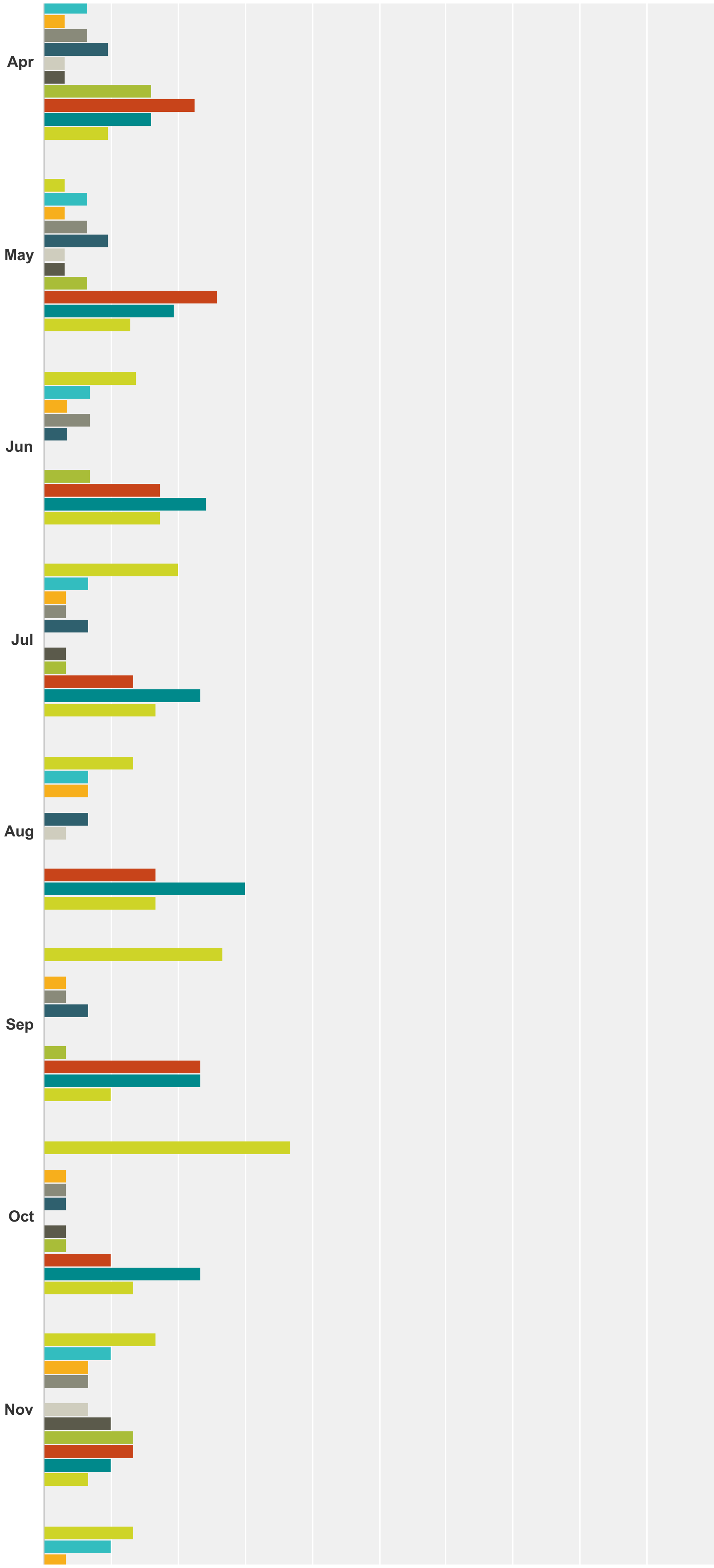
26	100	11/4/2014 9:14 PM
27	10	11/4/2014 9:05 PM
28	100	11/4/2014 8:24 PM
29	20	11/4/2014 7:59 PM
30	45	11/4/2014 7:50 PM
31	50	11/4/2014 6:44 PM
32	50	11/4/2014 6:33 PM
33	50	11/4/2014 6:01 PM
34	50	11/4/2014 5:38 PM
35	150	11/4/2014 1:19 PM
36	50	10/31/2014 9:47 AM
37	20	10/30/2014 10:54 PM
38	100	10/30/2014 4:40 PM
39	100	10/30/2014 11:03 AM
40	10	10/30/2014 4:42 AM
41	150	10/29/2014 10:46 PM
42	100	10/29/2014 10:17 PM

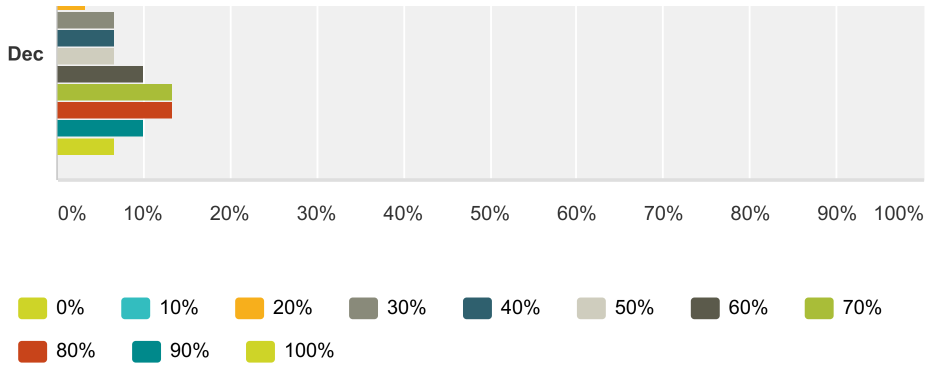
Q38 Please select the approximate percent of your landed catch per your grade.Your answers should add up to 100% in each month.In months when you didn't catch any crab, select 0% for each grade.

Answered: 34 Skipped: 42

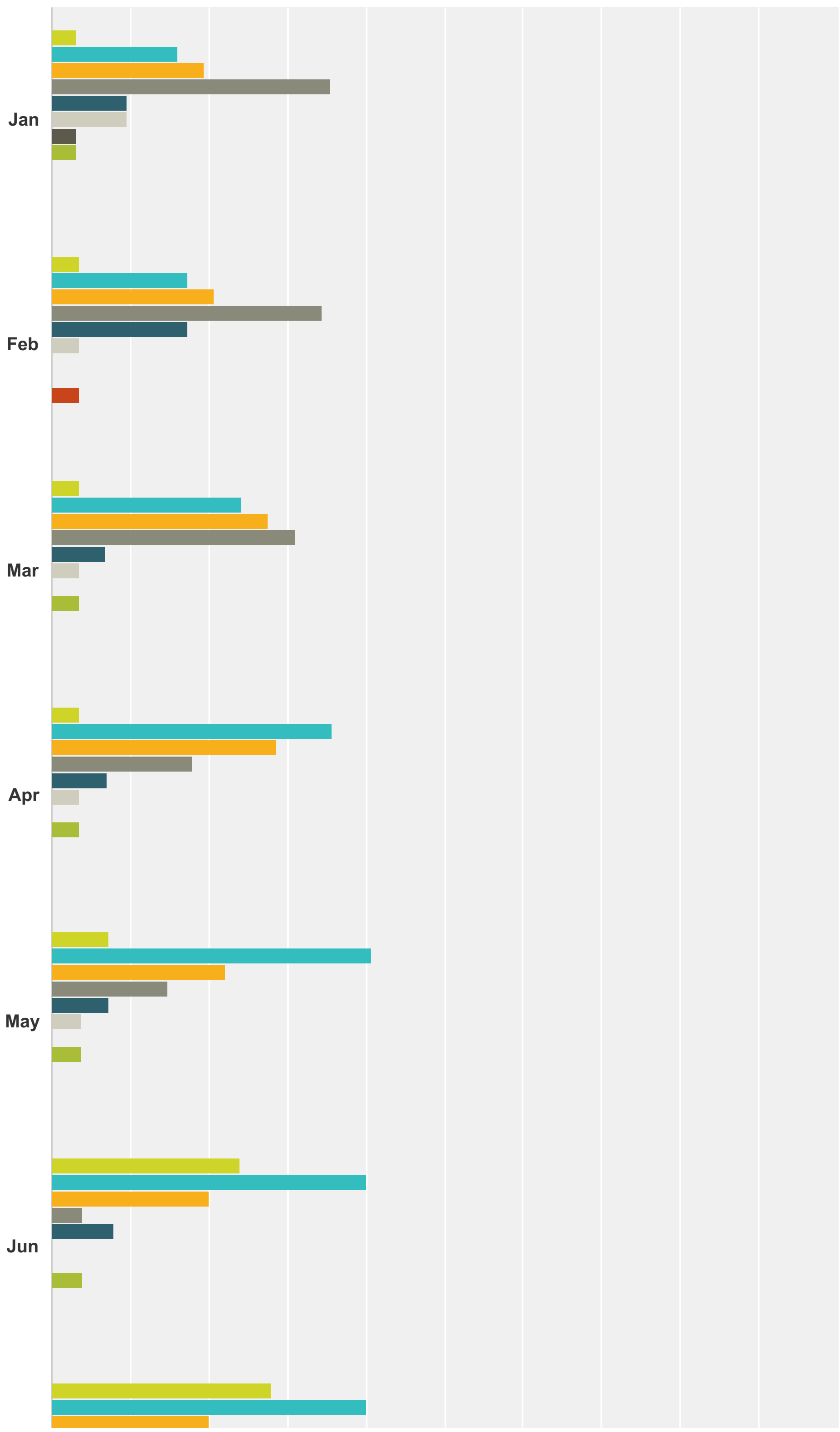


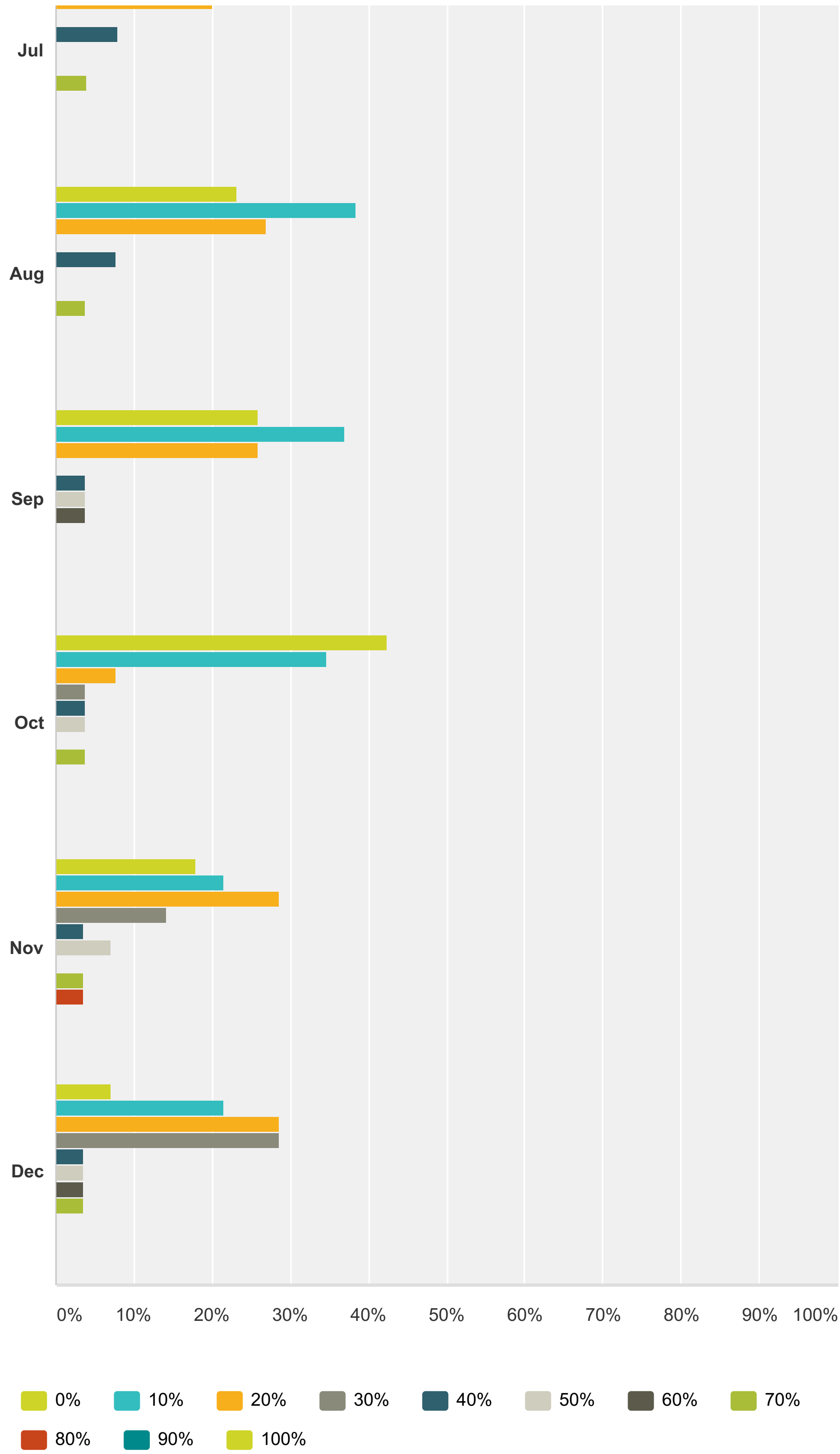
Live mud crab grading scheme



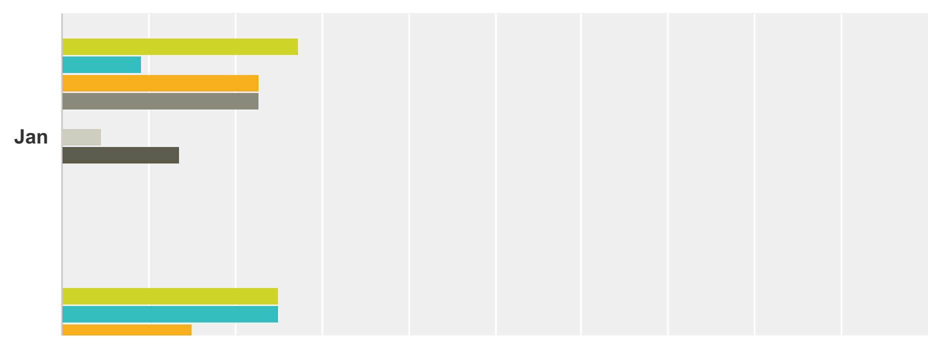

Dec
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

'B' grade

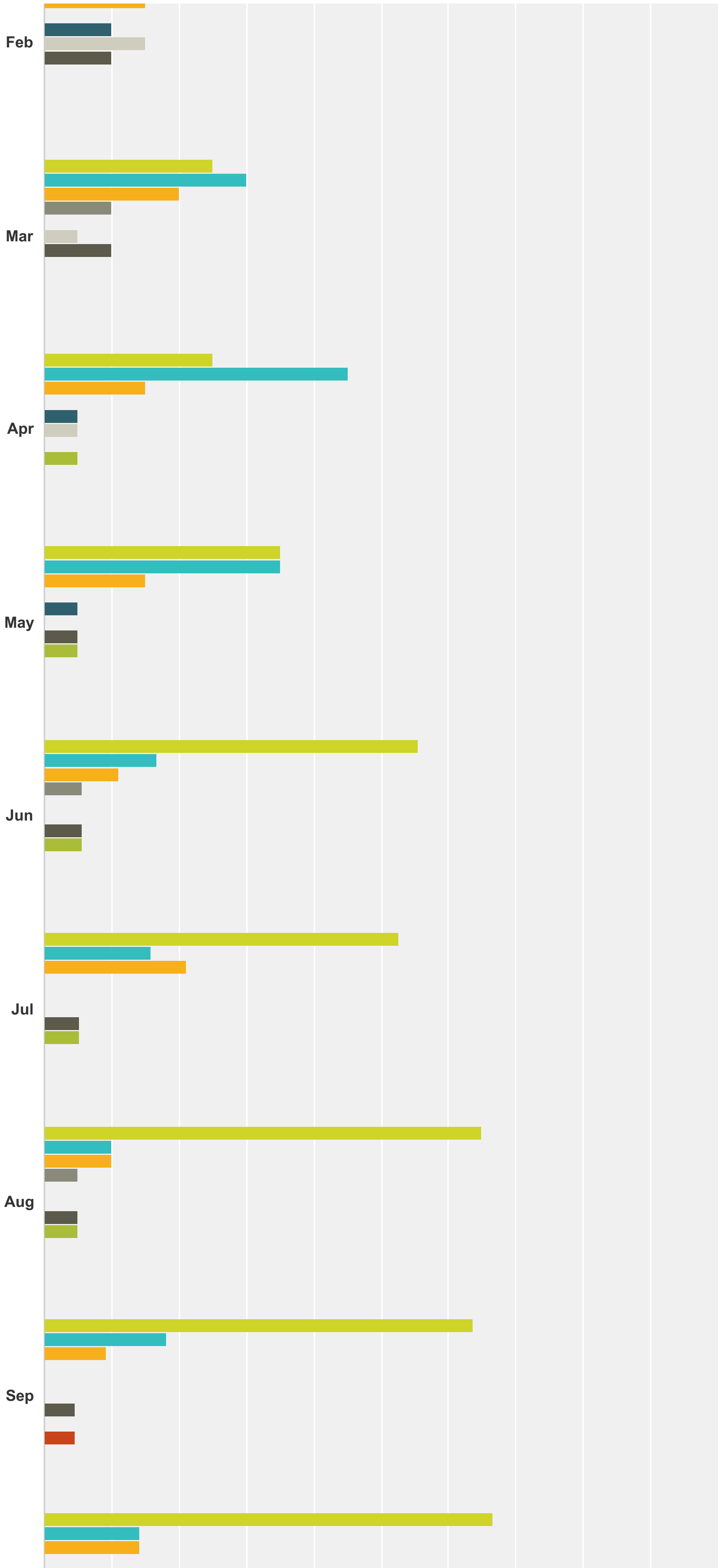

Jan
Feb
Mar
Apr
May
Jun


Jul
Aug
Sep
Oct
Nov
Dec
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

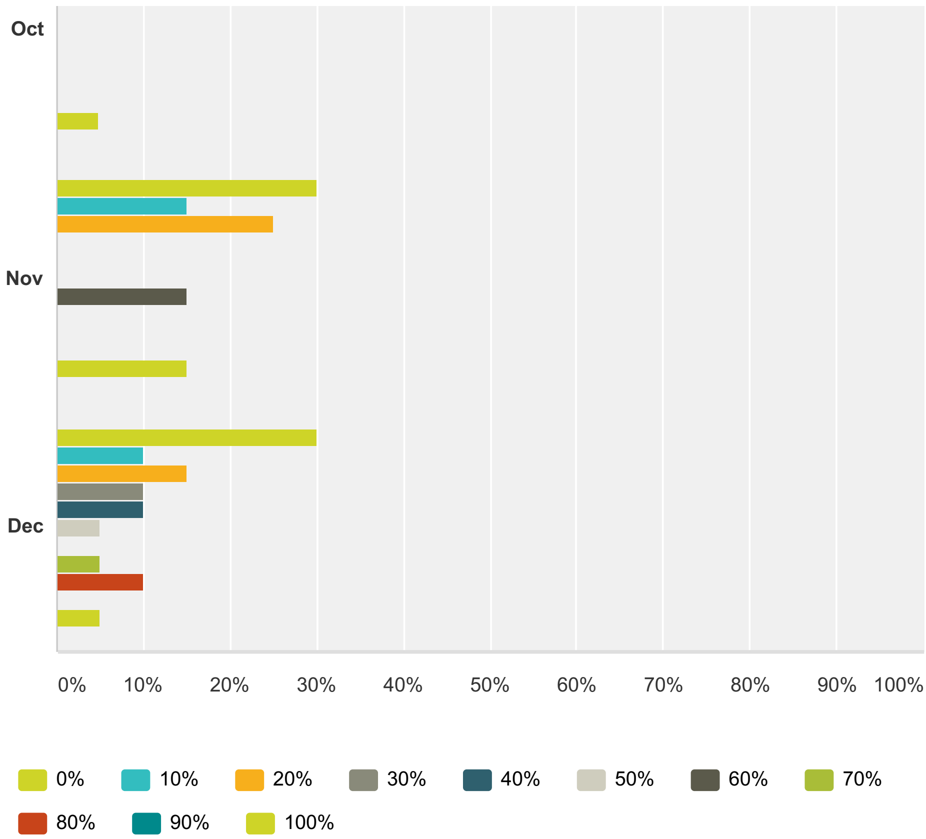
'C' grade


Jan

Live mud crab grading scheme



Live mud crab grading scheme



'A' grade

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Total
Jan	**3.03%** 1	**15.15%** 5	**9.09%** 3	**3.03%** 1	**12.12%** 4	**6.06%** 2	**9.09%** 3	**15.15%** 5	**9.09%** 3	**12.12%** 4	**6.06%** 2	33
Feb	**3.23%** 1	**12.90%** 4	**9.68%** 3	**6.45%** 2	**3.23%** 1	**12.90%** 4	**6.45%** 2	**16.13%** 5	**9.68%** 3	**12.90%** 4	**6.45%** 2	31
Mar	**3.23%** 1	**9.68%** 3	**6.45%** 2	**3.23%** 1	**6.45%** 2	**3.23%** 1	**9.68%** 3	**25.81%** 8	**9.68%** 3	**16.13%** 5	**6.45%** 2	31
Apr	**3.23%** 1	**6.45%** 2	**3.23%** 1	**6.45%** 2	**9.68%** 3	**3.23%** 1	**3.23%** 1	**16.13%** 5	**22.58%** 7	**16.13%** 5	**9.68%** 3	31
May	**3.23%** 1	**6.45%** 2	**3.23%** 1	**6.45%** 2	**9.68%** 3	**3.23%** 1	**3.23%** 1	**6.45%** 2	**25.81%** 8	**19.35%** 6	**12.90%** 4	31
Jun	**13.79%** 4	**6.90%** 2	**3.45%** 1	**6.90%** 2	**3.45%** 1	**0.00%** 0	**0.00%** 0	**6.90%** 2	**17.24%** 5	**24.14%** 7	**17.24%** 5	29
Jul	**20.00%** 6	**6.67%** 2	**3.33%** 1	**3.33%** 1	**6.67%** 2	**0.00%** 0	**3.33%** 1	**3.33%** 1	**13.33%** 4	**23.33%** 7	**16.67%** 5	30
Aug	**13.33%** 4	**6.67%** 2	**6.67%** 2	**0.00%** 0	**6.67%** 2	**3.33%** 1	**0.00%** 0	**0.00%** 0	**16.67%** 5	**30.00%** 9	**16.67%** 5	30
Sep	**26.67%** 8	**0.00%** 0	**3.33%** 1	**3.33%** 1	**6.67%** 2	**0.00%** 0	**0.00%** 0	**3.33%** 1	**23.33%** 7	**23.33%** 7	**10.00%** 3	30
Oct	**36.67%** 11	**0.00%** 0	**3.33%** 1	**3.33%** 1	**3.33%** 1	**0.00%** 0	**3.33%** 1	**3.33%** 1	**10.00%** 3	**23.33%** 7	**13.33%** 4	30
Nov	**16.67%** 5	**10.00%** 3	**6.67%** 2	**6.67%** 2	**0.00%** 0	**6.67%** 2	**10.00%** 3	**13.33%** 4	**13.33%** 4	**10.00%** 3	**6.67%** 2	30
Dec	**13.33%** 4	**10.00%** 3	**3.33%** 1	**6.67%** 2	**6.67%** 2	**6.67%** 2	**10.00%** 3	**13.33%** 4	**13.33%** 4	**10.00%** 3	**6.67%** 2	30

'B' grade

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Total

Jan	**3.23%**	**16.13%**	**19.35%**	**35.48%**	**9.68%**	**9.68%**	**3.23%**	**3.23%**	**0.00%**	**0.00%**	**0.00%**	
	1	5	6	11	3	3	1	1	0	0	0	31
Feb	**3.45%**	**17.24%**	**20.69%**	**34.48%**	**17.24%**	**3.45%**	**0.00%**	**0.00%**	**3.45%**	**0.00%**	**0.00%**	
	1	5	6	10	5	1	0	0	1	0	0	29
Mar	**3.45%**	**24.14%**	**27.59%**	**31.03%**	**6.90%**	**3.45%**	**0.00%**	**3.45%**	**0.00%**	**0.00%**	**0.00%**	
	1	7	8	9	2	1	0	1	0	0	0	29
Apr	**3.57%**	**35.71%**	**28.57%**	**17.86%**	**7.14%**	**3.57%**	**0.00%**	**3.57%**	**0.00%**	**0.00%**	**0.00%**	
	1	10	8	5	2	1	0	1	0	0	0	28
May	**7.41%**	**40.74%**	**22.22%**	**14.81%**	**7.41%**	**3.70%**	**0.00%**	**3.70%**	**0.00%**	**0.00%**	**0.00%**	
	2	11	6	4	2	1	0	1	0	0	0	27
Jun	**24.00%**	**40.00%**	**20.00%**	**4.00%**	**8.00%**	**0.00%**	**0.00%**	**4.00%**	**0.00%**	**0.00%**	**0.00%**	
	6	10	5	1	2	0	0	1	0	0	0	25
Jul	**28.00%**	**40.00%**	**20.00%**	**0.00%**	**8.00%**	**0.00%**	**0.00%**	**4.00%**	**0.00%**	**0.00%**	**0.00%**	
	7	10	5	0	2	0	0	1	0	0	0	25
Aug	**23.08%**	**38.46%**	**26.92%**	**0.00%**	**7.69%**	**0.00%**	**0.00%**	**3.85%**	**0.00%**	**0.00%**	**0.00%**	
	6	10	7	0	2	0	0	1	0	0	0	26
Sep	**25.93%**	**37.04%**	**25.93%**	**0.00%**	**3.70%**	**3.70%**	**3.70%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	
	7	10	7	0	1	1	1	0	0	0	0	27
Oct	**42.31%**	**34.62%**	**7.69%**	**3.85%**	**3.85%**	**3.85%**	**0.00%**	**3.85%**	**0.00%**	**0.00%**	**0.00%**	
	11	9	2	1	1	1	0	1	0	0	0	26
Nov	**17.86%**	**21.43%**	**28.57%**	**14.29%**	**3.57%**	**7.14%**	**0.00%**	**3.57%**	**3.57%**	**0.00%**	**0.00%**	
	5	6	8	4	1	2	0	1	1	0	0	28
Dec	**7.14%**	**21.43%**	**28.57%**	**28.57%**	**3.57%**	**3.57%**	**3.57%**	**3.57%**	**0.00%**	**0.00%**	**0.00%**	
	2	6	8	8	1	1	1	1	0	0	0	28

'C' grade

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Total
Jan	**27.27%**	**9.09%**	**22.73%**	**22.73%**	**0.00%**	**4.55%**	**13.64%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	
	6	2	5	5	0	1	3	0	0	0	0	22
Feb	**25.00%**	**25.00%**	**15.00%**	**0.00%**	**10.00%**	**15.00%**	**10.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	
	5	5	3	0	2	3	2	0	0	0	0	20
Mar	**25.00%**	**30.00%**	**20.00%**	**10.00%**	**0.00%**	**5.00%**	**10.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	
	5	6	4	2	0	1	2	0	0	0	0	20
Apr	**25.00%**	**45.00%**	**15.00%**	**0.00%**	**5.00%**	**5.00%**	**0.00%**	**5.00%**	**0.00%**	**0.00%**	**0.00%**	
	5	9	3	0	1	1	0	1	0	0	0	20
May	**35.00%**	**35.00%**	**15.00%**	**0.00%**	**5.00%**	**0.00%**	**5.00%**	**5.00%**	**0.00%**	**0.00%**	**0.00%**	
	7	7	3	0	1	0	1	1	0	0	0	20
Jun	**55.56%**	**16.67%**	**11.11%**	**5.56%**	**0.00%**	**0.00%**	**5.56%**	**5.56%**	**0.00%**	**0.00%**	**0.00%**	
	10	3	2	1	0	0	1	1	0	0	0	18
Jul	**52.63%**	**15.79%**	**21.05%**	**0.00%**	**0.00%**	**0.00%**	**5.26%**	**5.26%**	**0.00%**	**0.00%**	**0.00%**	
	10	3	4	0	0	0	1	1	0	0	0	19
Aug	**65.00%**	**10.00%**	**10.00%**	**5.00%**	**0.00%**	**0.00%**	**5.00%**	**5.00%**	**0.00%**	**0.00%**	**0.00%**	
	13	2	2	1	0	0	1	1	0	0	0	20
Sep	**63.64%**	**18.18%**	**9.09%**	**0.00%**	**0.00%**	**0.00%**	**4.55%**	**0.00%**	**4.55%**	**0.00%**	**0.00%**	
	14	4	2	0	0	0	1	0	1	0	0	22
Oct	**66.67%**	**14.29%**	**14.29%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**4.76%**	
	14	3	3	0	0	0	0	0	0	0	1	21
Nov	**30.00%**	**15.00%**	**25.00%**	**0.00%**	**0.00%**	**0.00%**	**15.00%**	**0.00%**	**0.00%**	**0.00%**	**15.00%**	
	6	3	5	0	0	0	3	0	0	0	3	20
Dec	**30.00%**	**10.00%**	**15.00%**	**10.00%**	**10.00%**	**5.00%**	**0.00%**	**5.00%**	**10.00%**	**0.00%**	**5.00%**	
	6	2	3	2	2	1	0	1	2	0	1	20

Q39 How many tonne of crab do you handle in a typical year ?

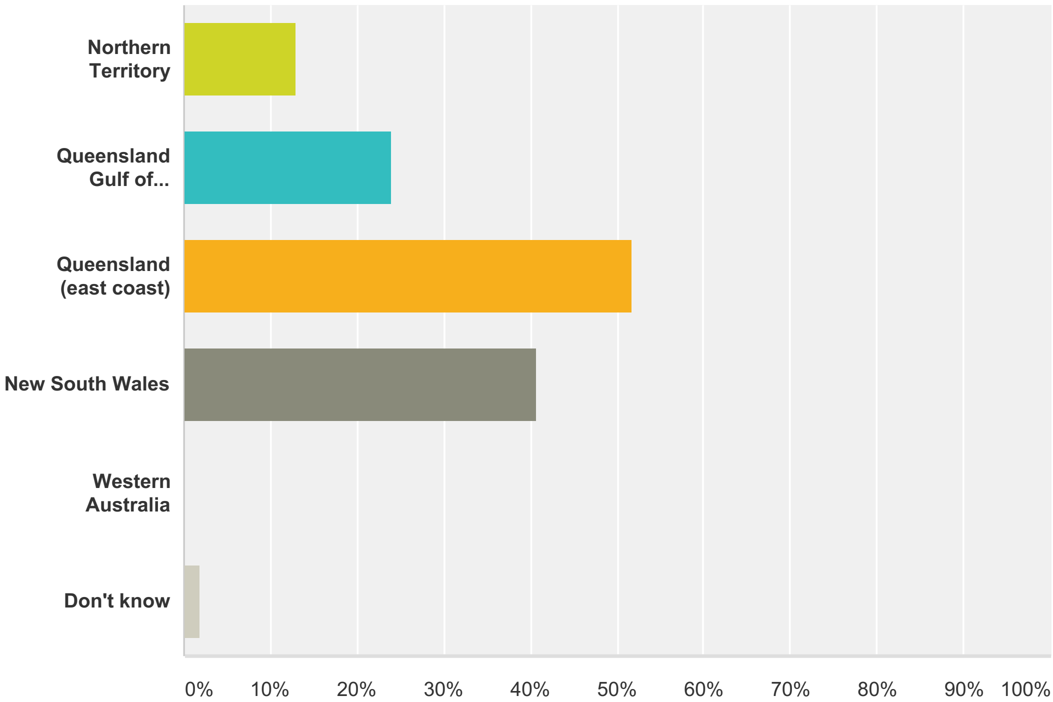
Answered: 54 Skipped: 22

#	Responses	Date
1	12	11/10/2014 3:24 PM
2	1.5	11/8/2014 6:56 PM
3	6	11/8/2014 10:01 AM
4	3	11/7/2014 8:00 PM
5	4000-5000kg	11/7/2014 12:23 PM
6	5 TON	11/7/2014 10:23 AM
7	na only sell too sfm	11/7/2014 6:51 AM
8	1.5	11/6/2014 8:42 PM
9	3.5	11/6/2014 4:39 PM
10	20	11/6/2014 1:22 PM
11	15	11/6/2014 11:29 AM
12	3	11/6/2014 9:35 AM
13	None of your business	11/6/2014 7:29 AM
14	1 to 1.5	11/6/2014 2:12 AM
15	8/11 tonnes	11/5/2014 7:53 PM
16	3 tonne	11/5/2014 5:52 PM
17	1-2	11/5/2014 5:45 PM
18	5	11/5/2014 5:37 PM
19	5000kg to 8000kg	11/5/2014 4:38 PM
20	6 to 8 tonne	11/5/2014 4:31 PM
21	10 tonne	11/5/2014 3:32 PM
22	8	11/5/2014 12:06 PM
23	3-4 tonne	11/5/2014 9:45 AM
24	about 5 ton	11/5/2014 8:23 AM
25	15-20 tonne	11/5/2014 8:22 AM
26	5 to 8	11/5/2014 7:42 AM
27	393	11/5/2014 6:59 AM
28	several	11/5/2014 6:49 AM
29	50	11/4/2014 9:29 PM
30	6000 - 8000kg	11/4/2014 9:15 PM
31	2	11/4/2014 9:07 PM
32	15-25t	11/4/2014 8:25 PM
33	2 ton approx	11/4/2014 8:00 PM
34	6	11/4/2014 7:50 PM
35	3 two 6 tonne depend on rain	11/4/2014 6:50 PM

36	12	11/4/2014 6:34 PM
37	5	11/4/2014 6:02 PM
38	15	11/4/2014 5:40 PM
39	1.5 tonnes	11/4/2014 4:58 PM
40	60 tonnes	11/4/2014 4:01 PM
41	2 approx	11/4/2014 1:25 PM
42	na	11/1/2014 11:02 PM
43	100kg	10/31/2014 10:35 AM
44	5	10/31/2014 9:48 AM
45	4	10/30/2014 10:57 PM
46	how long is a piece of string??	10/30/2014 4:41 PM
47	1	10/30/2014 11:13 AM
48	8-10 TONNE	10/30/2014 11:04 AM
49	350 - 400 tonne	10/30/2014 9:54 AM
50	about 60 ton	10/30/2014 9:50 AM
51	1200	10/30/2014 4:44 AM
52	15 to 26	10/29/2014 10:48 PM
53	10/15 tonne	10/29/2014 10:18 PM
54	40 tonnes +	10/29/2014 5:48 PM

Q40 From where are your mud crabs originally harvested? (Select as many as apply)

Answered: 54 Skipped: 22



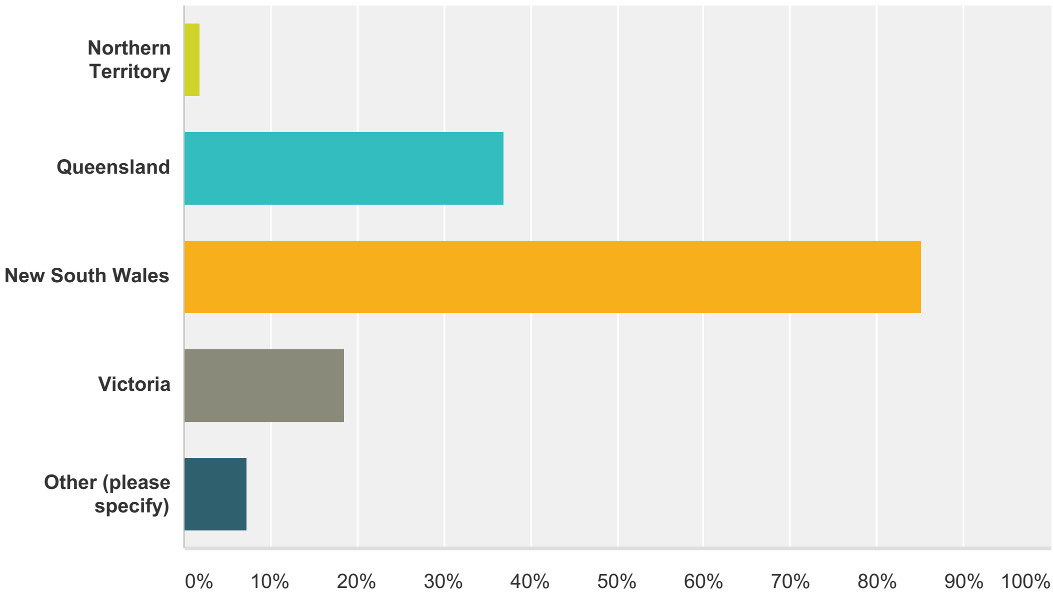
Answer Choices **Responses**

Northern Territory	**12.96%**	7
Queensland Gulf of Carpentaria	**24.07%**	13
Queensland (east coast)	**51.85%**	28
New South Wales	**40.74%**	22
Western Australia	**0.00%**	0
Don't know	**1.85%**	1

Total Respondents: 54

Q41 Where do you sell your mud crabs? (Select as many as apply)

Answered: 54 Skipped: 22



Answer Choices	Responses	
Northern Territory	**1.85%**	1
Queensland	**37.04%**	20
New South Wales	**85.19%**	46
Victoria	**18.52%**	10
Other (please specify)	**7.41%**	4

Total Respondents: 54

#	Other (please specify)	Date
1	Adelaide	11/10/2014 3:24 PM
2	.	11/6/2014 7:29 AM
3	sydney market	11/4/2014 6:50 PM
4	export Asia	11/4/2014 4:01 PM

Q42 What is your residential postcode?

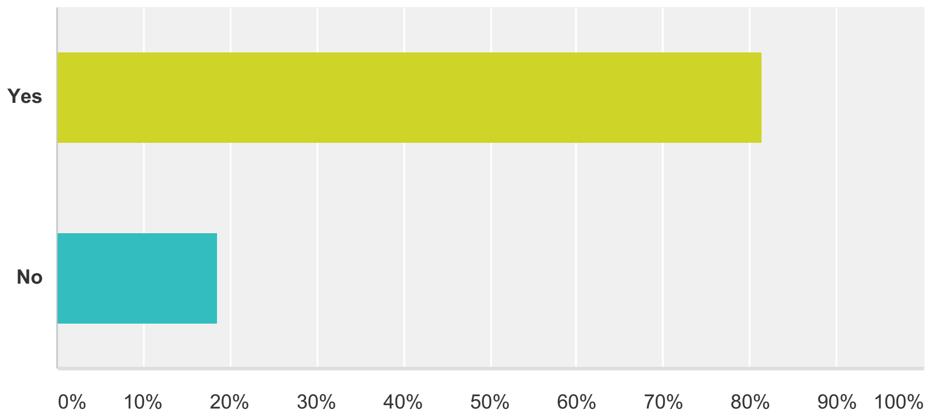
Answered: 54 Skipped: 22

#	Responses	Date
1	4165	11/10/2014 3:24 PM
2	2469	11/8/2014 6:56 PM
3	4280	11/8/2014 10:01 AM
4	2464	11/7/2014 8:00 PM
5	2486	11/7/2014 12:23 PM
6	4020	11/7/2014 10:23 AM
7	4680	11/7/2014 6:51 AM
8	2466	11/6/2014 8:42 PM
9	2443	11/6/2014 4:39 PM
10	4680	11/6/2014 1:22 PM
11	4165	11/6/2014 11:29 AM
12	2472	11/6/2014 9:35 AM
13	1234	11/6/2014 7:29 AM
14	2486	11/6/2014 2:12 AM
15	4738	11/5/2014 7:53 PM
16	2441	11/5/2014 5:52 PM
17	2443	11/5/2014 5:45 PM
18	2166	11/5/2014 5:37 PM
19	2164	11/5/2014 4:38 PM
20	4806	11/5/2014 4:31 PM
21	4680	11/5/2014 3:32 PM
22	4707	11/5/2014 12:06 PM
23	2441	11/5/2014 9:45 AM
24	4650	11/5/2014 8:23 AM
25	2431	11/5/2014 8:22 AM
26	4891	11/5/2014 7:42 AM
27	2009	11/5/2014 6:59 AM
28	4850	11/5/2014 6:49 AM
29	2192	11/4/2014 9:29 PM
30	4891	11/4/2014 9:15 PM
31	2312	11/4/2014 9:07 PM
32	4680	11/4/2014 8:25 PM
33	2324	11/4/2014 8:00 PM
34	4207	11/4/2014 7:50 PM
35	4737	11/4/2014 6:50 PM
36	4680	11/4/2014 6:34 PM

37	4702	11/4/2014 6:02 PM
38	4270	11/4/2014 5:40 PM
39	2170	11/4/2014 4:58 PM
40	4740	11/4/2014 4:01 PM
41	4871	11/4/2014 1:25 PM
42	4874	11/1/2014 11:02 PM
43	4891	10/31/2014 10:35 AM
44	4701	10/31/2014 9:48 AM
45	2450	10/30/2014 10:57 PM
46	4891	10/30/2014 4:41 PM
47	2423	10/30/2014 11:13 AM
48	4981	10/30/2014 11:04 AM
49	2009	10/30/2014 9:54 AM
50	3003	10/30/2014 9:50 AM
51	2485	10/30/2014 4:44 AM
52	4849	10/29/2014 10:48 PM
53	4891	10/29/2014 10:18 PM
54	3051	10/29/2014 5:48 PM

Q43 Do you wish to be added to our mailing list and be provided with on-going information regarding this project?

Answered: 54 Skipped: 22



Answer Choices	Responses	
Yes	**81.48%**	44
No	**18.52%**	10
Total		**54**

Q44 Please provide your contact details:

Answered: 44 Skipped: 32

Q45 Do you have any other comments, questions, or concerns?

Answered: 28   Skipped: 48

#	Responses	Date
1	the amount of calcium in the water system has a lot to do with the hardness of the shell all catchers should find out the amount of calcium in their system. this will lead to a better shell	11/7/2014 12:30 PM
2	BAND C GRADE MUD CRAB	11/7/2014 10:26 AM
3	Concerns about the future of the industry in regards to the new government regulations.	11/7/2014 6:54 AM
4	Market buyers have to much influence in grading and should accept product as listed.	11/6/2014 4:43 PM
5	Not at this stage	11/6/2014 11:30 AM

6	Concerned about the amount of crabs called dead or slow and the grading changes.	11/6/2014 9:37 AM
7	I believe that rural run off is the worst thing for crab population	11/6/2014 2:15 AM
8	i have stopped sending mud crabs to sydney fish markets because of the grading scheme. i even went for a tour thogh the market and well they've lost my business.	11/5/2014 7:59 PM
9	Crabs should be sold as the grades they were purchased as it is not fair that retailers can sell c grade crabs for a grade prices whilst giving the catcher sometimes up to 20 dollars a kg less for the product it is not fair and there should also be advertising how to cook crabs that have a softer shell not cook them for 20 minutes like they say even a hard crab has no meat left after 20 mins a c grade crab cooked for 5 minutes has as much meat as a hard crab cooked for 12 minutes altough you cook a c grade crab for 12 minutes it is just mush	11/5/2014 6:05 PM
10	C grade crab should not be sold by SFM. We have no ability to argue their grading practices due to distance.	11/5/2014 3:36 PM
11	Ban the taking and selling of c grade mud crabs	11/5/2014 12:12 PM
12	yes dont like the way slow crabs are discarded so easy ,when a simple wet down with a hose gets them moving and also beleive that a buyer buying a c-grade crab should be made to sell as a c-grade crab ,you go to a resturant or fish shop you dont see them advertise c-grade crab on the menu CHEAPER DO YOU ?	11/5/2014 9:51 AM
13	The re introduction of the c grade crab to market was a ploy to lower the price of a grade crab , it worked for the market but was detrimental to the supplier , it created a get me all attitude and has put the sustainability of crabs at risk , the market should dictate the price not the manipilators.	11/5/2014 7:46 AM
14	yes my crabbing business has suffered do to the operation of crabbers moving to our region and running shot gun over the local crabbers you may think the hinchinbrook channel is a large area but due to the high volume of pots its not unusual to see 3 pots covering the one spot [I AND OTHERS HAVE STRONG VIEWS ON THESE OPERATORS]	11/5/2014 6:59 AM
15	My business is new but big, we want to be contacted by direct fisher who has stable supply of 1 tone of crabs per week please!	11/4/2014 9:33 PM
16	Why dont crabs have a weight for size grading system as a soft shell doesn't always relate to the amount of meat a crab may contain more to the conditions it has been affected by or the amount of people that keep pushing the shell in the same place either at point of capture or more so at the markets.	11/4/2014 9:18 PM
17	I hope there will be change to the take of soft crab to save the crab industry for the future	11/4/2014 9:18 PM
18	Qld crab fishery has a lot of issues, a phone call would be easier thanks	11/4/2014 8:27 PM
19	C grade crabs are easier to peel, and the meat is sweeter. Occasionally they have more meat recovery than a crab graded as B or even A. Sometimes C crab meat is inedible (mushy and yuk), sometimes A crabs are completely empty (old age). Shell hardness gives only a likelyhood of meat content.	11/4/2014 8:04 PM
20	no	11/4/2014 8:01 PM
21	not sell c grade	11/4/2014 6:54 PM
22	Legislation is needed to cease the take of inferior quality mud crab. I was always against the take of B grade crab so how do you think I feel about C grade crab being sold ? P----- Off.	11/4/2014 6:08 PM
23	This should have been done long time ago and carry through to rec sector.	11/4/2014 4:04 PM
24	I believe there is too much compliance needs in my industry and we could do with more fishery inspectors to enforce the laws we already have!!	10/30/2014 4:51 PM
25	Fishers and Buyers are their own worst enemy, the sooner they realise schemes such as this are developed to assist them and not hinder them, the quicker their respective sector will progress. Everything possible needs to be deployed to convince the crab harvesting and trading sectors to fully support the outcome of any changes to the Scheme.	10/30/2014 9:59 AM
26	The current grading is controversial and has impacted on many through the Sydney market with "a" being downgraded... To "b" - this was dependent on who was grading and again down to "c". We do not sell "c" at all so question their methods and credibility	10/30/2014 4:47 AM
27	The buyers need to be regulated also I believe pot to plate tags need to be introduced to identify the crab as witch ever grade it is this will hold them responsible for what the are marketing and tags must be displayed at all times this would also help with the black marketing	10/29/2014 10:24 PM
28	Main concern - Qld crabs being substituted for Darwin crabs which has somewhat diluted the Darwin brand - people do it so they can charge more money for an inferior product	10/29/2014 5:53 PM

Appendix 6 – How full is your mud crab? Survey on satisfaction of meat fullness

Scheme questionnaire and results

How full is your mud crab?

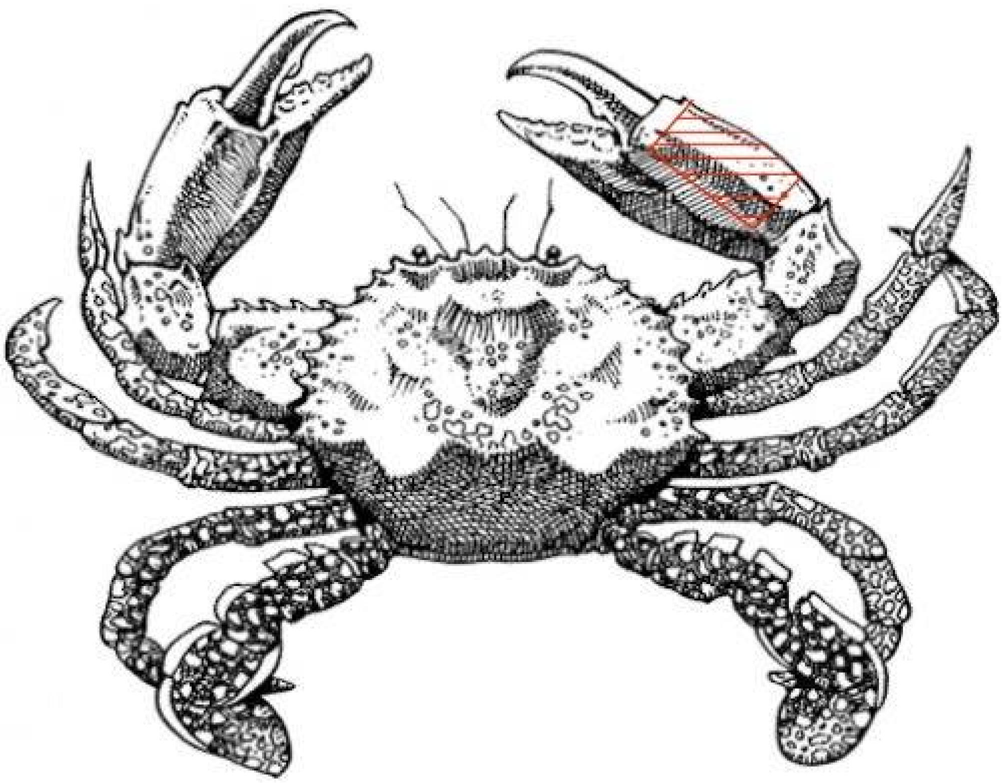
Welcome to My Survey

Thank you for participating in our survey. Your feedback is important to a joint Queensland Government DAF and Fisheries Research and Development Corporation project to improve mud crab grading.

You will be shown 3 photographs of mud crab claws that have had a section of shell removed as shown by the shaded section in the diagram below. The photographs are taken from above to show the exposed meat within the shell cavity.

Please answer the two questions with each photograph. The final page will ask a little background about yourself and your mud crab eating experience.

Scroll down and click in the Next box to proceed to the next page.
On the last page click in the Done box.



How full is your mud crab?

Crab claw #1

How satisfied are you with the meat fullness of this mud crab claw?

Please answer the two questions below the picture, then scroll down to click in the box for the Next Question.

- **Crab claw #842**

Respondents: 16.65%

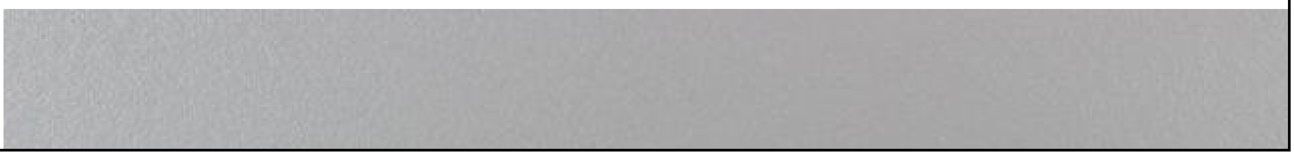
- **Crab claw #934**

Respondents: 16.67%

- **Crab claw #541**

Respondents: 16.67%

- **Crab claw #615**

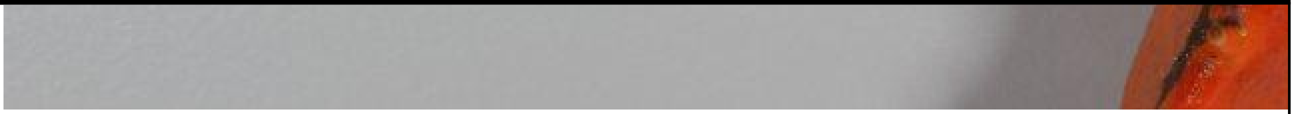


How full is your mud crab?

Respondents: 16.67%

- **Crab claw #677**

How full is your mud crab?



Respondents: 16.67%

- **Crab claw #935**

Respondents: 16.67%

1. How does this meet your expectation of a full mud crab?

Extremely satisfied	Quite satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Quite dissatisfied	Extremely dissatisfied
◯	◯	◯	◯	◯	◯	◯

2. If a full mud crab cost $35/kg how much are you willing to pay for this?

How full is your mud crab?

Crab claw #2

How satisfied are you with the meat fullness of this mud crab claw?

Please answer the two questions below the picture, then scroll down to click in the box for the Next Question.

- **Crab claw #642**

Respondents: 16.65%

- **Crab claw #798**

Respondents: 16.67%

- **Crab claw #763**

Respondents: 16.67%

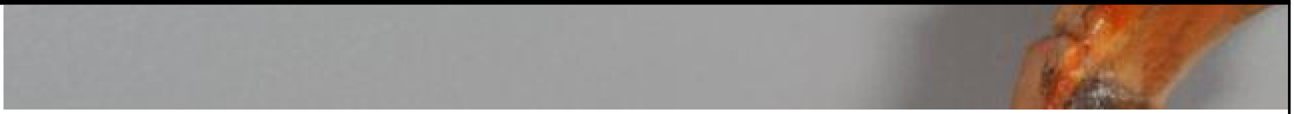
- **Crab claw #545**

How full is your mud crab?

Respondents: 16.67%

- **Crab claw #820**

How full is your mud crab?



Respondents: 16.67%

- **Crab claw #621**

Respondents: 16.67%

3. How does this meet your expectation of a full mud crab?

Extremely satisfied	Quite satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Quite dissatisfied	Extremely dissatisfied
◯	◯	◯	◯	◯	◯	◯

4. If a full mud crab cost $35/kg how much are you willing to pay for this?

How full is your mud crab?

Crab claw #3

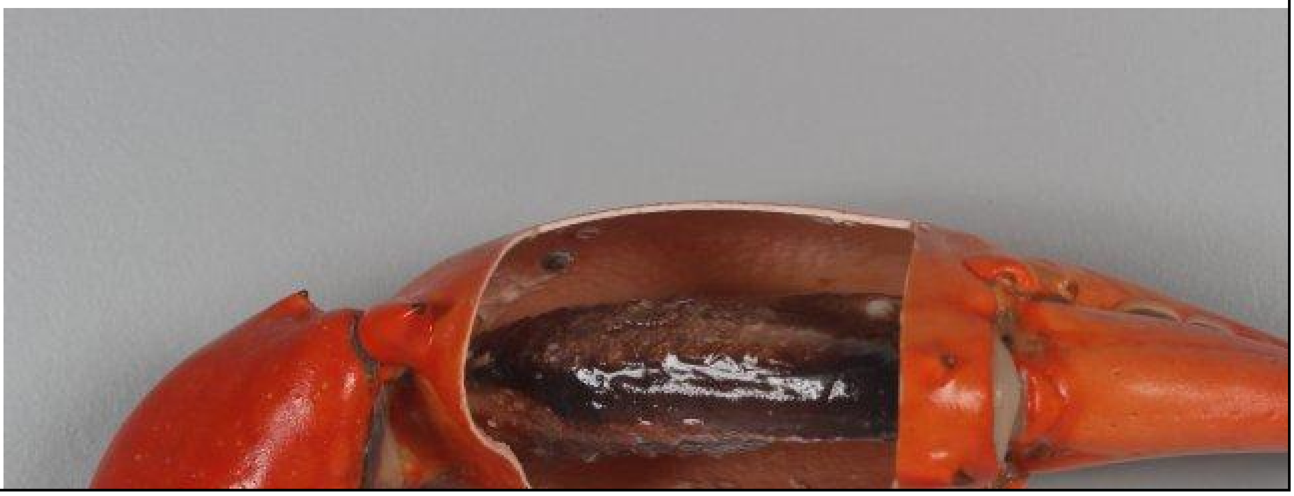
How satisfied are you with the meat fullness of this mud crab claw?

Please answer the two questions below the picture, then scroll down to click in the box for the Next Question.

- **Crab claw #278**

Respondents: 16.65%

- **Crab claw #321**



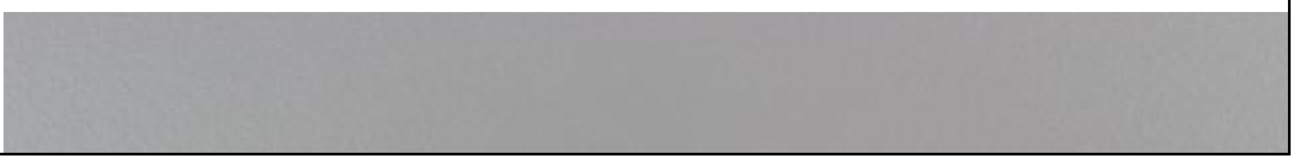
How full is your mud crab?

Respondents: 16.67%

- **Crab claw #769**

Respondents: 16.67%

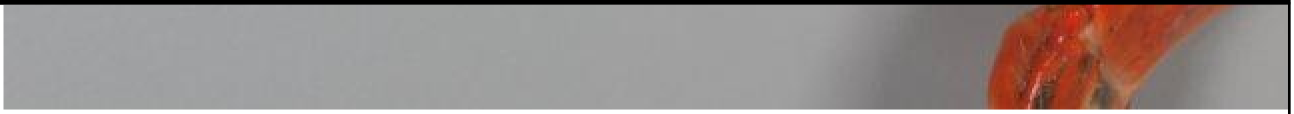
- **Crab claw #481**



Respondents: 16.67%

- **Crab claw #927**

How full is your mud crab?



Respondents: 16.67%

- **Crab claw #902**

Respondents: 16.67%

5. How does this meet your expectation of a full mud crab?

Extremely satisfied	Quite satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Quite dissatisfied	Extremely dissatisfied
◯	◯	◯	◯	◯	◯	◯

6. If a full mud crab cost $35/kg how much are you willing to pay for this?

How full is your mud crab?

Demographics

Tell us a little about yourself and your mud crab eating experience.

7. Are you a professional or amateur mud crab fisher or a consumer of mud crabs ?

- [ ] Professional mud crab fisher
- [ ] Amateur mud crab fisher
- [ ] Consumer of mud crabs
- [ ] None of the above

8. How regularly do you eat mud crabs ?

- ○ Weekly
- ○ Monthly
- ○ Every three months
- ○ Rarely
- ○ Never

9. What is your ethnic eating background ?

- ○ Asian
- ○ Australian
- ○ European
- ○ Other (please specify)

Thank you for particpating in My Survey.

The information you have provided will benefit a joint Queensland Government DAF and Fisheries Research and Development Corporation project to improve mud crab gradings.

Q1 Crab claw #842

Variable: 1 Viewed: 41 (17.75%)

Q1 Crab claw #934

Variable: 2 Viewed: 35 (15.15%)

Q1 Crab claw #541

Variable: 3 Viewed: 42 (18.18%)

Q1 Crab claw #615

Variable: 4 Viewed: 29 (12.55%)

Q1 Crab claw #677

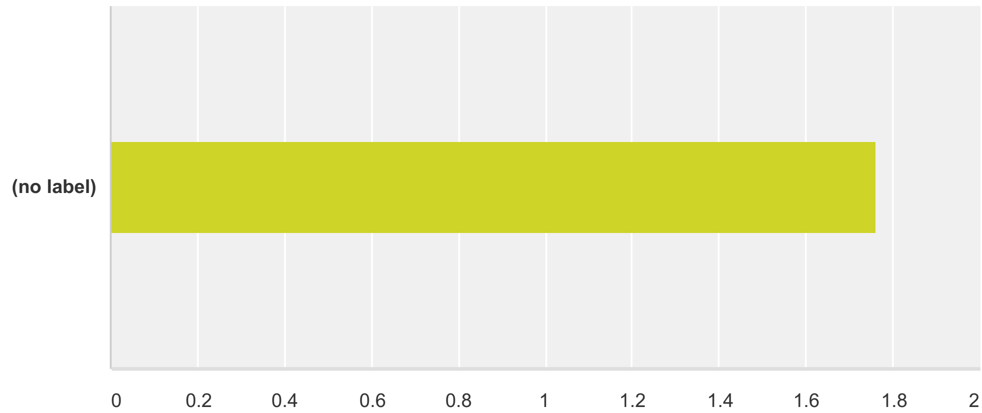
Variable: 5 Viewed: 41 (17.75%)

Q1 Crab claw #935

Variable: 6   Viewed: 43 (18.61%)

Q2 How does this meet your expectation of a full mud crab?

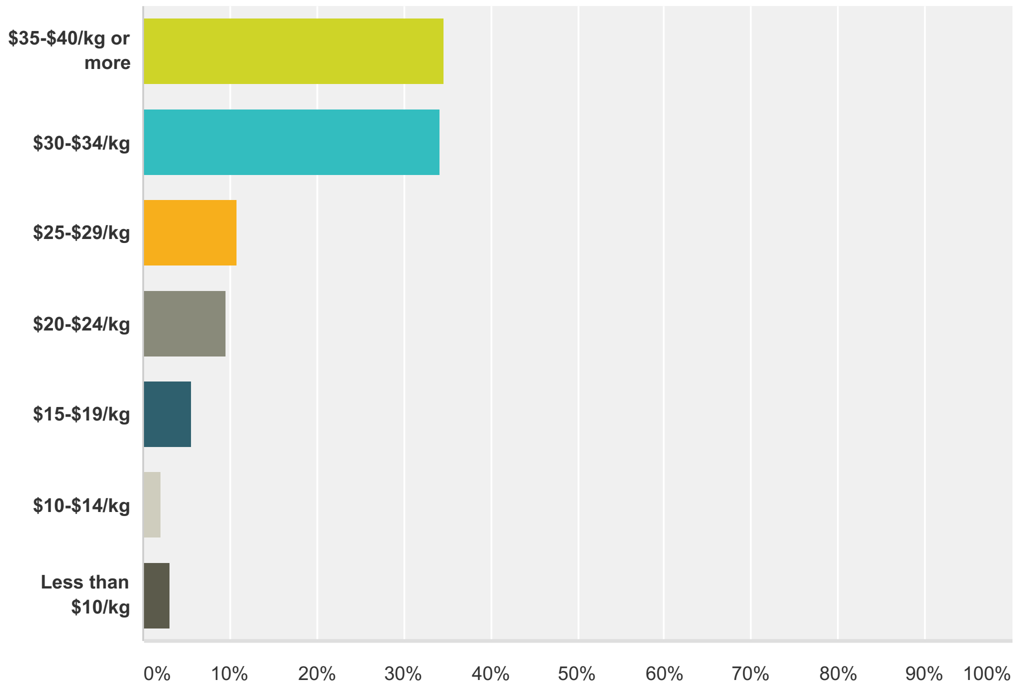
Answered: 231 Skipped: 7



	Extremely satisfied	Quite satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Quite dissatisfied	Extremely dissatisfied	Total	Weighted Average
(no label)	**51.08%** 118	**38.53%** 89	**4.33%** 10	**0.87%** 2	**1.30%** 3	**2.60%** 6	**1.30%** 3	231	1.76

Q3 If a full mud crab cost $35/kg how much are you willing to pay for this?

Answered: 231 Skipped: 7



Answer Choices	Responses	
$35-$40/kg or more	**34.63%**	80
$30-$34/kg	**34.20%**	79
$25-$29/kg	**10.82%**	25
$20-$24/kg	**9.52%**	22
$15-$19/kg	**5.63%**	13
$10-$14/kg	**2.16%**	5
Less than $10/kg	**3.03%**	7
Total		**231**

Q4 Crab claw #642

Variable: 1 Viewed: 34 (14.91%)

Q4 Crab claw #798

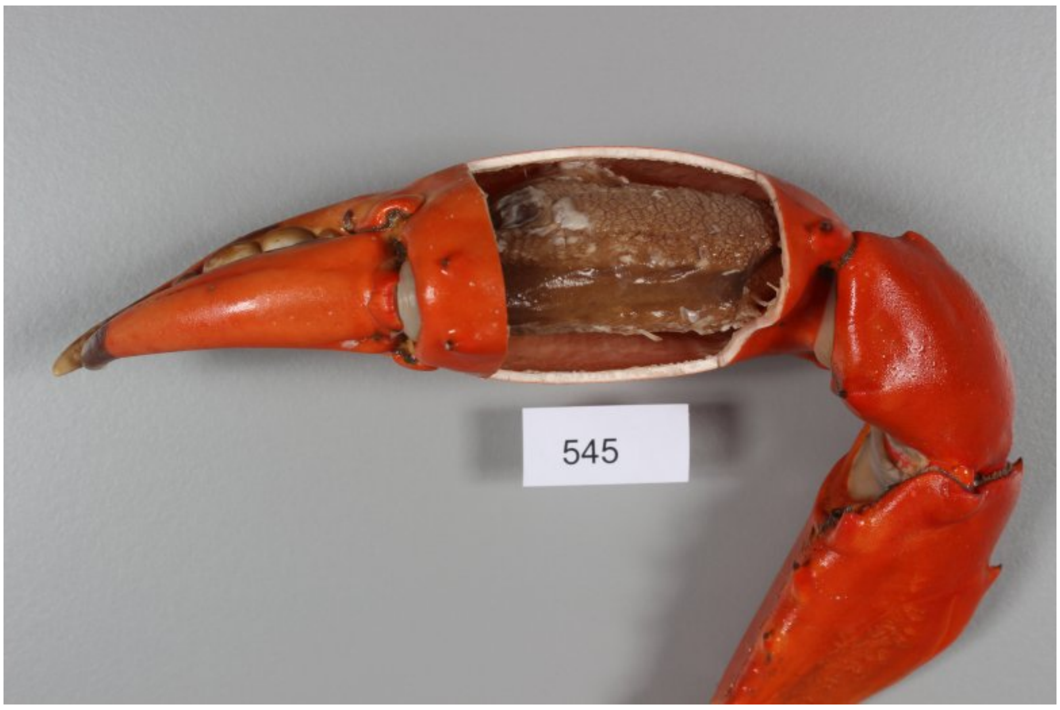
Variable: 2 Viewed: 33 (14.47%)

Q4 Crab claw #763

Variable: 3 Viewed: 36 (15.79%)

Q4 Crab claw #545

Variable: 4   Viewed: 41 (17.98%)



Q4 Crab claw #820

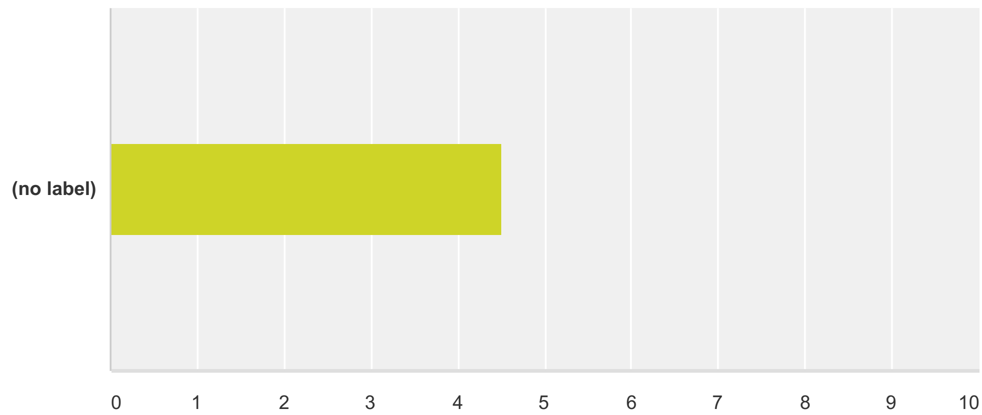
Variable: 5 Viewed: 49 (21.49%)

Q4 Crab claw #621

Variable: 6 Viewed: 35 (15.35%)

Q5 How does this meet your expectation of a full mud crab?

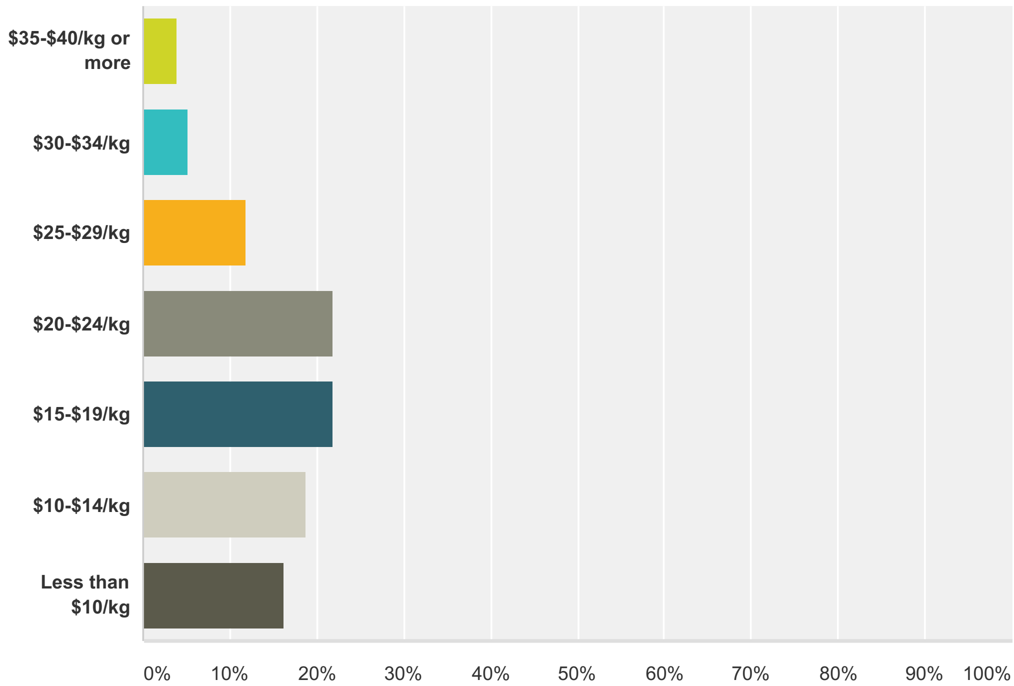
Answered: 228 Skipped: 10



	Extremely satisfied	Quite satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Quite dissatisfied	Extremely dissatisfied	Total	Weighted Average
(no label)	**1.32%** 3	**7.89%** 18	**17.54%** 40	**20.61%** 47	**24.12%** 55	**21.05%** 48	**7.46%** 17	228	4.51

Q6 If a full mud crab cost $35/kg how much are you willing to pay for this?

Answered: 228 Skipped: 10



Answer Choices	Responses	
$35-$40/kg or more	**3.95%**	9
$30-$34/kg	**5.26%**	12
$25-$29/kg	**11.84%**	27
$20-$24/kg	**21.93%**	50
$15-$19/kg	**21.93%**	50
$10-$14/kg	**18.86%**	43
Less than $10/kg	**16.23%**	37
Total		**228**

Q7 Crab claw #278

Variable: 1 Viewed: 37 (16.44%)

Q7 Crab claw #321

Variable: 2   Viewed: 33 (14.67%)

Q7 Crab claw #769

Variable: 3 Viewed: 34 (15.11%)

Q7 Crab claw #481

Variable: 4 Viewed: 37 (16.44%)

Q7 Crab claw #927

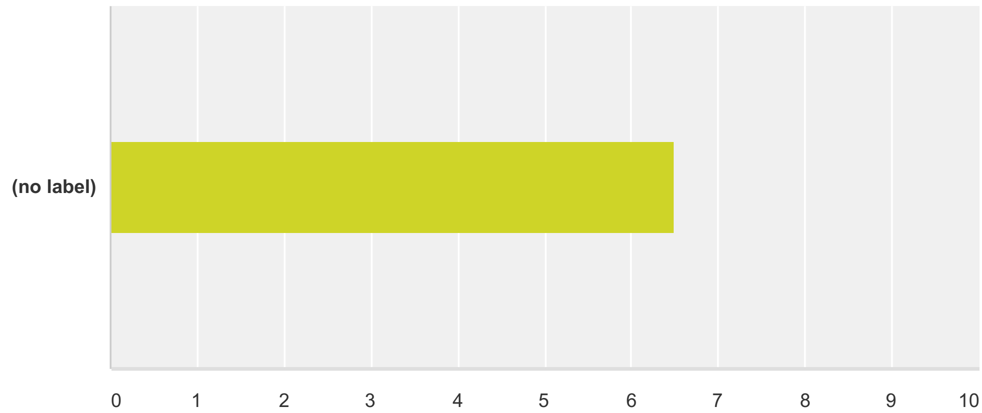
Variable: 5 Viewed: 42 (18.67%)

Q7 Crab claw #902

Variable: 6 Viewed: 42 (18.67%)

Q8 How does this meet your expectation of a full mud crab?

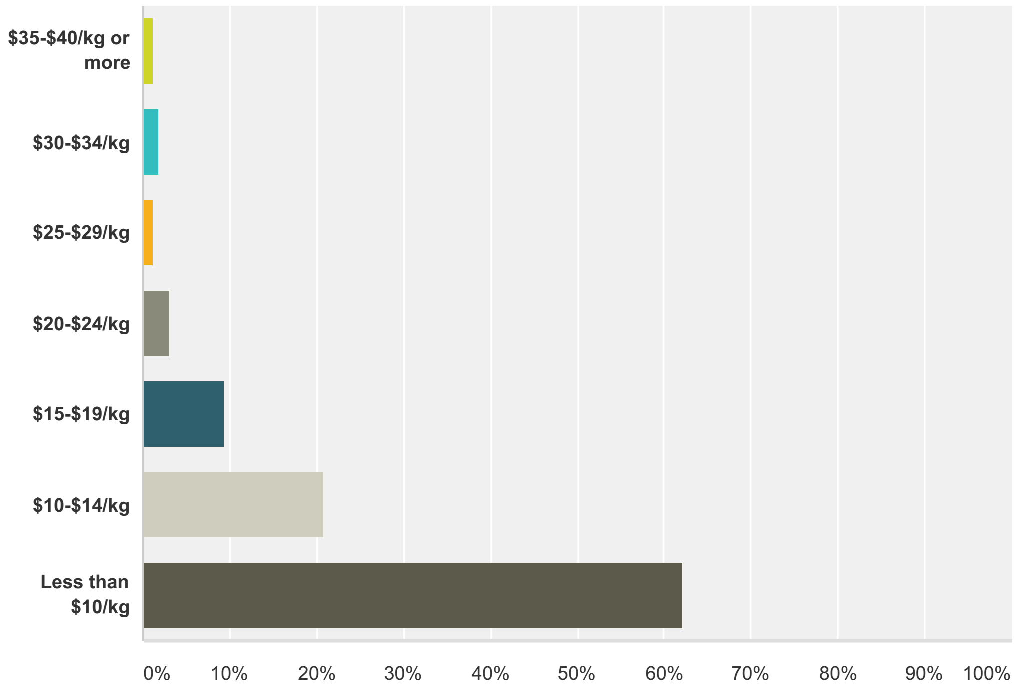
Answered: 225 Skipped: 13



	Extremely satisfied	Quite satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Quite dissatisfied	Extremely dissatisfied	Total	Weighted Average
(no label)	**0.00%** 0	**1.33%** 3	**0.89%** 2	**0.89%** 2	**4.89%** 11	**28.44%** 64	**63.56%** 143	225	6.49

Q9 If a full mud crab cost $35/kg how much are you willing to pay for this?

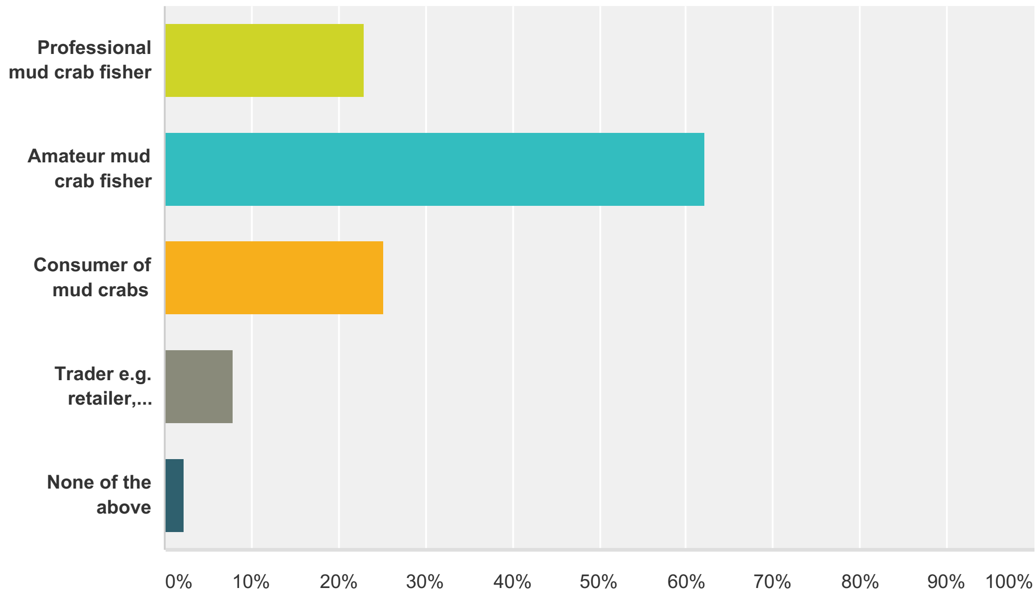
Answered: 225 Skipped: 13



Answer Choices	Responses	
$35-$40/kg or more	**1.33%**	3
$30-$34/kg	**1.78%**	4
$25-$29/kg	**1.33%**	3
$20-$24/kg	**3.11%**	7
$15-$19/kg	**9.33%**	21
$10-$14/kg	**20.89%**	47
Less than $10/kg	**62.22%**	140
Total		**225**

Q10 What is your involvement with mud crabs?

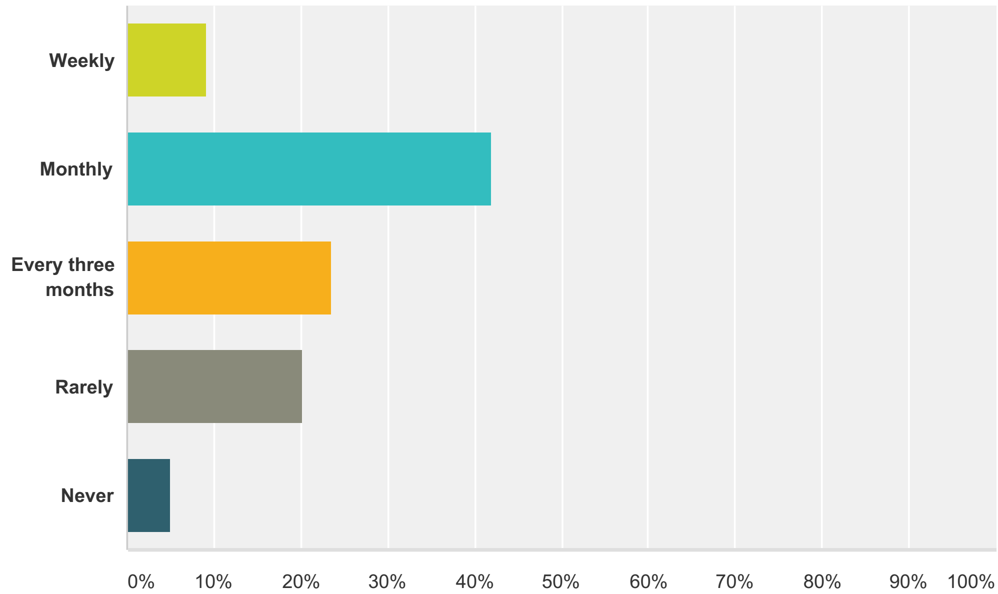
Answered: 217 Skipped: 21



Answer Choices	Responses	
Professional mud crab fisher	**23.04%**	50
Amateur mud crab fisher	**62.21%**	135
Consumer of mud crabs	**25.35%**	55
Trader e.g. retailer, wholesaler, restaurateur	**7.83%**	17
None of the above	**2.30%**	5
Total Respondents: 217		

Q11 How regularly do you eat mud crabs ?

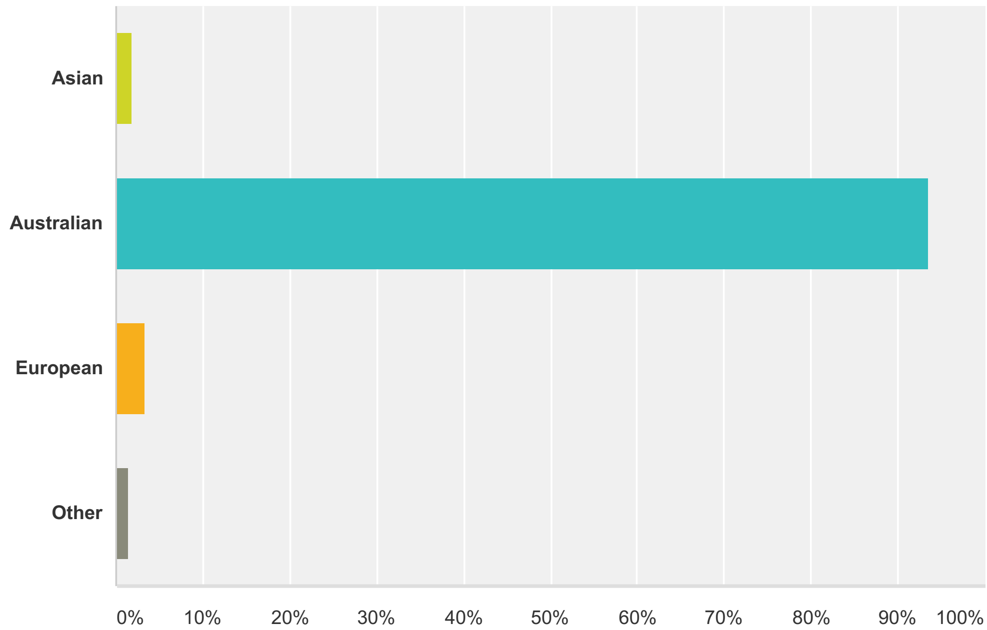
Answered: 217 Skipped: 21



Answer Choices	Responses	
Weekly	9.22%	20
Monthly	41.94%	91
Every three months	23.50%	51
Rarely	20.28%	44
Never	5.07%	11
Total		217

Q12 What is your ethnic eating background ?

Answered: 216 Skipped: 22



Answer Choices	Responses	
Asian	**1.85%**	4
Australian	**93.52%**	202
European	**3.24%**	7
Other	**1.39%**	3
Total		**216**

Appendix 7 – Workshop presentation

Mud crab grading workshop

John Mayze, Sue Poole - DAF

and

Chris Calogeras - C-AID

26-27th May 2016

Background

Prior to 2011 – various schemes

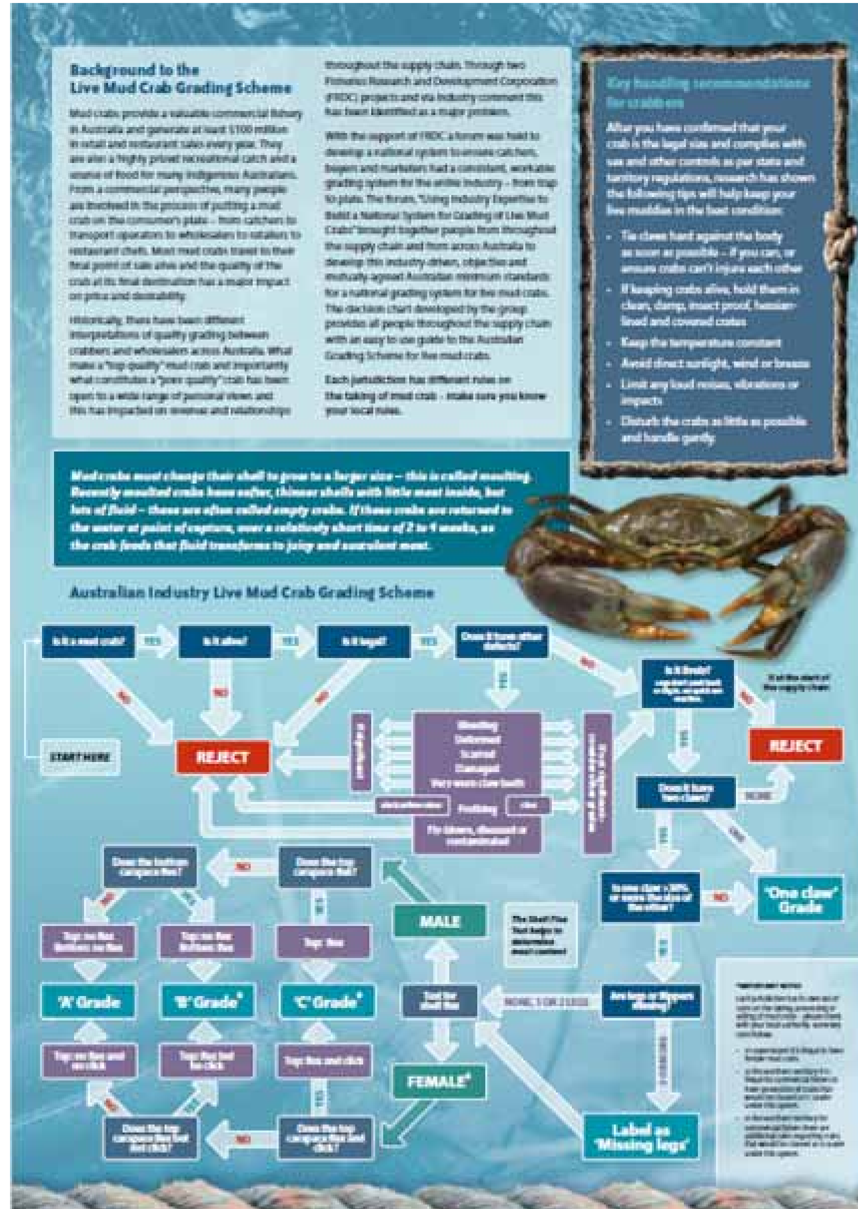
- e.g. SFM Handling Guidelines, NT Fisheries Regulations & local ‘standards’

2012 - FRDC Project – AILMGS Version 1

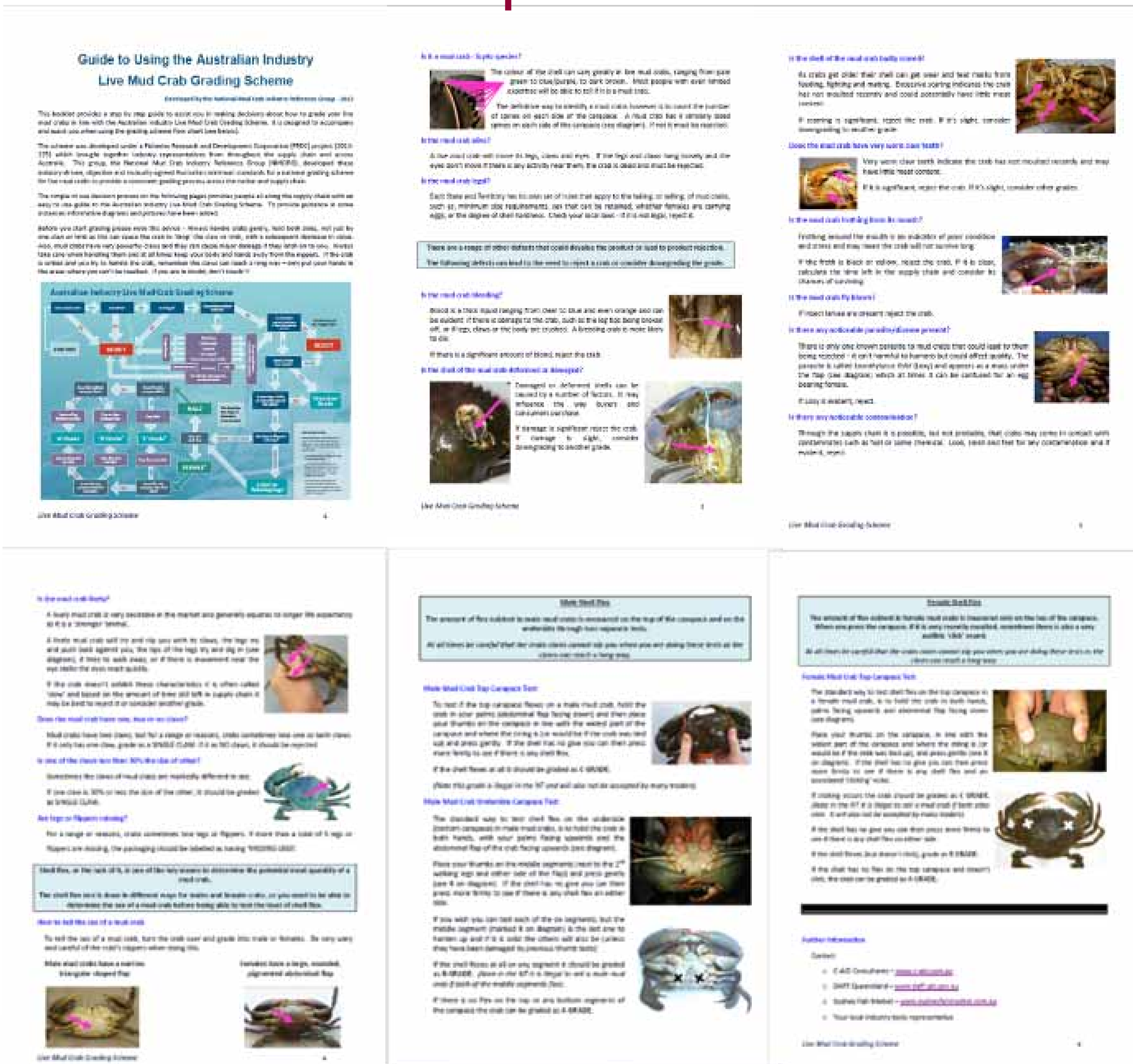
July 2014 - FRDC Project – Anomalies

- 15th Jan 2015 - PFA meeting at SFM
- 4th May 2015 - SFM phase-in of Version 2
- 27th May 2015 - Version 2 released via Steering Committee

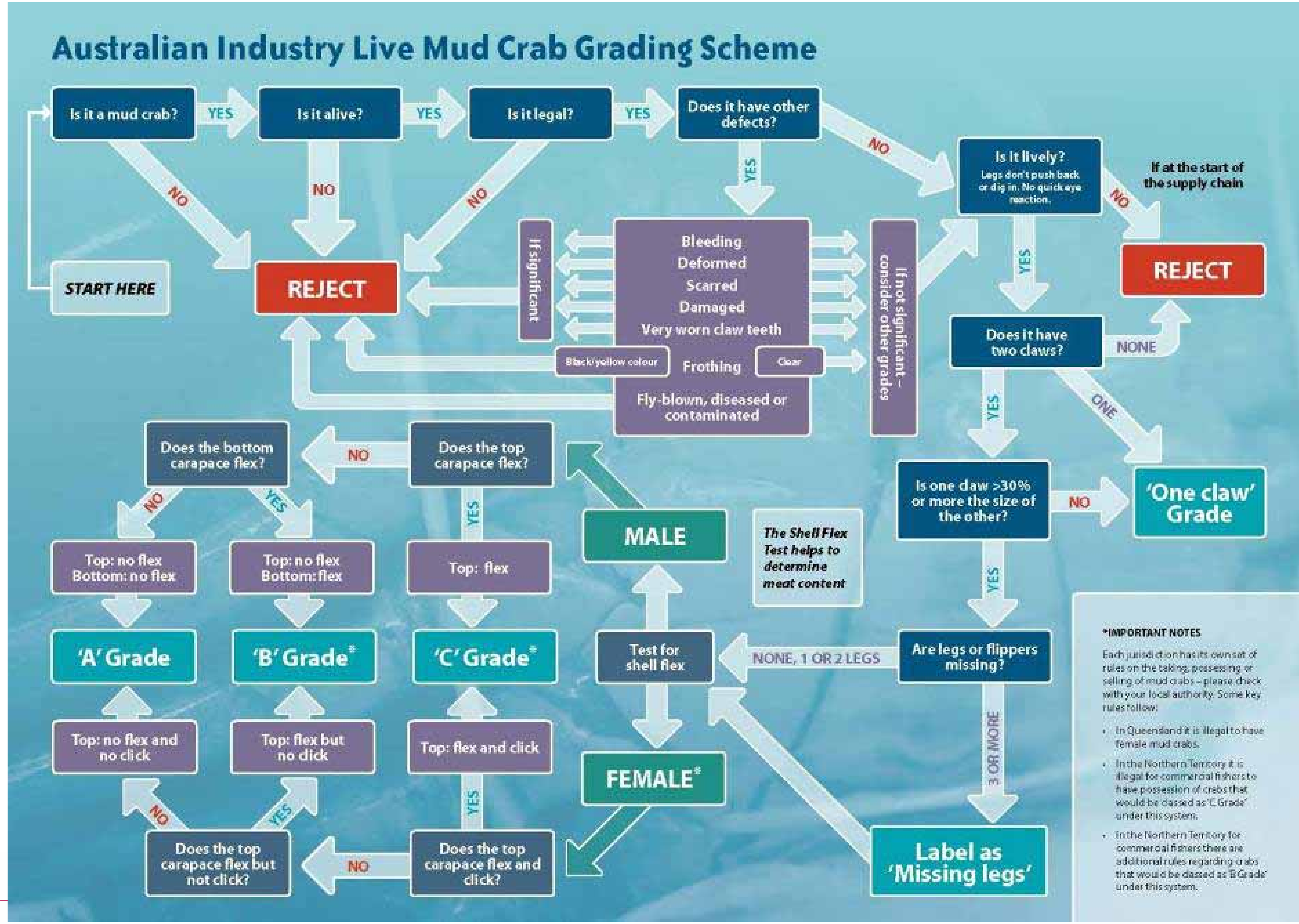
2012 project - Version 1 - Booklet



Version 1 - Guide p1-3



Version 1 - Flowchart



2014 - FRDC Project - R&S Anomalies

- **Project Outline**

  - Substantiate if there are seasonal or regional anomalies that would impact use of the AILMCGS
  - Determine the appropriateness of the assessment methods in the current scheme
  - Seek to reduce downgrades
  - Identify or develop objective technologies to support in field grading to compliment the AILMCGS.

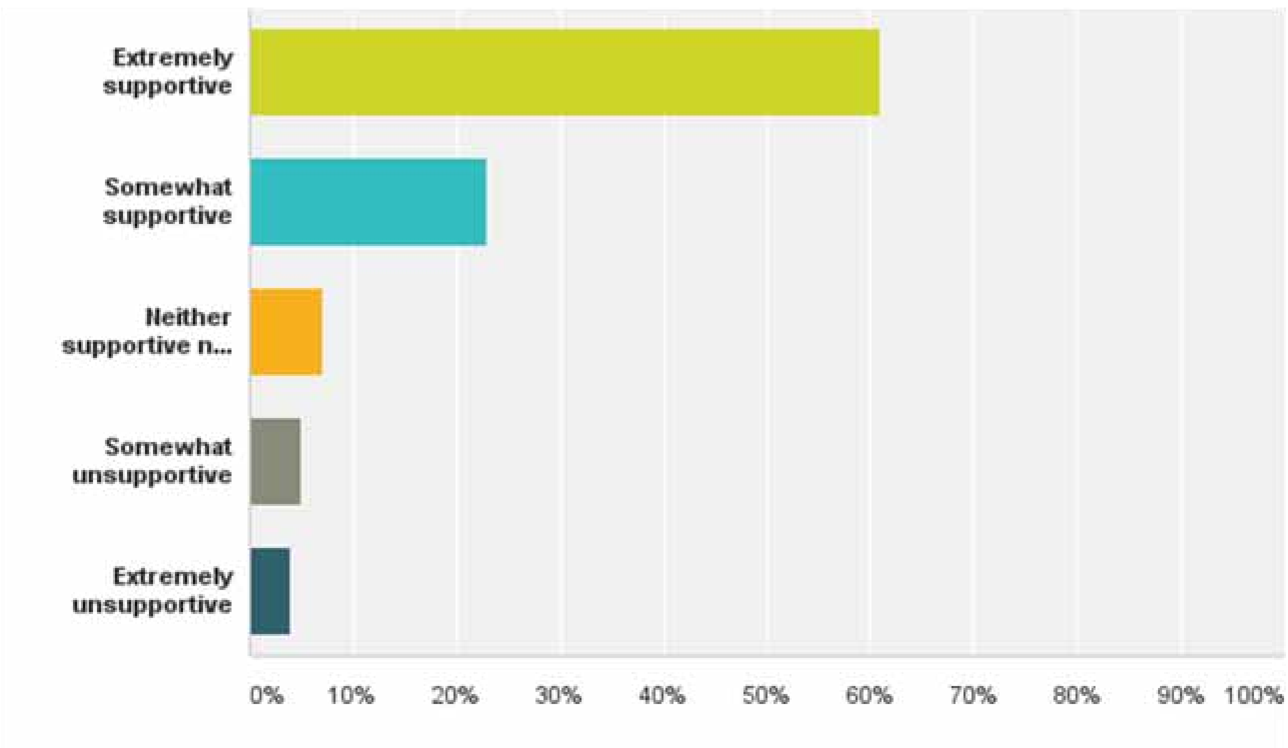
Research Undertaken - overview

- Identify scope of non-fit occurrence
  - Survey 1 – Scheme feedback
  - Regional samples
- Issues
  - Thumb pressure test
  - Hardness changes during storage
  - Not hardening
- Meat fullness
  - Survey 2 – How full is your mud crab?
  - Regional samples
- Overview of findings
- Modifications to scheme?

Scheme feedback – Oct 2014

Q1: Do you support the concept of having a national live mud crab grading scheme?

Answered: 100 Skipped: 1



Survey 1 – Scheme feedback Oct 2014

Q4: Overall, are you satisfied, dissatisfied, or neither satisfied nor dissatisfied with the Grading Scheme?

Answered: 90 Skipped: 11

Answer Choices	Responses	
Extremely satisfied	8.89%	8
Quite satisfied	18.89%	17
Somewhat satisfied	13.33%	12
Neither satisfied nor dissatisfied	17.78%	16
Somewhat dissatisfied	11.11%	10
Quite dissatisfied	6.67%	6
Extremely dissatisfied	23.33%	21
Total		**90**

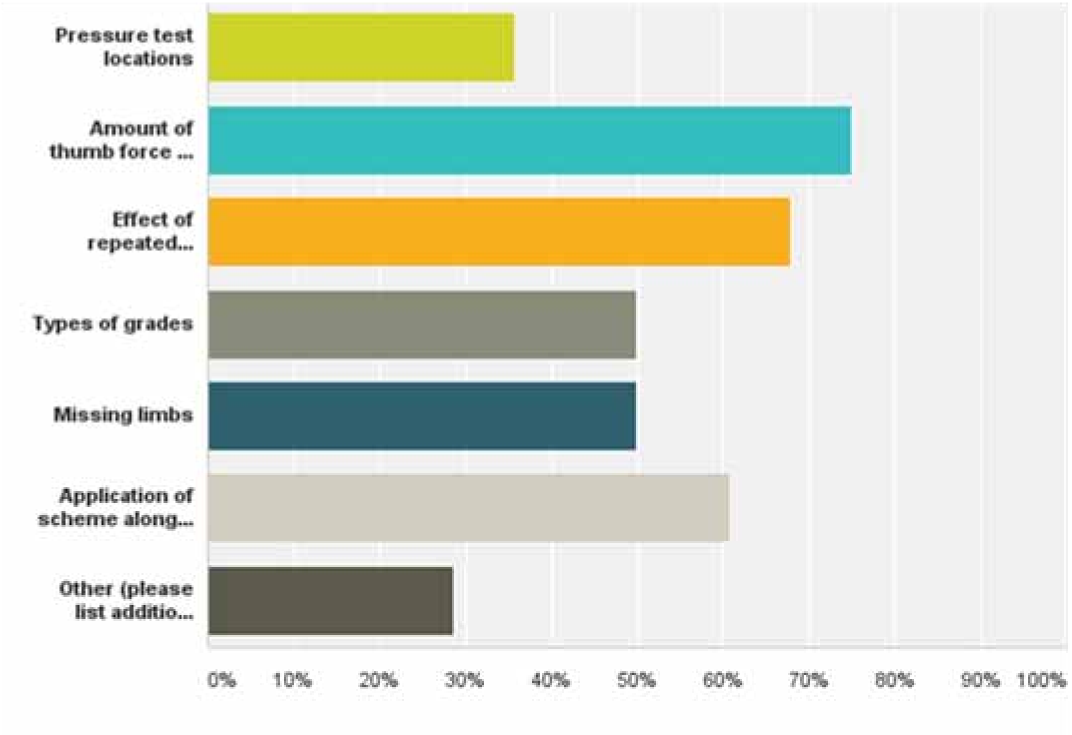
37 ☺

37 ☹

Survey 1 – Scheme feedback Oct 2014

Q7: What are your concerns with the attributes used within the Grading Scheme to differentiate grades?(select as many as apply)

Answered: 28 Skipped: 73

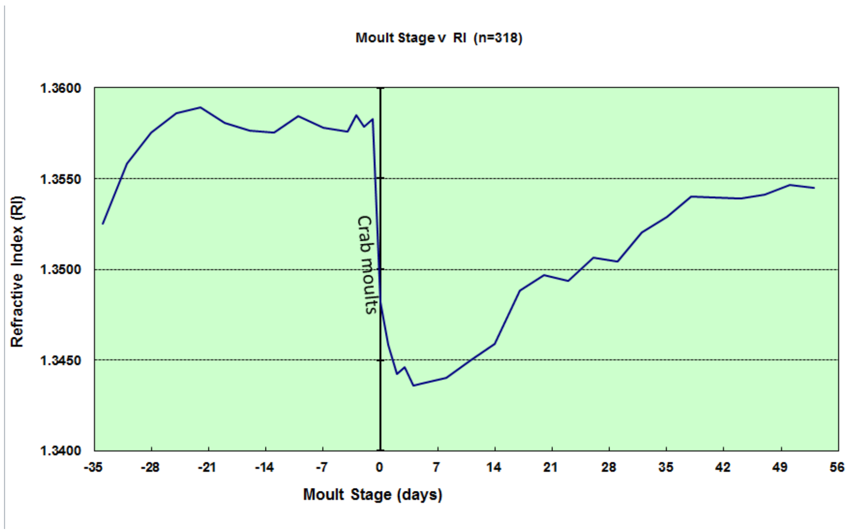


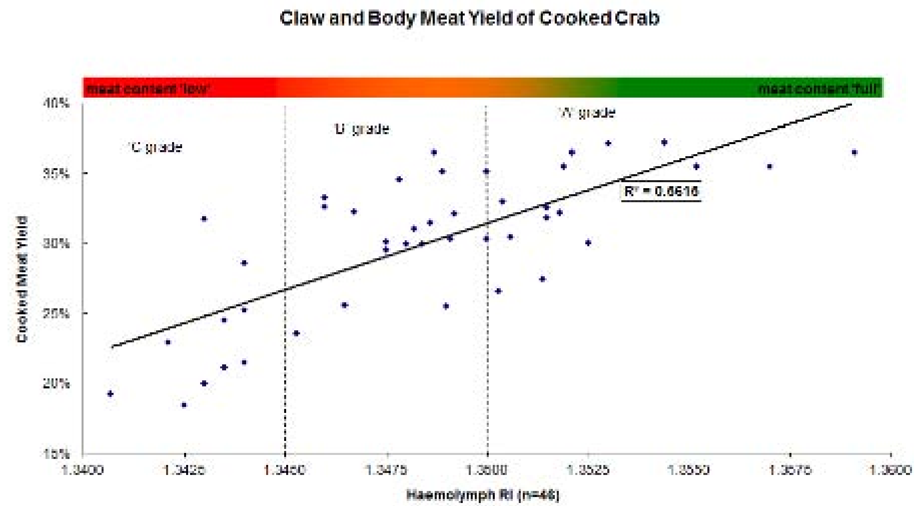
Grading Issues

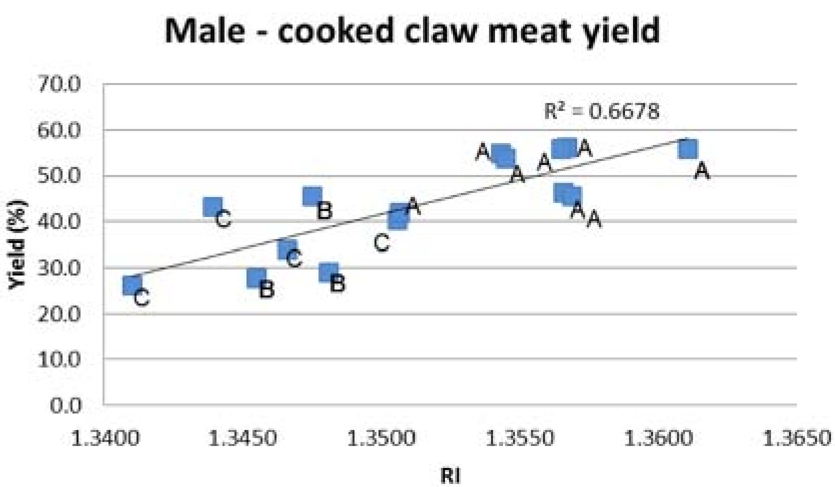
- Downgrades – option to label as ‘ungraded’
- Male top carapace flex test
  - Thumb damage/deaths
  - Unreliable test method and indicator
- Regional anomalies
  - Inconsistencies between NSW & QLD
  - NSW crab shell flex but full of meat
  - Some NSW crab never reach ‘A’ grade by shell flex
- Seasonal anomalies
  - Rainfall & salinity
- Liveliness – objective, cold, motionless
- Females, old crusties, regrown claws etc

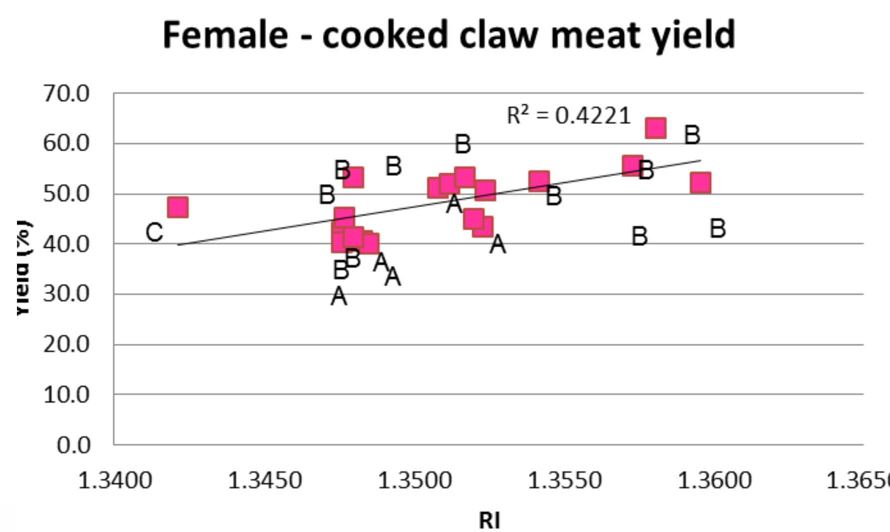

Dead

Regional Samples
SFM workshop 30th May 2015

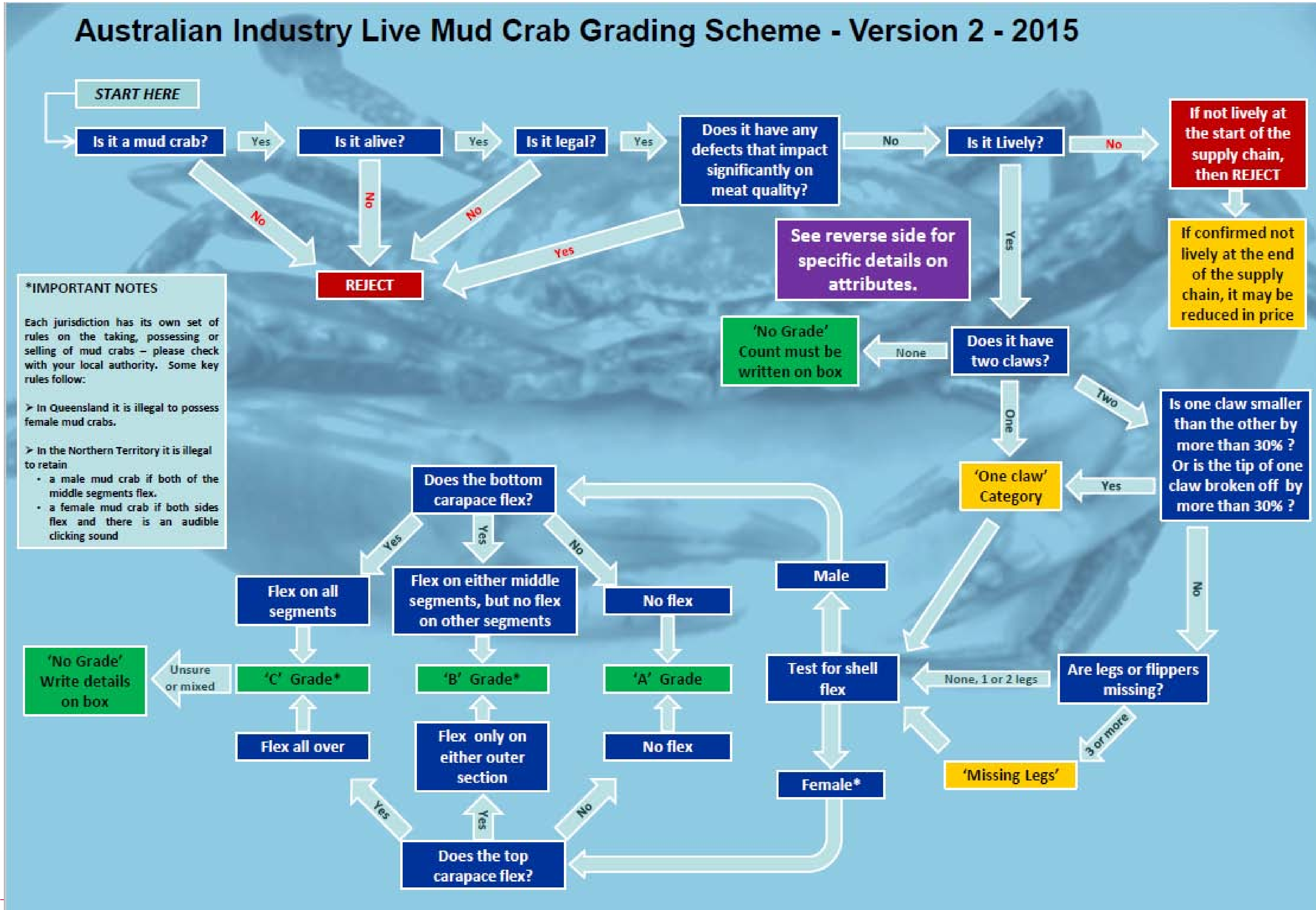






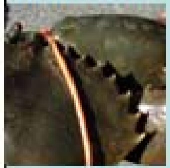


Version 2 - Flowchart



Version 2

Is it a mud crab - *Scylla* species



A mud crab has nine similarly sized spines on each side of the carapace . If not, it must be rejected.

Bleeding

If there is a significant amount of blood, reject the crab. A small amount of blood may not be 'A grade'.

Damaged or deformed

If damage or deformity is significant **and likely to impact on meat quality or survivability**, reject the crab. Minor damage and excessive barnacles are not defects.

Old empty crabs

If scarring is significant, claw teeth completely worn **and** the crab is light in weight for its size, reject the crab.

Frothing

If the froth is black or yellow, reject the crab. If there is a significant amount of clear froth and the crab is slow, it may be downgraded. Short exposure to cold can cause temporary frothing and the crab will recover.

Parasite

Loxothylacus ihlei (Loxy) appears as a mass under the flap which can be confused for an egg bearing female. If evident, reject.

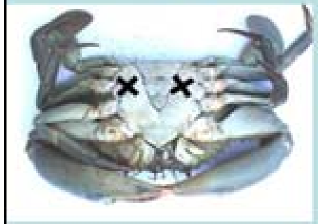
Is it lively?

A lively crab's legs will provide resistance or push back against you, and their eyes react to movement. A cold crab may appear to be slow and can be revived. Crabs placed on their back may appear motionless, so confirm liveliness by untying or wetting.

Two normal and complete claws

If one claw is smaller than the other by more than 30% or the top tip is broken off by more than 30% and signs of spoilage, then 'One claw' category.

Male shell flex test



Hold the crab in both hands, with your palms facing upwards and the abdominal flap of the crab facing upwards. Place the flat of your thumbs on the middle segments (next to the 2nd walking legs and either side of the flap, see **X** on diagram) and press gently at first.

'A' Grade - No flex with firm pressure

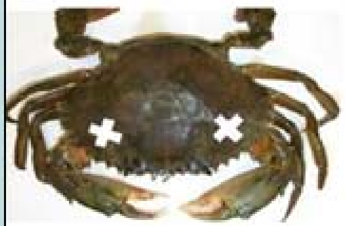
'B' Grade – Shell flexes with moderate pressure on either middle segment and no flex on the other segments

'C' Grade - Shell flexes with minimal pressure on all six segments

Note:

- Only press once. Repeated pressure will damage the shell.
- Segments already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a male mud crab if both of the middle segments flex.

Female shell flex test



Hold the crab in both hands, palms facing upwards and the abdominal flap facing down. Place the flat of your thumbs on the carapace, in line with the widest part of the carapace and where the string is (or would be if the crab was tied up, see **X** on the diagram), and press gently at first.

'A' Grade - No flex with firm pressure

'B' Grade - Shell flexes with moderate pressure on either side

'C' Grade - All the top carapace (sides and centre) flexes with minimal pressure

Note:

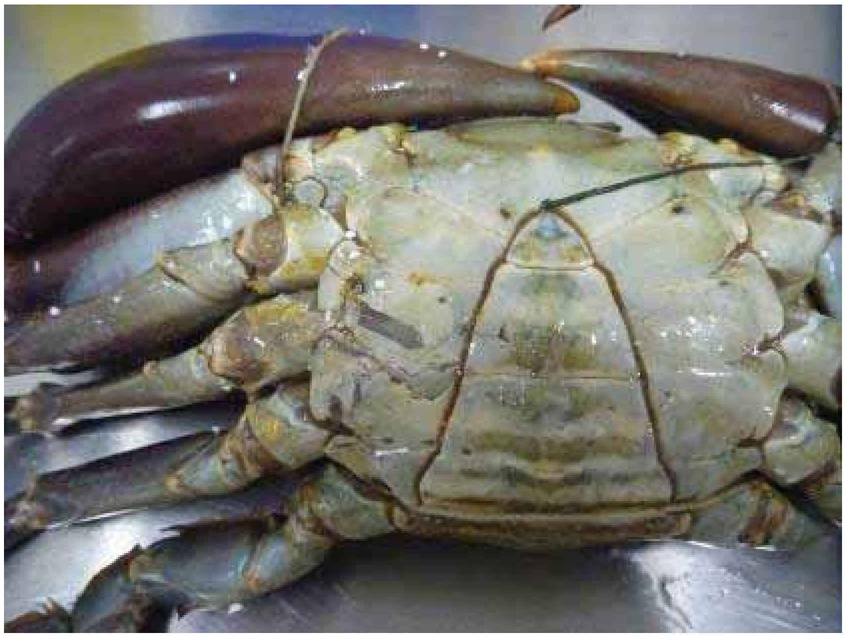
- Only press once. Repeated pressure will damage the shell.
- Carapace already damaged from previous tests should not be used to determine grade.
- Do not use the tip of your thumb to apply pressure.
- Avoid excessive pressure as shell damage will reduce survivability.
- In the NT it is illegal to retain a female mud crab if both sides flex and there is an audible clicking sound.

'No Grade' - Write details on box.

Accessed only for liveliness, shell damage, missing legs or claws and other 'defects'.
Details to include:- sex, one or no claws, 'missing legs', count & weight of each category.
Mandatory that number of no claws crabs be written on box or buyer can reject.

Shell hardness assessment by pressure

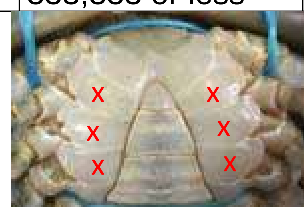
- Multiple thumb tests



Shell hardness assessment by pressure

- Assessor variability of thumb test
  - Assessment scoring used in AILMCGS Version 2

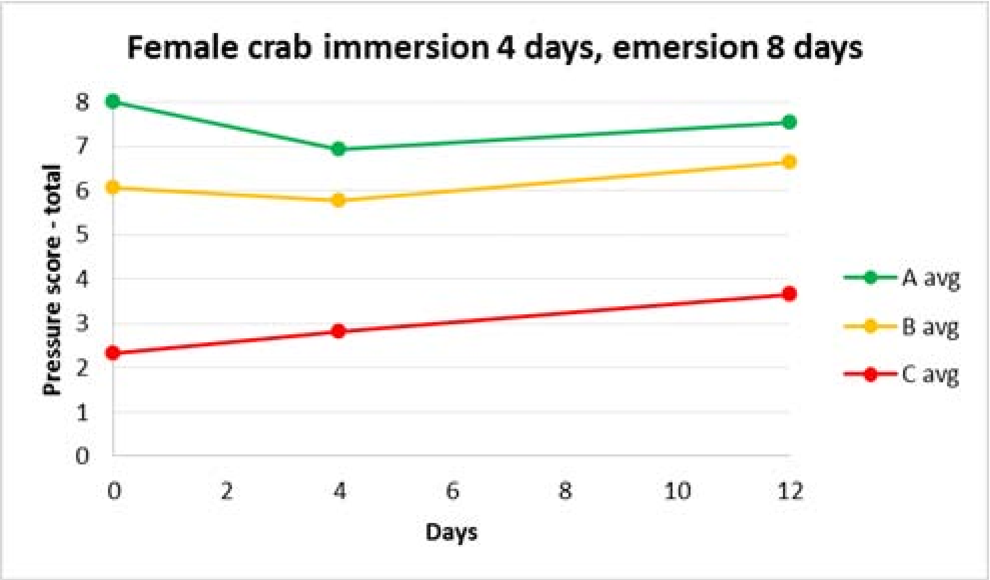
Grade	Male	Segments	Total Score	Female	Segments	Total score
A	No flex	444,444	24	No flex	4,4	8
B	Flex on either middle segment, but no flex on other segments	444,434 - 434,434	23-22	Flex on at least one side	3,4 - 3,3	6-7
C	Flex on all segments	333,333 or less	18-6	Very flexible on both sides	2,2 - 1,1	4-2

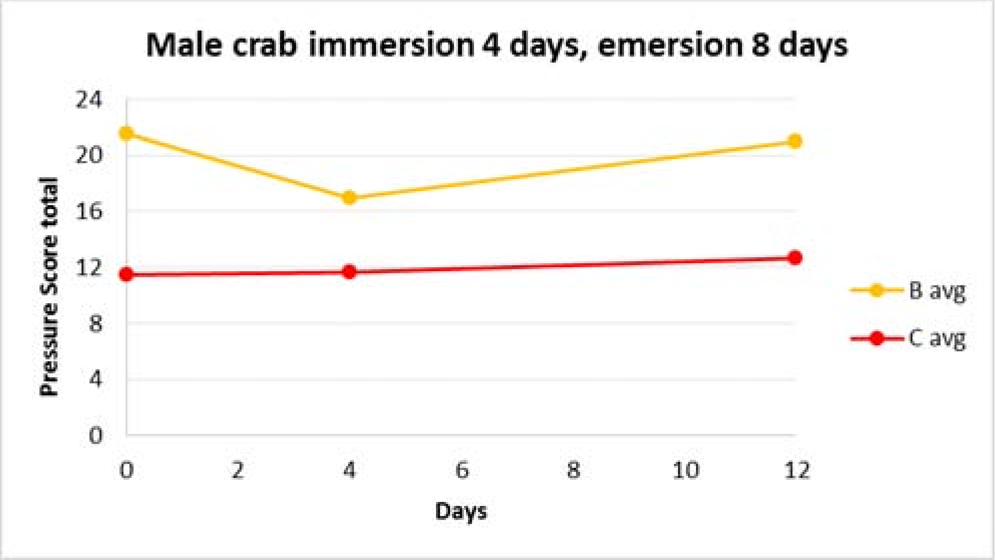


  - Industry example of grade variation

	Female		Male	
Grade	**Res grade**	**Ind Grade**	**Res grade**	**Ind Grade**
A	13	0	1	1
B	34	2	2	
C	10	55	13	15

Shell hardness changes post capture

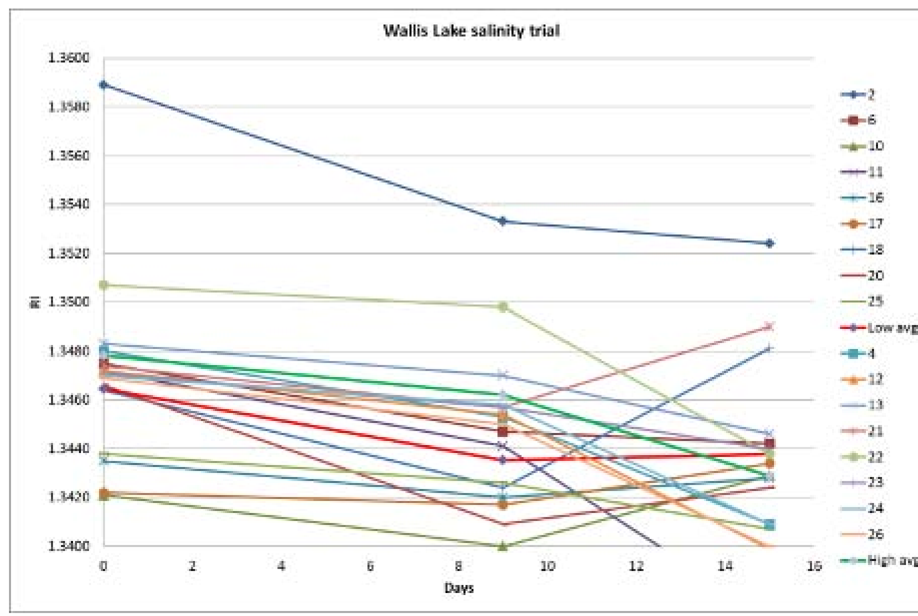




	Female		Male	
Grade	My grade	Ind Grade	My grade	Ind Grade
A	13	0	1	1
B	34	2	2	
C	10	55	13	15

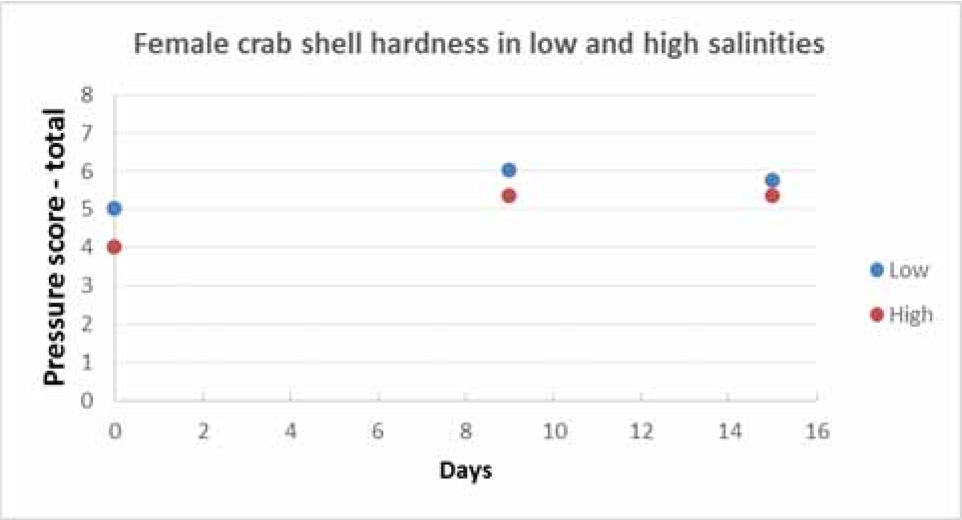
Shell not ever completely hardening

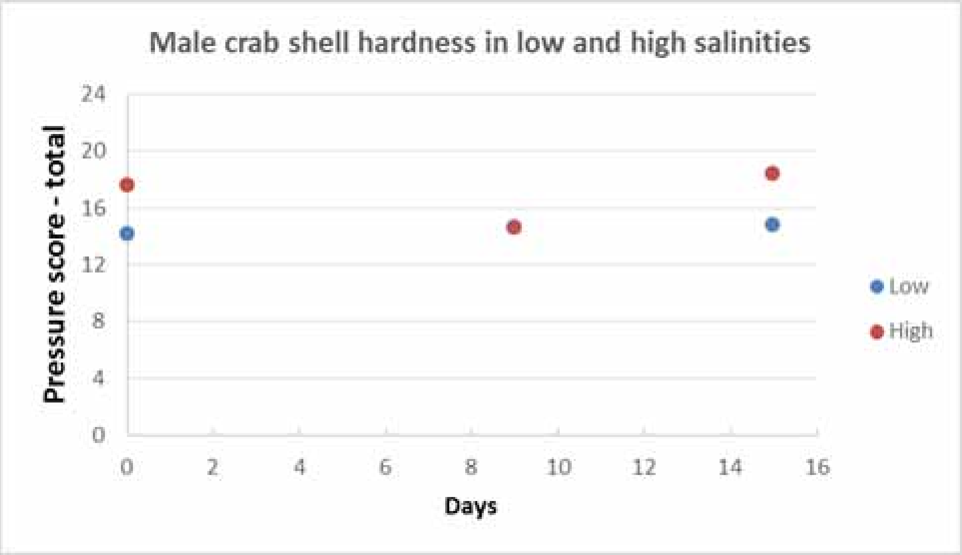
- Salinity trials
  - Regional comparison
    - NT
    - Qld - Moreton Bay to Gulf of Carpentaria
    - NSW – Evans to Wallis Lake
- Wallis Lake
  - Didn't eat normally
  - Esp. in high salinity



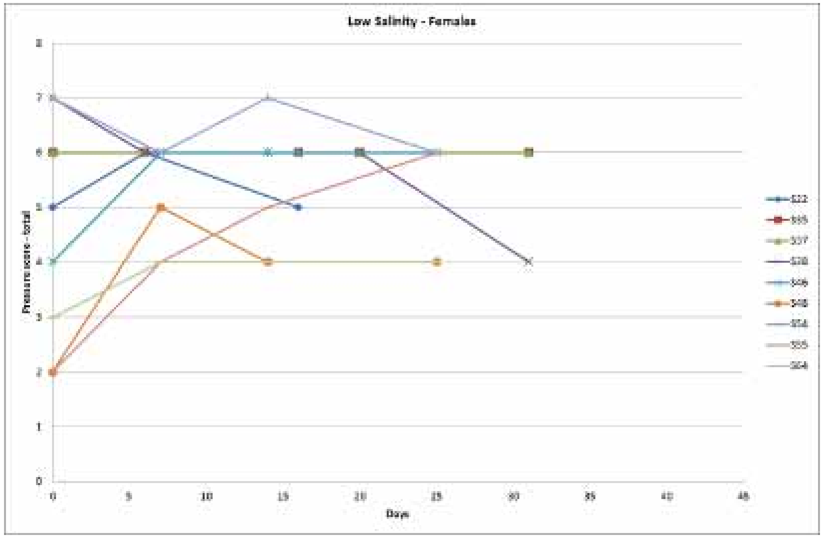
Salinity trials

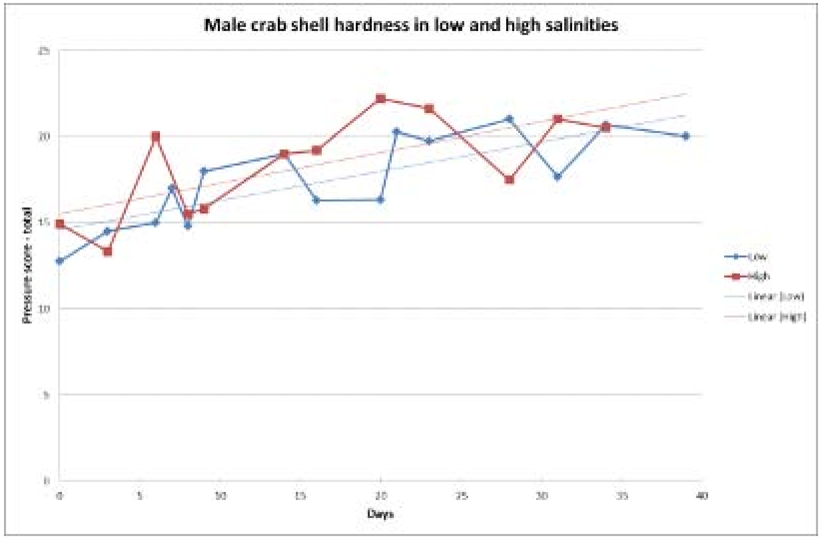
Wallis Lakes





Various locations





Meat fullness

Survey 2 – How full is your mud crab?

How full is your mud crab?

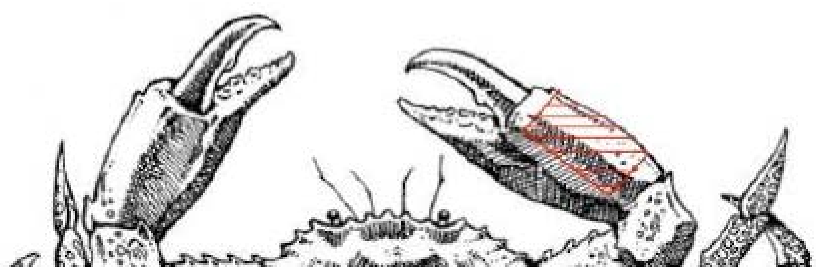
Welcome to My Survey

Thank you for participating in our survey. Your feedback is important to a joint Queensland Government DAF and Fisheries Research and Development Corporation project to improve mud crab grading.

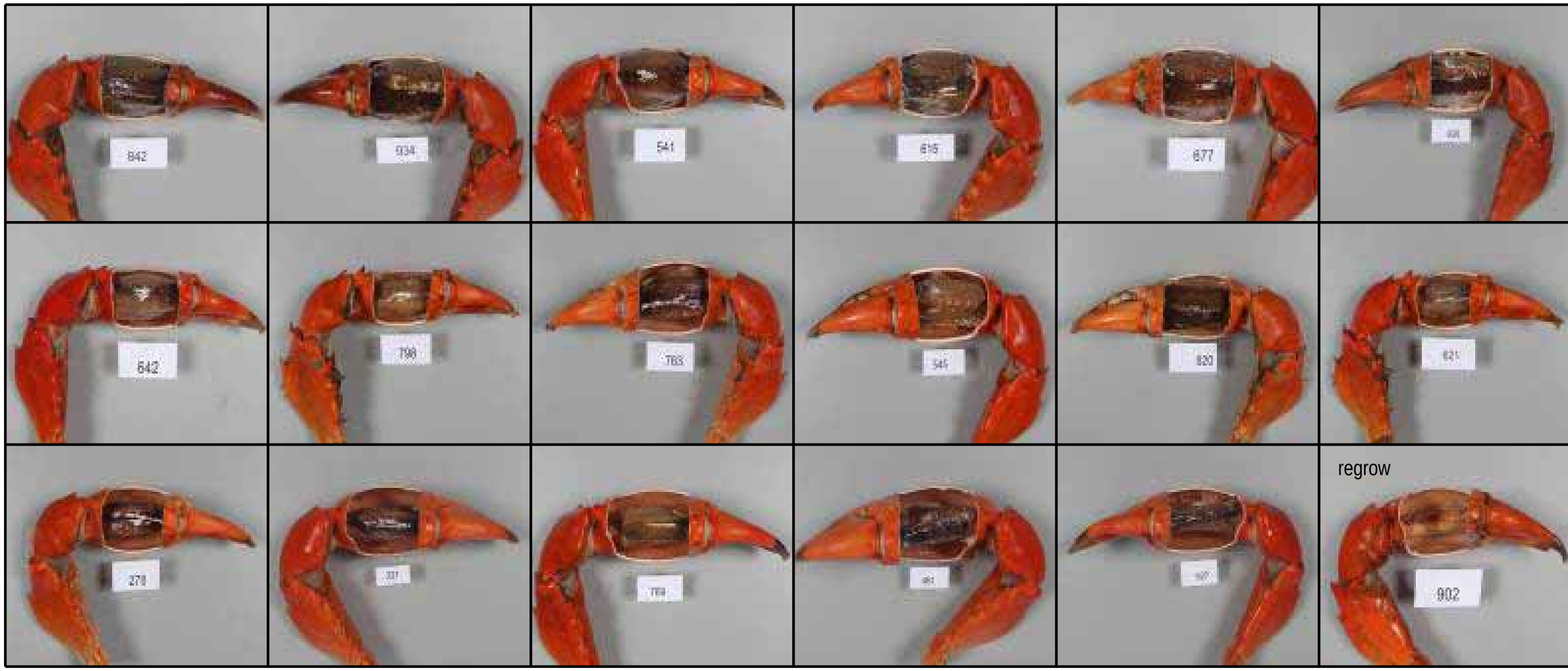
You will be shown 3 photographs of mud crab claws that have had a section of shell removed as shown by the shaded section in the diagram below. The photographs are taken from above to show the exposed meat within the shell cavity.

Please answer the two questions with each photograph. The final page will ask a little background about yourself and your mud crab eating experience.

Scroll down and click in the Next box to proceed to the next page.
On the last page click in the Done box.



Survey 2 – How full is your mud crab?

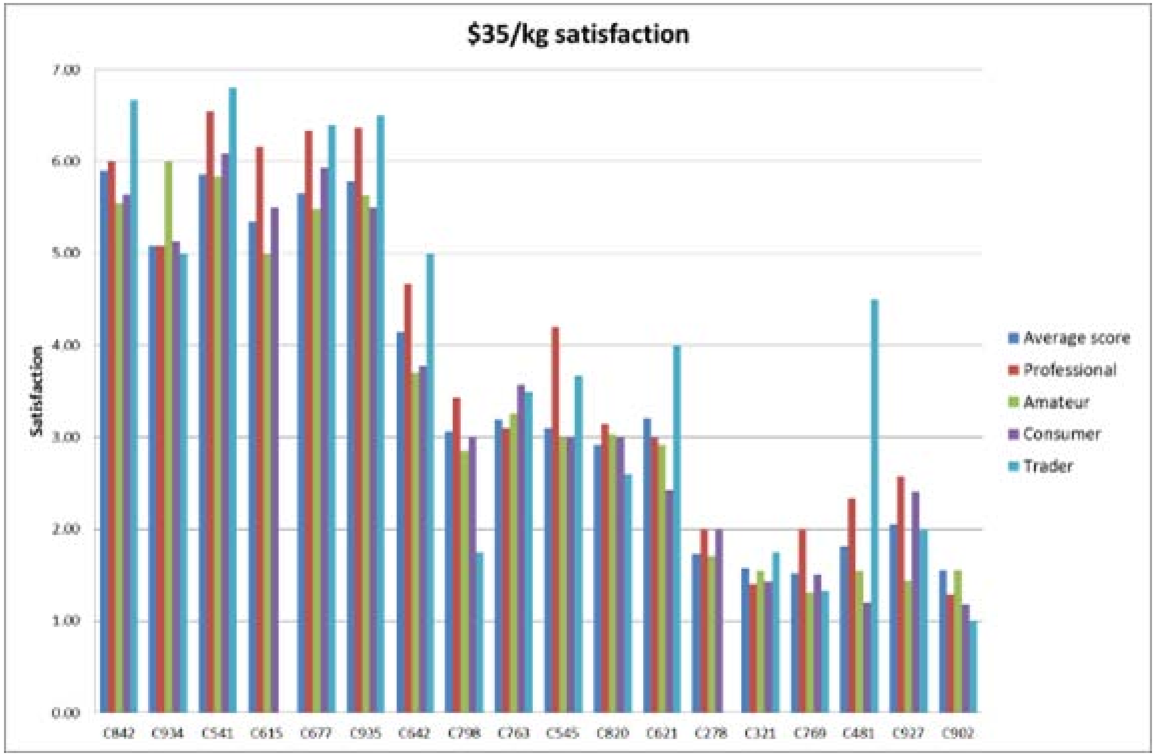


'A' grade
Avg RI 1.3576
Avg Yield 54.5%

'B' grade
Avg RI 1.3490
Avg Yield 39.9%

'B & C' grade
Avg RI 1.3452
Avg Yield 33.2%

Survey 2 – How full is your mud crab?



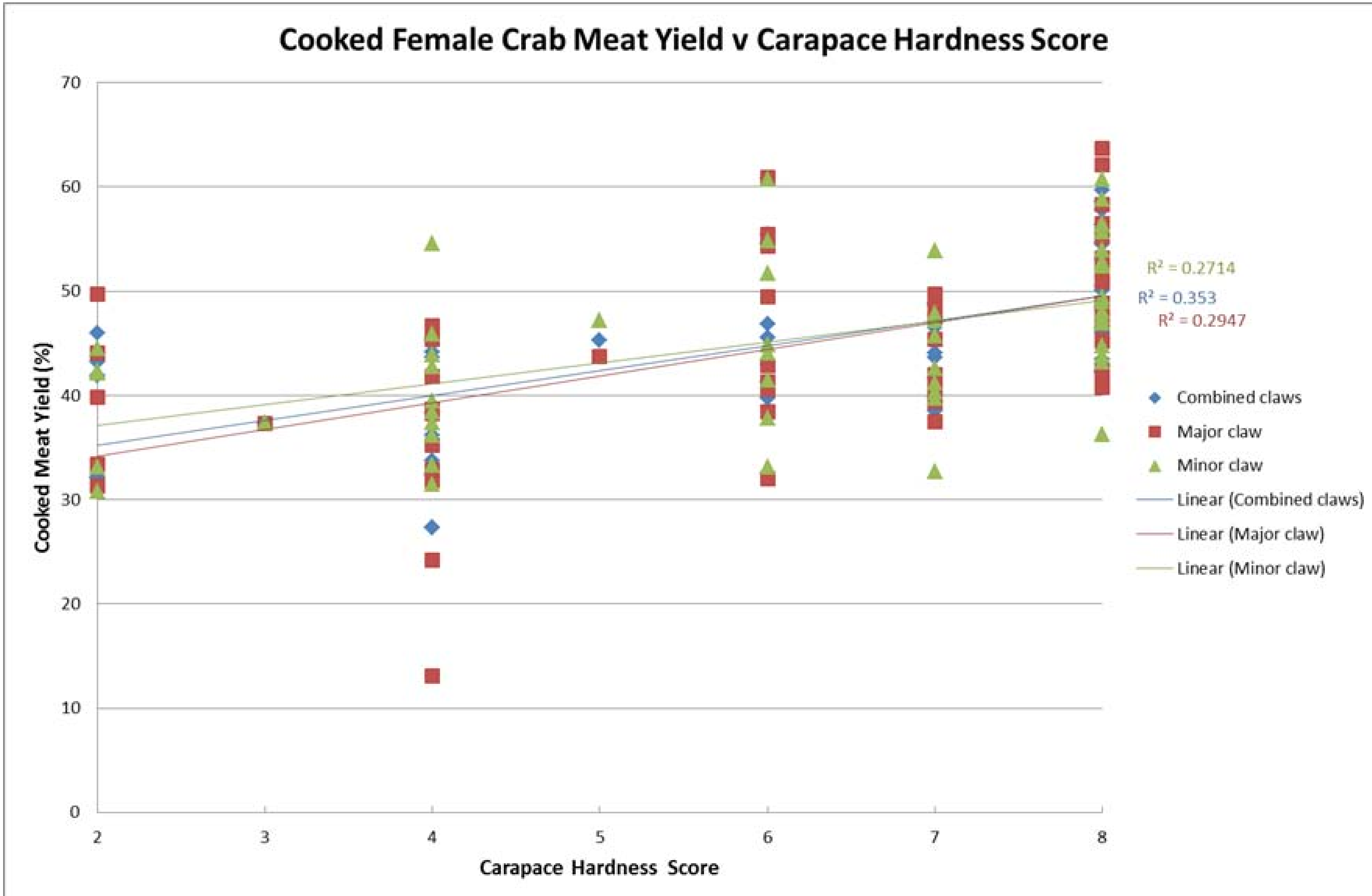
Average prices ($)

	Survey	SFM Low	SFM High
A	35-40	26	65
B	15-19	20	44
C	<10	17	26

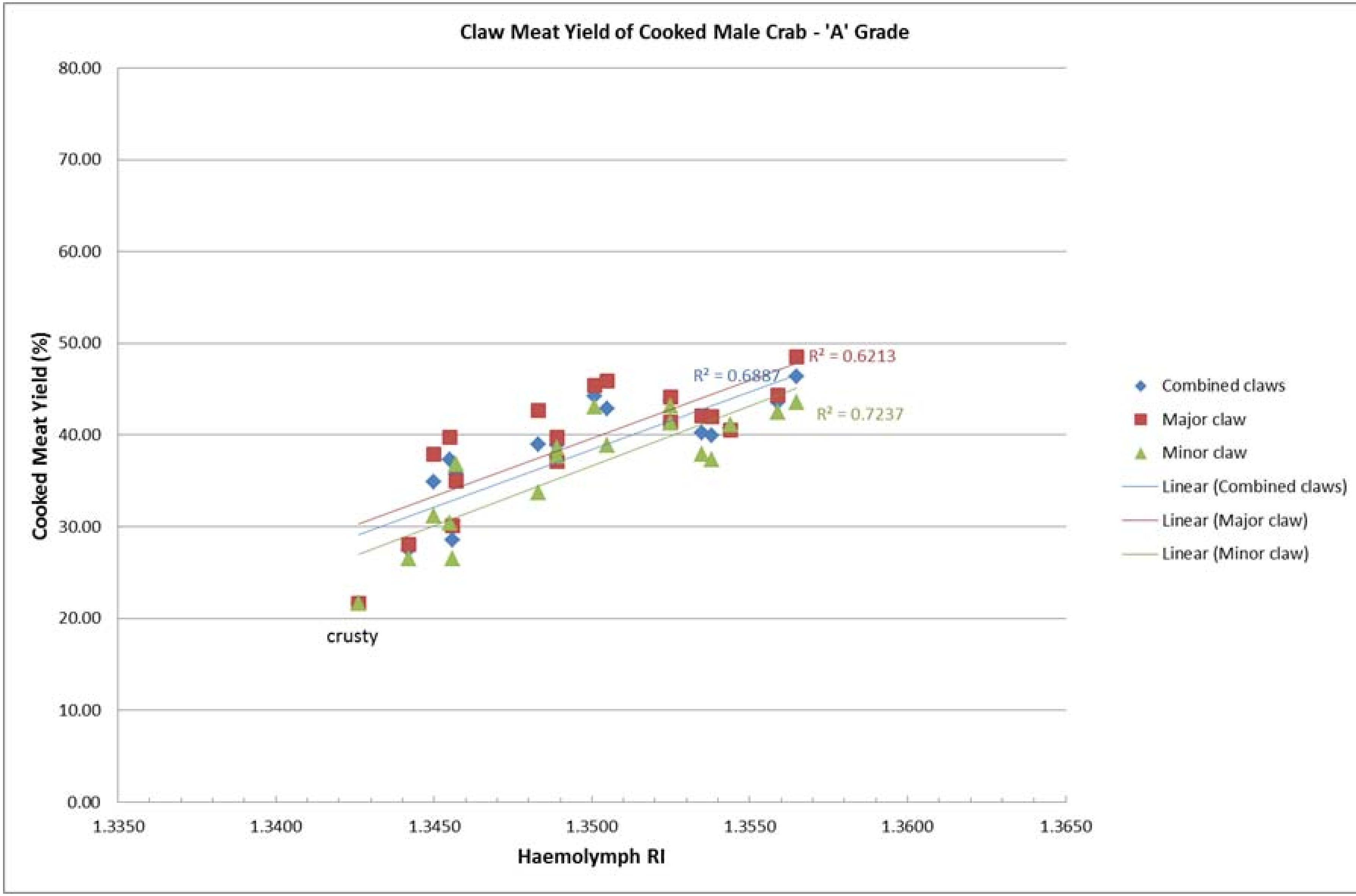
Meat fullness

- Measurement techniques
  - Total protein – RI
    - Analogue and digital refractometer
    - Laboratory test strips
  - Crab depth, width v weight relationships
    - Major/minor claw and major claw dimensions
  - Cooked meat yield
    - Body / Claw – claw best to use
    - Male/ Female – female poor correlation to RI (initial results)
      - Female ‘A’ well defined by shell hardness
      - Female ‘B’ yield generally relate to shell hardness
      - Female ‘C’ variable by shell hardness

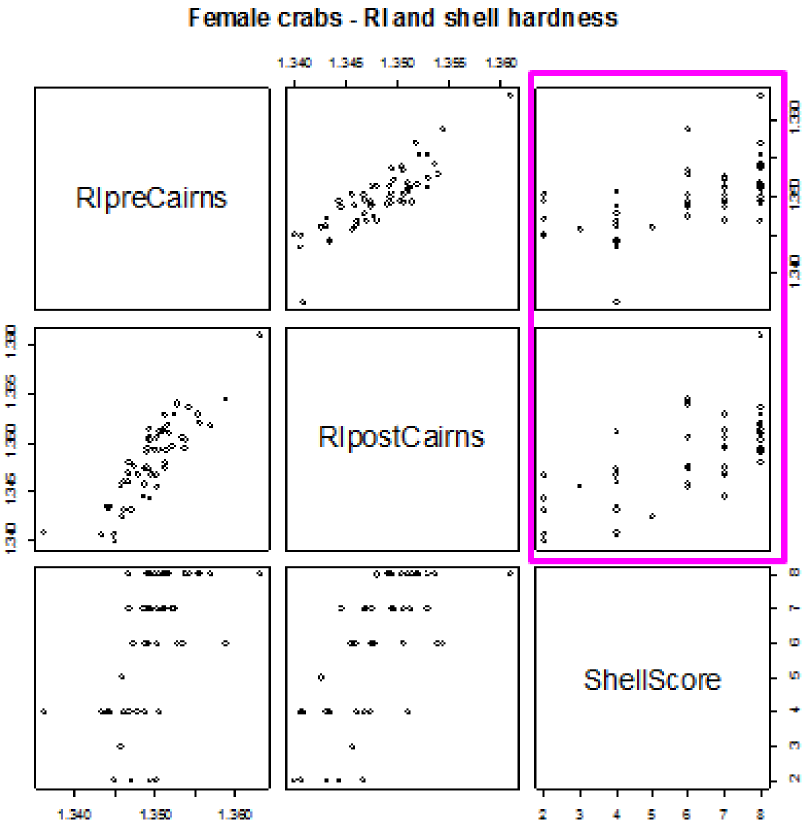
Female Yield vs Shell Hardness

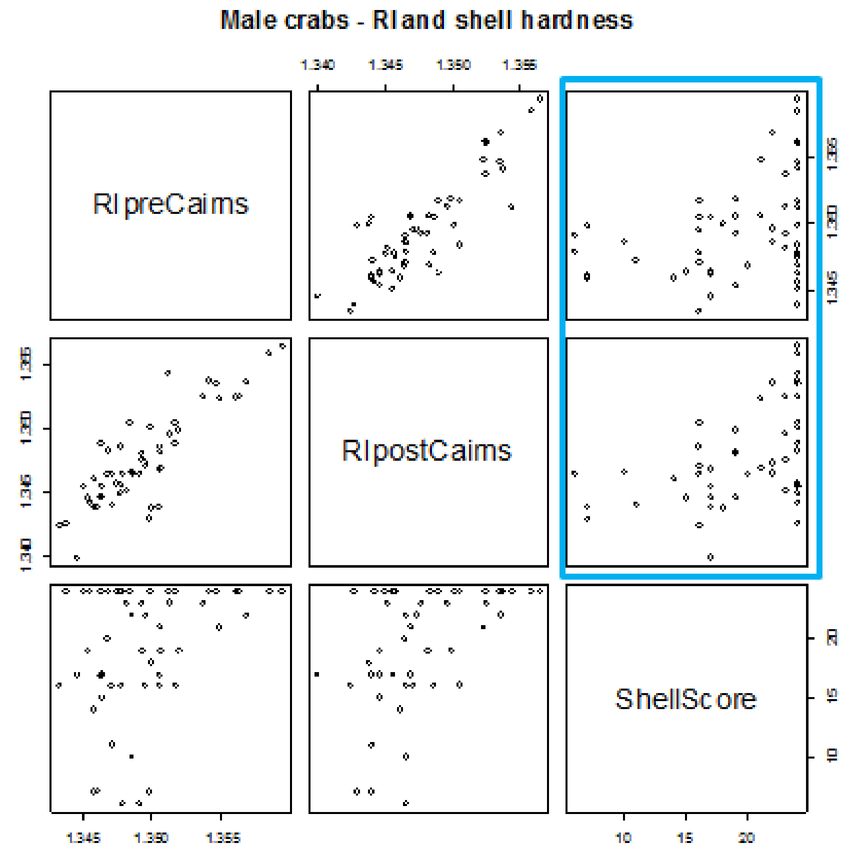


Male Yield vs RI



Relationship between shell hardness score and RI





The Shell score for female crabs seems to correlate with RI values.

The Shell score for male crabs reaches a maximum of 24. This value of 24 corresponds to the whole range of RI values! The lower scores (< 15) aren't necessarily associated with the lowest RI values. Shell scores between 15 and 23 seem to correlate a bit more with RI values.

Meat fullness – crusty old crabs

Summary – grade by shell hardness

	Grade	Claw %Yield	Shell Score	RI
Female	A	40 – 60	8	>1.3475
	B	40 – 50	6-7	1.3450 – 1.3500
	C	30 – 50	2-4	<1.3450
Male	A	30 – 50	24	>1.3450
	B	30 – 40	22-23	1.3450 – 1.3500
	C	20 – 40	6–8	<1.3465

Discussion - Chris

- Grading Scheme – Resolutions
  - Agreement
  - Distribution
  - Education
  - Adoption
  - Review process

Shell hardness assessment by pressure- Consensus reached for AILMGS Version 3

Grade	Male	Segments	Total Score	Female	Segments	Total score
A	No flex	444,444	24	No flex	4,4	8
B	flex on either middle segment, but no flex on other segments	444,434 - 434,434	23-22	flex on at least one side	3,4 - 3,3	7-6
C	flex on all segments	333,333 or less	<18	very flexible on both sides	2,2 - 1,1	4-2
Grade	Male	Segments	Total Score	Female	Segments	Total score
A	No flex or slight flex on middle segments	444,444 - 434,434	24-22	No flex	4,4	8
B	flex on some segments	434,433 - 323,323	21-16	flex on at least one side	3,4 -3,3	7-6
C	flex on all segments	323,322 - or lower	15 - 6	very flexible	2,3 - 1,1	5-2

Or ‘A’ grade and ‘other’ ???

DAY 2

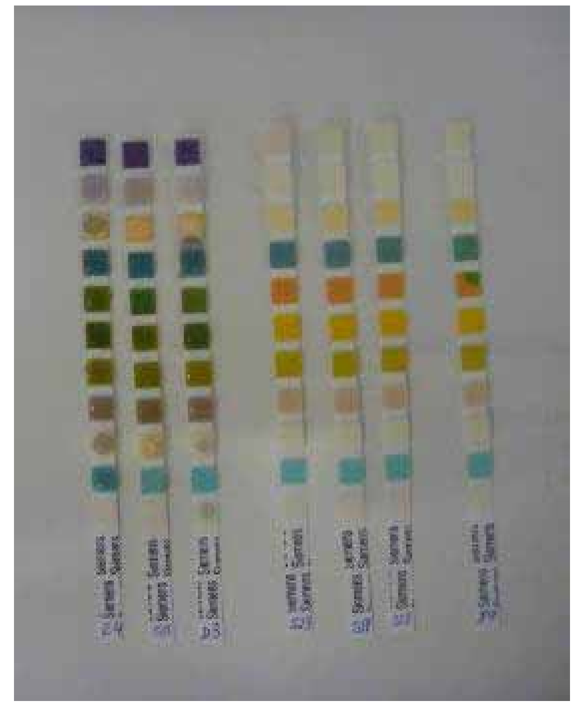
Overview of technology methods

- Need and considerations

- Investigated:
  - Blood protein
    - Refractometer
    - Test strips
  - Force sensitive resistance
    - Durometer
    - Tekscan FlexiForce
    - Avocado glove
  - Candling
  - X-ray
  - Ultrasound
  - Near infra-red

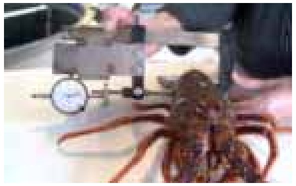
Blood protein

- Refractometer
- Test strips



Shell hardness assessment by pressure

- Optional pressure measurements
  - Durometer (Mark Grubert, NT Fisheries)
    - Variability between models
    - Shell damage, site placement
    - “Research tool”



  - Force Sensitive Resistance
    - 2kg = ‘C’ grade; 4kg = ‘B’ grade; 6kg = ‘A’ grade
    - Sensor too large for small crab segments
    - Tend to repeat pressure test – damage
    - Durability

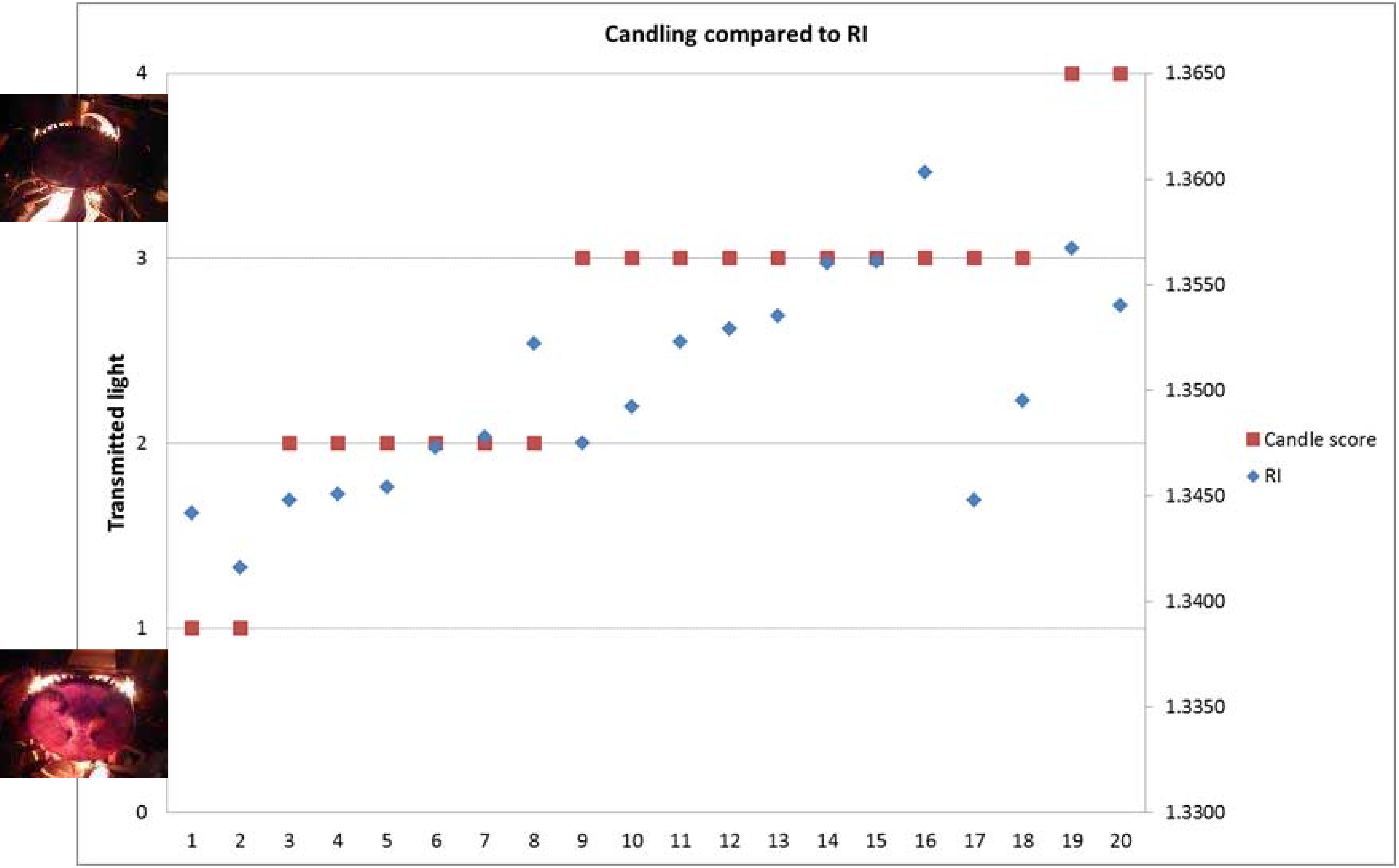
Candling

- similar concept to candling eggs
- light will be visible through shell when ‘soft’ and little meat to impede the beam

Empty of meat

Full of meat

Candling – preliminary look

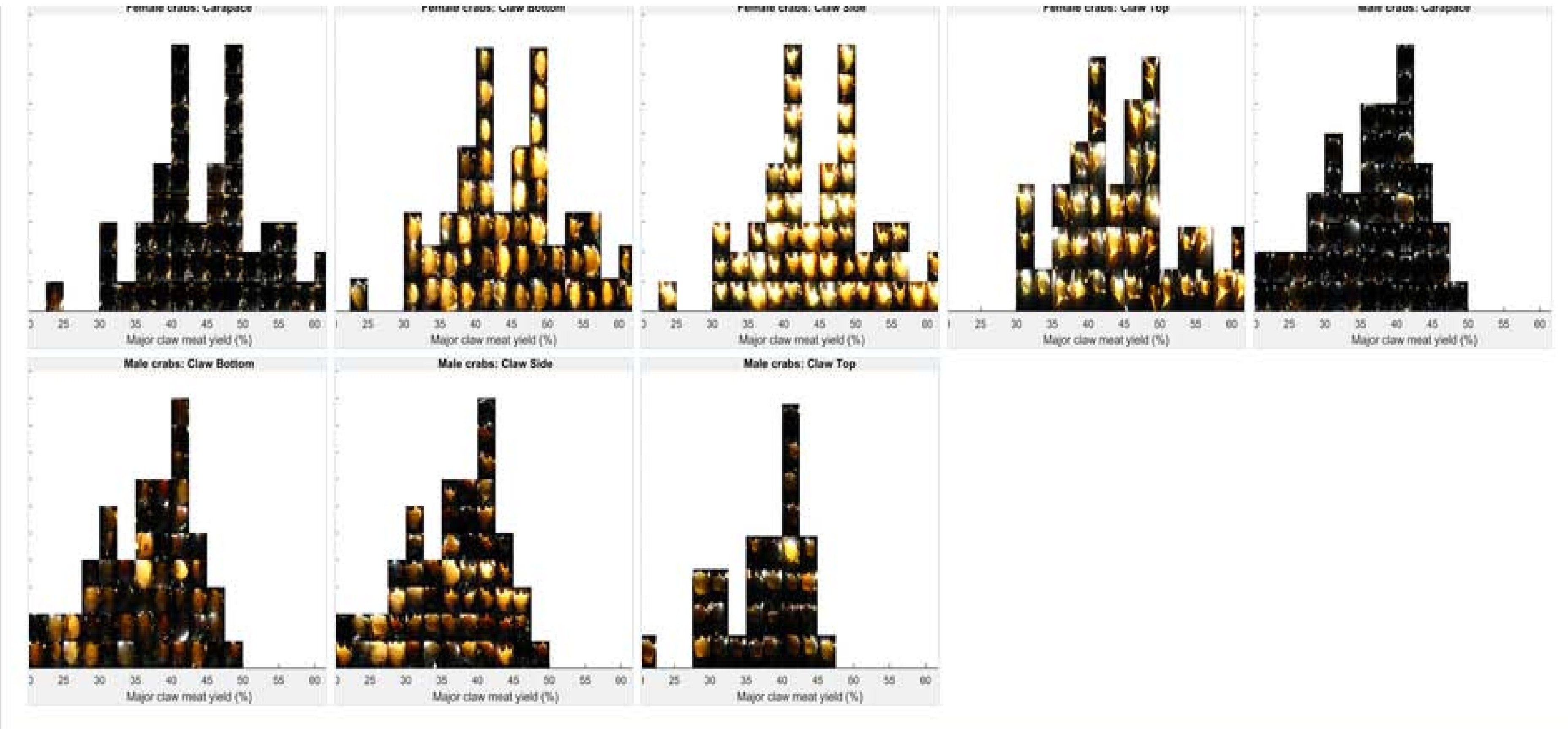


Candling

- tried intense light source
- photographic record

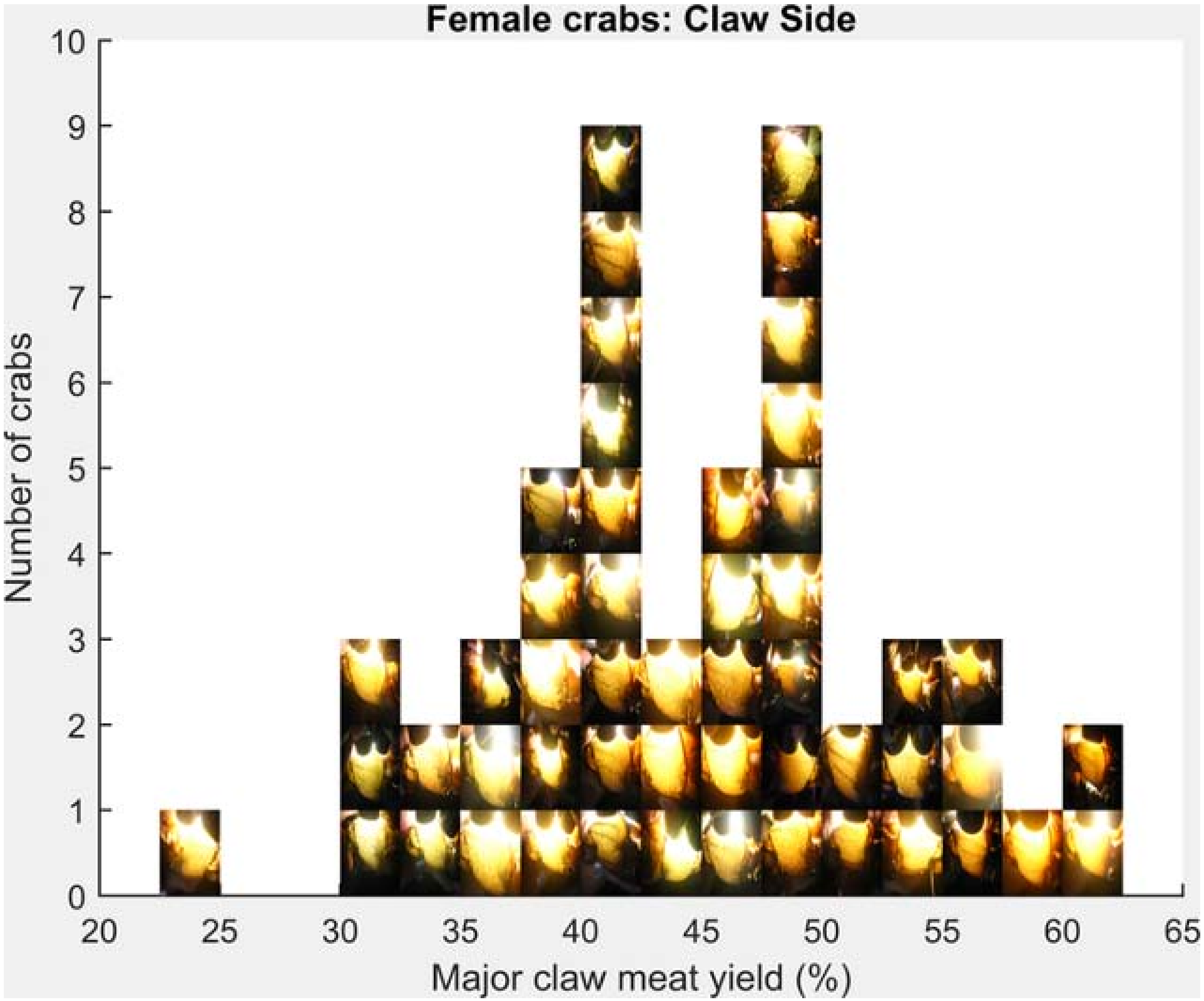
Candling

Candling



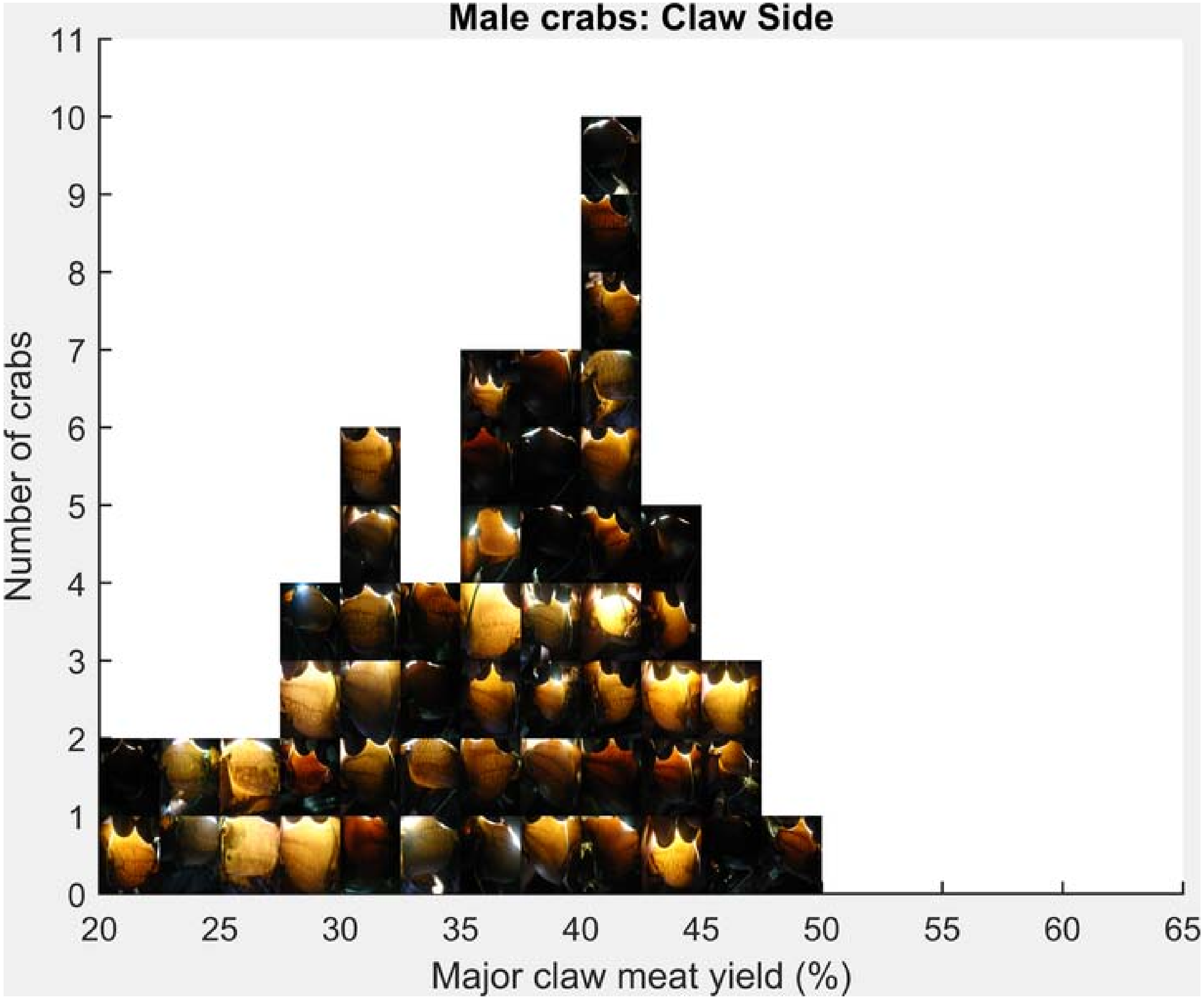
Male crabs: Claw Bottom
Male crabs: Claw Side
Male crabs: Claw Top
25 30 35 40 45 50 55 60
Major claw meat yield (%)

Candling



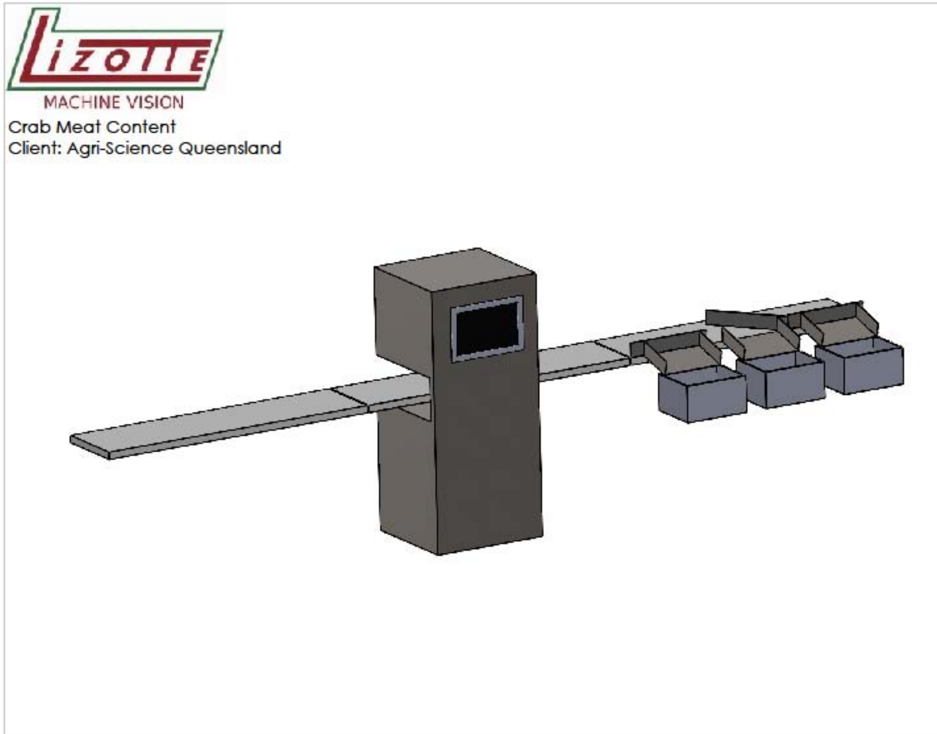
Female crabs: Claw Side
Number of crabs
0
1
2
3
4
5
6
7
8
9
10
20
25
30
35
40
45
50
55
60
65
Major claw meat yield (%)

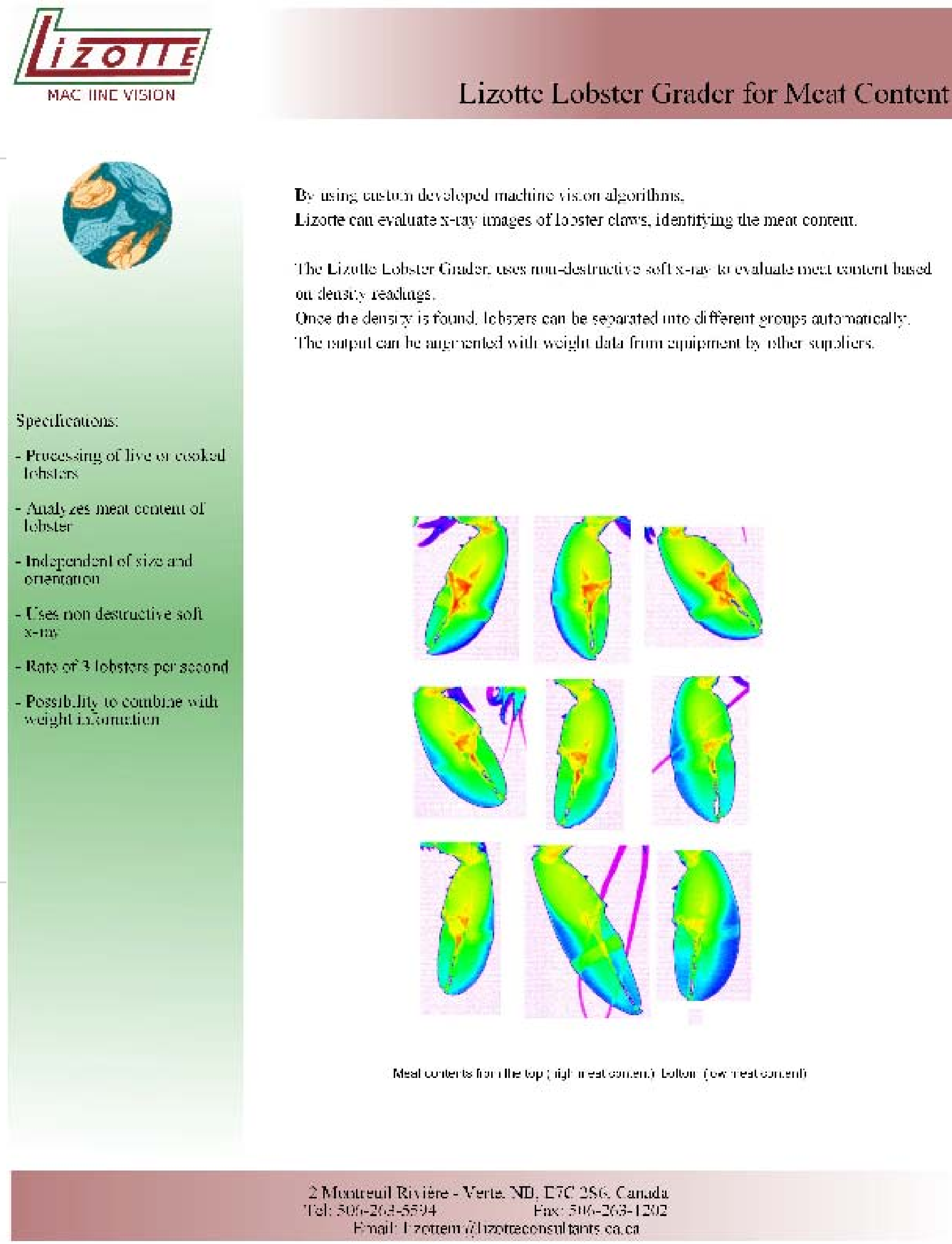
Candling



Male crabs: Claw Side
Number of crabs
0
1
2
3
4
5
6
7
8
9
10
11
20
25
30
35
40
45
50
55
60
65
Major claw meat yield (%)

X-Ray





Lizotte
MAC HINE VISION

Lizotte Lobster Grader for Meat Content

By using custom developed machine vision algorithms,
Lizotte can evaluate x-ray images of lobster claws, identifying the meat content.

The Lizotte Lobster Grader, uses non-destructive soft x-ray to evaluate meat content based on density readings.
Once the density is found, lobsters can be separated into different groups automatically.
The output can be augmented with weight data from equipment by other suppliers.

Specifications:

- Processing of live or cooked lobsters
- Analyzes meat content of lobster
- Independent of size and orientation
- Uses non destructive soft x-ray
- Rate of 3 lobsters per second
- Possibility to combine with weight information

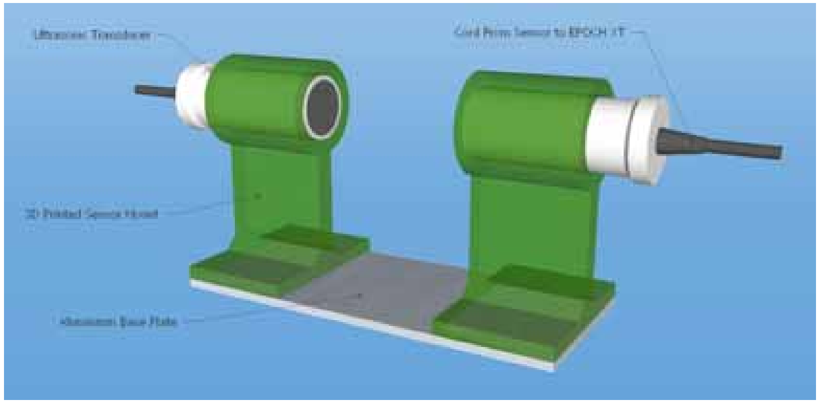
Meat contents from the top (high meat content) bottom (low meat content)

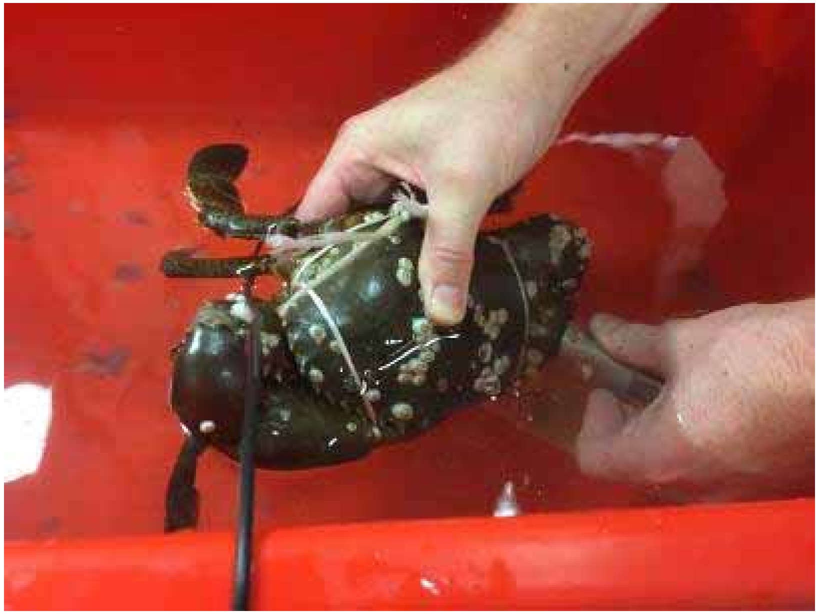
2 Montreuil Rivière - Verte, NB, E7C 2S6, Canada
Tel: 506-263-5594 Fax: 506-263-1202
Email: lzottem@lizotteconsultants.ca.ca

Price (Excluding data acquisition, installations & commissioning):
$200,000.00 US f.o.b. our shop

Additional cost, on invoice (**Estimate**): $1,250 per day

Ultrasound


Ultrasonic Transducer
Cord From Sensor to EPOCH XT
3D Printed Sensor Mount
Aluminium Base Plate



Near infra-red

Raw Data

	Known Grade A	B	C
Predicted as A	25	3	0
Predicted as B	6	36	5
Predicted as C	0	10	18
Correct %	81	73	78

Second Derivative Transformation

	Known Grade A	B	C
Predicted as A	28	8	0
Predicted as B	3	39	10
Predicted as C	0	2	13
Correct %	90	80	57

A:>45%, B:45-35% and C:<35%

No grade A where classified as C and no C crabs classed as A.

Industry applicability

- X-ray – expensive, uncertain, high running costs, not applicable locally

- Hand held NIR – relatively cheap, versatile, best meat yield predictor

What next?

Thank you

Appendix 8 – SFM notice - Mud Crab Grading

Mud Crab Grading

Dear valued customers,

Sydney Fish Market Pty Ltd (SFM) wish to advise that effective Monday 5 September 2016, the downgrading of mud crabs, based on shell hardness (flex test), will no longer be permitted at the auction.

SFM is strongly of the view that the grading of mud crabs is the responsibility of the fisher and that excessive "flex test" further down the supply chain is detrimental to mud crabs. Fishers will therefore be required to grade their crabs in accordance with the 'Australian Industry Live Mud Crab Grading Scheme' and quote the respective grade clearly on their crate/carton label.

All boxes will be listed for auction with the grade quoted by the supplier. SFM will not be responsible for the accuracy of the grades declared by fishers.

SFM auction buyers will continue to be permitted to claim 'Dead' mud crabs and 'Short In Weight', as per the current Quality Assurance system.

Please refer any feedback or concerns to Erik Poole on 0401 996 459.

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