Methods for Monitoring the Abundance and Habitat of the Northern Australian Mud Crab *Scylla serrata*

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Tracy Hay, Neil Gribble, Christina de Vries,
Karen Danaher, Malcolm Dunning, Mark Hearnden, Peter Caley,
Carole Wright, Ian Brown, Stephen Bailey and Michael Phelan

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Principal Investigator: Ms Tracy Hay

Fisheries Group
Department of Business Industry and Resource Development
GPO Box 3000
Darwin NT 0801
Tel 08 89992144 Fax 08 8999 2065

Objectives:

1. Identify and quantify the area of critical mud crab habitat in Northern Territory (NT) and Queensland (Qld).

2. Develop and assess methods to estimate the size of northern Australian (NT and Qld) mud crab stocks.

Non-Technical Summary:

A significant achievement of this project has been the completion of mapping of coastal wetland habitats using remote sensing techniques, which provided a complete broad-scale coverage of mud crab habitats in the NT and Qld. A major outcome/output of this work has been the incorporation of the mapping into a geographical information system (GIS) permitting a much wider application across a variety of natural resource management agencies and issues. The updated Qld maps are now available electronically to the public via the QDPI&F website CHRIS. The identification and quantification of northern Australian coastal wetland habitats will benefit a broad range of northern Australian inshore fisheries.

Survey and analysis methodologies, based on mark-recapture techniques, have been developed to estimate mud crab density for two key habitat types in northern Australia. Density estimates for each habitat type were extrapolated up across adjacent regions in each state providing the first broad scale estimates of mud crab stock size. A direct and recent output from this work has been the use of preliminary biological and fishery data, to compare trends between years for Qld and NT mud crab fisheries, during a recent fishery assessment. This fishery assessment was convened in July 2004, to investigate the reduction in commercial mud crab catch in the NT. Negotiations on adjustment to the NT management arrangements are currently in progress.

Declines in catch and catch rate were observed in both the NT and Qld Gulf of Carpentaria (GOC) surveys over the two years of this study. This suggests large-scale environmental drivers influence mud crab recruitment success, at least for Gulf region. Estimated abundance for this region in the NT indicates a very high proportion of the legal sized mud crab stock was removed in 2003. Provision of information such as this may be far more useful for management purposes than logbook catch per unit effort (CPUE) data alone. The assessment techniques developed during this project provide a means to increase the value of CPUE data, setting up a benchmarking process that will ultimately assist in making well informed and timely management decisions.

Keywords: mud crab, abundance, habitat mapping, depletion, mark recapture, removal, trapping web

The recommendations of a 1996 NT mud crab fishery assessment, chaired by Professor Carl Walters University of British Columbia, provided the concept behind the development and implementation of the work presented in this document. Problems with the use of CPUE data providing a valid reflection of the way in which the fishery operated, resulted in the development of a simple model. The model was based on the aggressive nature of the mud crab and the resultant behaviour, under the threat of cannibalism, to disperse evenly over suitable habitat. With this in mind, Professor Walters suggested a simple model for mud crab abundance estimation:

Abundance = area of critical habitat x density of animals per unit of habitat

Therefore two parameters needed to be estimated: the area of each critical habitat type and animal abundance per unit of critical habitat type.

The identification and quantification of coastal wetland habitats across northern Australia was therefore an important objective of this work. Consultation with fishery stakeholders and a survey of the literature provided information on the key habitat associations of the mud crab. The two habitats of primary interest, mangroves and mud flats, form part of coastal wetlands that in northern Australia are generally remote and difficult to access. Remote sensing techniques were used to successfully meet this objective.

The utility of remote sensing in the broad scale assessment of coastal fisheries habitats has been proven in Qld (Danaher 1995). Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images have been used to obtain coastal wetland information throughout Qld. The mapping of the NT coastal wetland habitats using Landsat ETM+ imagery was undertaken in order to complement the existing Qld dataset, to produce a consistent wetlands mapping product for the northern Australian coast (east of 129º E) at a regional scale.

Landsat ETM+ imagery was processed using the standard technique of Danaher (1995) to produce a digital dataset of the tidal coastal wetland habitats. This technique has been recognized by Environment Australia (Ward et al. 1998) as a suitable protocol for the assessment of tidal coastal wetland habitats at a regional scale. A northern Australian mud crab habitat GIS was created. This GIS integrated tidal coastal wetland habitat information with datasets of foreshore flats and land subject to inundation. Specific field site information and photographs were also incorporated into this GIS. A standard map template was created to allow the production of hardcopy mud crab habitat maps.

The second objective of this project was to develop and assess methods to estimate mud crab abundance within habitat type. Abundance estimates were obtained using various tagging models and these include mark-recapture, depletion and distance sampling techniques. The initial work focused on gaining an understanding of the effect of the lunar cycle on mud crab catch rates. Anecdotal reports from fishers indicated that catch rates changed over the lunar cycle, inferring that the timing of each study may have some influence on the results of abundance surveys. Fishery dependent (commercial catch) and fishery independent (research) catches were monitored over the June 2001 lunar cycle. The commercial catch increased during spring tides and this was due to increased levels of fishing effort, when fishers are able to fish two tides. When analysis for cyclic pattern on catch per unit effort was applied to both datasets, the results provided little support that catch rates follow the lunar cycle.

Techniques for estimating the abundance of mud crabs were assessed at two sites in the NT and Qld. A study design incorporating depletion and mark recapture methods was utilised for mangrove-lined streams and a trapping web design for the foreshore mudflat areas. While both NT and Qld applied similar study techniques, sampling effort and the size of the area sampled differed between states.

A significant reduction in catch and catch rates was reported for the NT and Qld GOC commercial mud crab fisheries between the two years of this study (2002 and 2003). Estimates of mud crab abundance from survey data reflect similar downward trends in abundance at the two NT study sites and the Karumba, Qld site, over the two-year study period.

When abundance estimates from the two NT study sites were multiplied by the estimated area of habitat in each corresponding fishing grid, the results confirmed previous assessment findings and followed commercial catch trends. The Gulf of Carpentaria is the most significant region for the NT mud crab fishery, contributing 78% to the total NT catch in 2003. The Adelaide River/Darwin region reported 14% of the NT total catch in 2003. Comparison of the reported commercial catch to the estimated abundance of mud crabs in 2003 confirmed the high levels of exploitation (70-90%) for the NT Fishery reported by Walters et al. (1996). The results of this study estimate that > 90 % of adult mud crabs from the NT GOC fishery were removed in 2003 and removals of between 19-23 % of adult crabs were estimated for the second most important NT region, the Adelaide River/Darwin region.

Likewise, abundance estimates from the two Qld study sites were multiplied by the corresponding estimated area of habitat and the results for Karumba indicate around 25% of adult (male only) crabs were removed from the fishery in 2003. At the Trinity Inlet site it was estimated that the fishery removed around 3-8% of adult crabs in 2003. These estimates do not take into account the recreational harvest, which in Qld is thought to at least equal the commercial harvest and this would effectively double the removal estimates.

When abundance estimates from each site are extrapolated across each States entire fishery the estimates seem unrealistically high, when compared with the reported commercial catch from each region. While it may be reasonable to extrapolate abundance estimates up to adjacent local regions, some caution needs to be applied when interpreting the extrapolated results over broader spatial scales. Tagging studies were conducted only at two sites in each state and where these results have been applied across other regions, it is very likely that the actual carrying capacity may differ from the sites examined in each state. Also the presence of habitat deemed suitable for mud crabs may not necessarily indicate that mud crabs are present, as each location may have its own mud crab “carrying capacity”, depending on micro-habitat factors that are not captured by broad-scale habitat mapping. Improved estimates for these regions could be achieved by undertaking additional surveys in areas of key interest.

1. Northern Australian Mud Crab Fishery

1.1 Background

The northern Australian commercial mud crab (*Scylla serrata*) fishery was valued in the order of $20 million in 2000 (Calogeras 2000). The majority of commercial fishing activity for mud crabs in Australia occurs within NT and Qld waters. Mud crabs are also an important focus of the recreational sector particularly in Qld where the recreational catch is thought to be at least equal to the Qld commercial catch. The mud crab is also a significant food source for northern Australian coastal Aboriginal communities.

Northern Australian mud crab fisheries are highly regulated, but differ for each State and Territory. Regulations for the commercial industry include the use of input and output controls. In the NT a total of 49 mud crab licences are issued and each licence holder is entitled to use a maximum of 60 pots. Output controls are also applied with NT size limits set at a minimum of 130 mm carapace width (CW) for male and 140 mm CW for female mud crabs. Recreational fishing controls include a possession limit of 10 crabs per angler or 30 crabs per boat in the NT, a total of 10 crab pots and size limits as applied to the commercial fishery.

In Qld, 950 licences (endorsements) are issued and each licence holder may use a maximum of 50 pots. A single-sex harvest policy is applied with the possession of female mud crabs prohibited and a minimum size limit of 150 mm CW for male mud crabs. Recreational fishing controls include a possession limit of 10 crabs per angler, size limits as per the commercial fishery and gear restrictions of four crab pots per angler.

The ‘Northern Australia Mud Crab Research Priority Workshop’ held in Darwin during May 1999 was attended by researchers and managers from the NT, Qld, and Western Australia, as well as key NT industry representatives. The major outcome from the workshop was the development of a five-year research plan for northern Australian mud crab, based on both industry and management issues. In order to maximise the benefits of available resources it was decided to adopt a phased approach to be achieved over the following five years. The three phases were:

1. Examination of the relative productivity of mud crab habitat types.
2. Comparison of stock abundance indicators.
3. Investigation the spatial differences in population reproductive characteristics.

The aim of this project was to address the priorities identified for phase one of the research plan in meeting the following two objectives:

1. Identify and quantify critical mud crab habitat using remote sensing techniques.
2. Estimate the corresponding animal density per unit of habitat using novel mark–recapture and depletion techniques.

1.2 Need

An estimate of stock size is a fundamental requirement in predicting a fishery’s production potential and subsequently in developing ecologically sustainable management practices. However, as yet no stock estimates are available for Australian mud crab fisheries. Efforts to date have been hampered by a combination of factors that make traditional stock assessment methods inappropriate for this fishery. A recent review of the NT mud crab fishery, determined that catch-effort models and assessment methods based on catch-rate data, cannot be applied to this fishery due to the non-random fishing effort (Walters et al. 1997). It appears commercial crabbers in northern Australia operate by systematically fishing and resting local areas over the fishing season, and in this manner they maintain a hyperstable catch per effort.

Likewise, the use of length-based methods for estimating growth and mortality rates of populations is not valid due to the way crabs grow and the subsequent lack of discrete length cohorts in the stock (Walters et al. 1997). In common with all other Crustacea, mud crabs possess an exoskeleton which must be shed through a series of moults (ecdyses), before growth can occur (Brown 1993), and there is high variance in individual growth rates (Arriola 1940; Ong 1966; Knuckey 1999). Other forms of assessment are also inappropriate. The high turbidity of northern Australia’s estuaries and inshore waters prevents visual counts (Melville-Smith 1986; Robertson 1989). Trawling has been shown to be ineffective due to the burrowing behaviour of this species and fishing gear selectivity (Williams and Hill 1982; Melville-Smith 1986).

1.3 The Fishery

In northern Australia, mud crabs are considered an “icon” species. Yet prior to 1995, the impact of recreational fishing on northern Australian fisheries was unknown. The first NT recreational fishing survey in 1995 estimated the recreational harvest of mud crabs at 52 000 (Coleman 1998). A second survey in 2000 estimated the NT recreational harvest of mud crabs had increased to around 82 000 crabs (Henry and Lyle 2003). The NT recreational catch is relatively insignificant when compared with estimates of the Qld recreational harvest of 993 400 mud crabs (Higgs 2001). These results infer that the Qld recreational harvest is at least equal to the Qld commercial catch.

The mud crab is also a significant food source for northern Australian coastal Aboriginal communities and the work of Henry and Lyle (2003) importantly provides the first estimates of indigenous fishery harvest for northern Australia. In 2000, the authors report an estimated 86 000 mud crabs were harvested by indigenous Australians in the NT, roughly equal to the NT recreational harvest for the same year. To provide some perspective, the combined estimated NT recreational and indigenous mud crab harvest for 2000 was 125 t, approximately 12% of the commercial catch (1037 t) for the same year.

Recent trends in commercial mud crab catches suggest that a degree of urgency in gaining estimates of mud crab stock size is warranted. The 1996 stock assessment reported by Walters et al. (1997), suggested that the NT fishery was fully exploited.

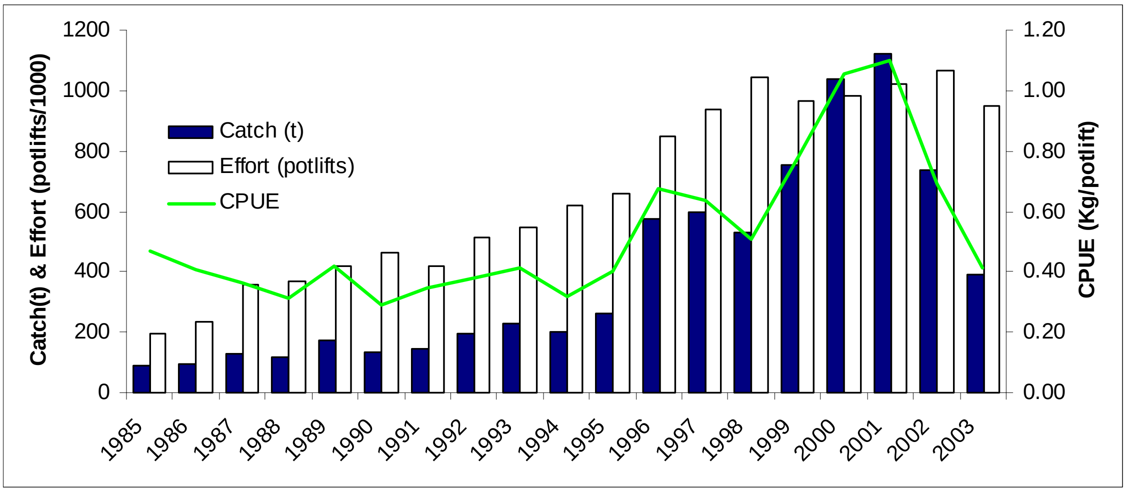

Figure 1. NT Mud Crab Fishery total catch, effort and CPUE 1985-2003

The authors estimated annual exploitation rates of 70-90% of the available stock, suggesting that there was little room for further development. However, within 12 months, the total NT commercial mud crab catch doubled, reaching 595 t, almost certainly reflecting a pulse of strong recruitment. Commercial catch in the NT continued to increase, reaching 1139 t in 2001. Catch has since returned to pre-1996 levels declining to 393 t in 2003 (Figure 1). Over this same period reported effort has remained high and stable.

In northern Australia, the largest proportion of commercial fishing effort for mud crabs is reported from the GOC. While a five-fold difference in commercial catch is evident, the NT and Qld GOC commercial mud crab fisheries demonstrate similar trends in catch and catch rates over time (Figure 2). Both fisheries recorded record catches in 2000 and 2001 and likewise both fisheries catch rates declined in 1998 (Figure 2). Considering the differences in fishing pressure between States, the trends suggest that, in the GOC, large scale biological and environmental linkages primarily influence recruitment and the possibility that the GOC population may consist of one stock.

Recent declines in the NT commercial fishery have triggered two management plan trigger points, demonstrating both a substantial decline in catch and significant declines in mean size across the majority of the fishery. An assessment was conducted in July 2004 reviewing all available data. The assessment provided strong evidence that the NT fishery was under duress. Haddon et al. (2004) report, “There is evidently too much effort is being applied, the harvest rate or fishing mortality rate is too high, and the stock is exhibiting many signs of stress. The situation may not be sustainable. Even a good recruitment year would only provide short-term respite. Management action to reduce fishing mortality by reducing fishing effort is required with some urgency.”

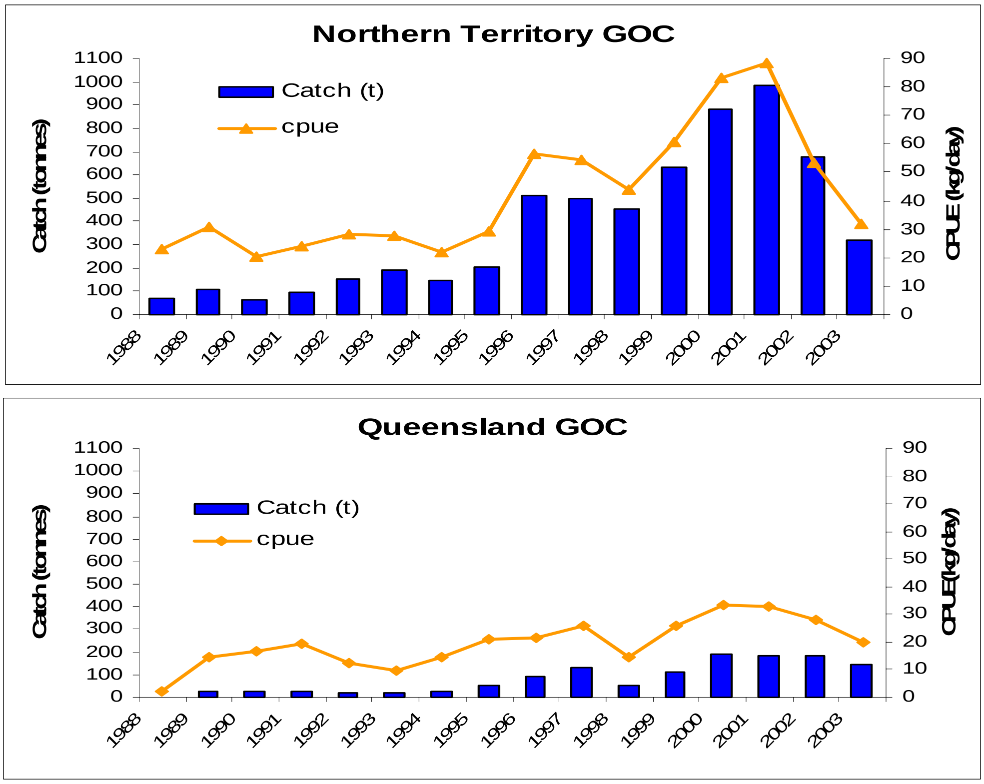

Figure 2. NT and Qld catch and CPUE 1988-2003

Difference in the catch and catch rate between the Qld and NT GOC mud crab fisheries are greater than can be expected when taking into account the single sex harvest policy and increase size limit applied in Qld. One contributing factor might be that the increased effort applied to the NT gulf fishery may well have had a strong influence on productivity, particularly in years of good recruitment. In 2003 the NT GOC fishery reported 693 210 potlifts, with each pot requiring a daily bait refresh, usually around 300-500 g of fish or red meat. Without attempting to quantify high levels of unreported effort, this would effectively add around 300 t of bait to the NT GOC system, (interestingly, this is of similar magnitude to the 304 t of mud crabs that were removed). High fishing pressure and the aggressive nature of mature crabs would effectively remove the larger predators from the fishery allowing smaller crabs an increased opportunity at the bait and for growth. In years of poor recruitment, the available legal size crabs are removed, but few recruits are available to take advantage of the additional productivity.

1.4 The Species

The portunid crab, *Scylla serrata* is a large, aggressive, omnivorous scavenger (Figure 3) that demonstrates strong cannibalistic tendencies (Arriola 1940). This agonistic behaviour provides substantial incentive for individual animals to avoid each other and disperse over the available habitat. As such, the mud crab utilises a variety of inshore habitats and environmental conditions during its life cycle.

Figure 3. Adult male *Scylla serrata*

S. serrata occurs throughout much of the inshore regions of the Indo-West Pacific Ocean (Hill et al. 1982) (Figure 4). Within this broad geographical distribution, *S. serrata* is commonly found in mangrove swamps, estuaries and sheltered parts of coastal shoreline (Hill 1975). It strongly prefers muddy substrates, which contributes to its common name as the mud or mangrove crab (Brown 1993).

Within Australian waters, *S. serrata* occurs from Exmouth, Western Australia (latitude 22°S) across the entire NT and Qld coastlines and extends down the east coast to Port Jackson, New South Wales (latitude 34°S) (Heasman 1980). Recent reports from Western Australia Fisheries (Bellchamber pers. comm.) indicate the species has been found in estuaries surrounding Perth, but it is unclear whether this has resulted from recruitment anomalies, migration or translocation.

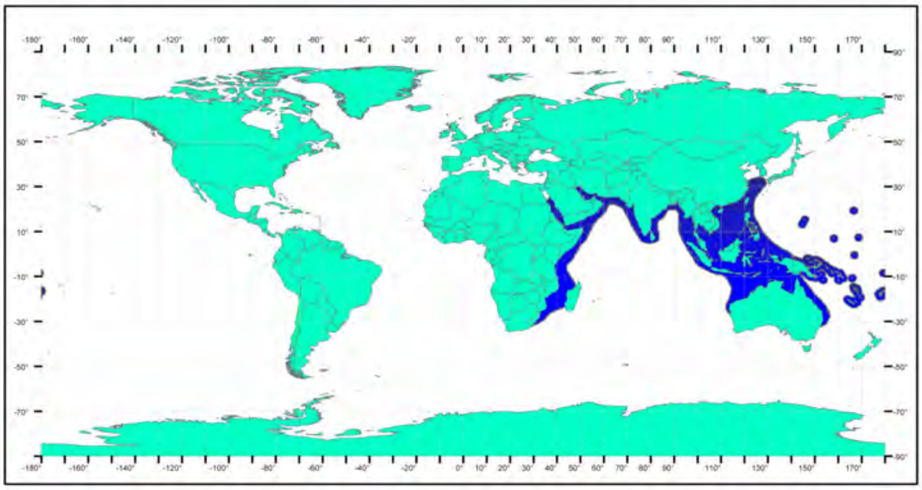

Figure 4. Distribution Scylla serrata Indo-West Pacific: From East and South Africa to Southeast and East Asia, northern and subtropical Australia, Marianas, Fiji and the Samoa Islands

1.4.1 Taxonomy

The taxonomy of the genus *Scylla* has provoked much discussion. Until recently numerous conflicting scientific observations indicated the existence of between one and six additional species throughout the Indo-West Pacific. Much of this confusion can be attributed to the loss of the type specimen *Cancer serrata* (Forskål) collected from the Red Sea in 1775.

This uncertainty prompted Keenan et al. (1998) to conduct a taxonomic review of the genus. This revision employed two independent genetic methods, allozyme electrophoresis (Keenan et al. 1995; Keenan et al. 1998) and mitochondrial DNA sequencing (Keenan and Lavery 2001). Through these studies Keenan et al. (1998) have confirmed the presence of four distinct species within the genus *Scylla: S. serrata* (Forskål 1775), *S. olivacea* (Herbst 1796), *S. tranquebarica* (Fabricius 1798), and *S. paramamosian* (Estampador 1949).

It appears that confusion surrounding the taxonomy of the *Scylla* genus has arisen from a number of issues including studies concentrated at regional scales where each of the four species spatial distribution partially overlaps and morphological similarities between species are confounded by some incorrect nomenclature. These problems have only been overcome by Keenan et al. (1998) revisiting the original type locality in the Red Sea and collecting additional material from around the Indo-Pacific.

Commercial catch monitoring and fishery independent sampling provides evidence of *S. serrata's* dominance in the NT. *S. olivacea* can be found in small numbers (<1% of the total commercial catch) in areas adjacent and to the west of Darwin, and has not been observed in the GOC (Hay unpublished data). With around 75% of the NT commercial catch sourced from the GOC the NT commercial mud crab catch is, therefore, dominated by *S. serrata* and is considered monospecific for the purposes of fisheries management.

2. Habitat Mapping

de Vries, C., Danaher, K. and Dunning, M. C. Queensland Department of Primary Industries and Fisheries.

2.1 Background

Coastal wetland environments (including mangroves, salt marshes and foreshore flats) are recognised for their value to fisheries production. Marine plants establish habitats that directly support local inshore and offshore fisheries through the provision of food, shelter, breeding and nursery areas. Previous Qld Department of Primary Industries and Fisheries research (Quinn 1992) established that in Qld, the estuarine habitats provided by mangroves and sea grasses are critical to many commercially and recreationally important fish and crustacean species during some stage of their life cycle. Species that are estuarine dependent include mud and blue swimmer crabs, prawns, barramundi, threadfins, whiting, flathead, bream and mullet.

Salt marsh habitat is also important for the life cycles of many marine species. Connolly (1999) studied the use by fish species of subtropical salt marsh habitat. This study confirmed that both vegetated and non-vegetated salt marsh habitats are utilised by surprisingly abundant and diverse communities of both estuarine-resident and estuarine-marine fish species. More than half of the fish species caught on the salt marsh habitat were of direct economic importance, and several of them were common without dominating the catch numerically.

Coastal wetland habitats across northern Australia include a diverse range of community types from sparsely vegetated saltpans through to dense mangrove forests over 30 m tall. At a regional level, wetland structure and species composition are influenced by a range of environmental parameters, including rainfall, temperature, humidity, freshwater runoff (Smith 1992) and terrain (Danaher 1995b). At a local level, the intertidal zone is subject to other environmental influences, such as salinity change, frequency of both tidal and freshwater inundation and wave action (Smith 1992), which result in patterns (zonation) of vegetation species distribution according to their tolerance.

Collecting information on coastal wetlands in northern Australia presents several logistical challenges. The vast area of coastline and the remote locations means that often these habitats are difficult to access through conventional means of transportation. Tides, soft substrates, mangrove root structure and unfriendly fauna (e.g. crocodiles, wild pigs and buffalo) are a further hindrance to ground activities. Additionally, remote areas in northern Australia are often inaccessible during the wet season due to inundation.

Coastal wetland habitat types have different spectral reflectance characteristics due to variations in type and concentrations of pigments within the vegetation canopy. The differences in canopy reflectance can be utilised to collect habitat information remotely. The Thematic Mapper (TM) sensor on the Landsat 5 satellite and the Enhanced Thematic Mapper Plus (ETM+) sensor on the Landsat 7 satellite collect bands of reflectance information that can be analysed to produce classifications of coastal wetland habitats.

The creation of coastal wetland habitat datasets throughout Qld through the analysis of Landsat TM and ETM+ data has been successfully completed (Bruinsma 2001). The Qld Fisheries Service developed a cost-effective method to map coastal wetlands by digitally classifying Landsat imagery with verification by aerial photography and limited field data (Danaher 1995a). The technique used has been recognised by Environment Australia (Ward et al. 1998) as an appropriate model for a national approach to coastal wetland mapping. It has also been demonstrated in previous studies (Bruinsma 2001), that this technique developed for broad scale coastal wetlands mapping is transferable to similar coastal wetland systems.

This method of investigating and mapping coastal wetland communities of relatively large coastal regions, as utilised in this study, has proven to be cost effective at this scale with a high degree of accuracy (90%). The resolution of the satellite imagery and the mapping process used results in a mapping product at a scale of 1: 100 000.

This standard technique of mapping coastal wetland habitats on a regional scale has now been applied to the NT to produce a dataset to complement the existing Qld dataset. Section 2 of this report outlines the results of the mapping undertaken in the NT. The original objective of this project was to map the coastal wetlands of the NT and Qld. However, the Qld component was completed prior to the start of this project and so only the NT was mapped using project funds.

The coastal wetlands information generated from Landsat imagery provides a dataset that can be used in many ways to assist the management of these habitats. In the first instance, it provides a suitable baseline dataset for monitoring broad-scale changes in area and composition of coastal wetland communities. Additionally, it provides information required by managers for choosing representative habitats for protection.

Within Qld, spatial analysis of the coastal wetland dataset has been undertaken to determine the degree to which coastal wetland communities protected by existing fish habitat areas (FHAs) are representative of the coastal wetland communities present regionally. By mapping the coastal wetlands within each marine/coastal region (Interim Marine and Coastal Regionalisation of Australia), it has been possible to assess protection of coastal wetlands within existing FHAs and to identify gaps in the FHA network in order to set priorities for future investigation and FHA declaration.

2.2 Need

To develop a method to quantify the vast and remote area of habitat utilised by the northern Australian mud crab. Given the accelerating pace of coastal development in northern Australia the identification and quantification of critical inshore fishery habitat is a priority for future protection of the ecosystems on which various fisheries depend. Development of fisheries resource assessment techniques that incorporate important ecosystem information such as habitat can only improve assessment reliability and accuracy.

2.3 Objective

Identify and quantify the area of critical mud crab habitat in the NT and Qld.

2.4 Methods

2.4.1 Data

The distribution of coastal wetland communities in the NT was investigated using remote sensing data from the Landsat 7 Advanced Thematic Mapper Plus (ETM+) sensor. Sixteen Landsat ‘scenes’ were required to map the coastal wetland habitats. The coastal wetland habitats of Qld have been mapped (de Vries et al. 2002). The NT mapping was undertaken in a consistent manner and using the same technique to complement this existing dataset.

Table 1. Landsat imagery utilised in the project

Path/Row	Locality	Date	Bands	Source
100/72	Qld Border	31-May-00	1-7	AGO 2000
101/71	Robinson River	12-Nov-99	1-7	NT Parks and Wildlife
102/69	Arnhem Land	14-Jun-91	1-7	NT DLPE
102/70	Groote Eylandt	15-Aug-99	1-7	NT Parks and Wildlife
102/71	Borroloola	15-Aug-99	1-7	NT Parks and Wildlife
103/69	Goyder River	31-May-95	3-5,7	NT DLPE
103/70	Roper River	12-May-94	3-5,7	AGO 2000
104/68	Junction Bay	22-May-95	3-5,7	NT DLPE
104/69	East Alligator River	14-Jul-00	1-7	AGO 2000
105/68	Cobourg Peninsula	18-May-00	1-7	NT Parks and Wildlife
105/69	Mary River	22-Aug-00	1-7	NT DLPE
106/68	Tiwi Islands	11-Aug-99	1-7	NT DLPE
106/69	Darwin	29-Aug-00	1-7	NT DLPE
106/70	Port Keats	26-Jun-00	1-7	NT DLPE
106/71	Victoria River	26-Jul-99	1-7	AGO 2000
107/70	WA Border	19-Sep-99	1-7	AGO 2000

Aerial photography was used as reference data to aid in the classification of the coastal wetland vegetation. The photography used is listed in Table 2. Recent aerial photography was not available for some remote areas. Additionally, the available aerial photography did not provide a complete coverage of the coastal wetlands in the study area.

Table 2. Aerial Photography utilised in the project

Aerial Photography Project Name	Month-Year	Scale
Arnhem Highway	07/09-1982	1: 50 000
Auverge	09/1992	1:50 000
Bathurst Island	06/07-1981	1: 20 000
Cape Scot – Port Keats – Fergusson River	06/1997	1:50 000
Cooper Creek Murgenella	09-1979	1: 20 000
Cobourg Peninsula	05/06-1982	1: 20 000
Darwin-Kakadu Regional	08-1987	1: 60 000
Darwin Medium Scale Revision	06-1993	1: 60 000
Darwin Rural	08-1997	1: 20 000
Fog Bay Road	05/1991	1:50 000
Glyde Point	07-1998	1: 20 000
Junction Bay	07-2001	1: 50 000
Limmen Gate	09-1995	1: 50 000
Mary River IRC	10-1993	1: 50 000
Melville Island Skymap Controlled	08/09-1996	1: 50 000
McArthur River Mine Site	06-1994	1: 50 000
Ngukurr-Groote	08/09-1982	1: 50 000
Pellew Islands	06-1994	1: 50 000
Robinson River	06-1995	1: 50 000

Where available, local scale historical mapping of some estuaries within the study area was used to complement the information obtained through air photo interpretation and field surveys. The datasets used are listed in Table 3.

Table 3. Local vegetation information used to aid the current mapping exercise**.**

Title	Details	Reference/s
Surveys of tidal river systems in the NT of Australia and their crocodile populations: Monographs 1, 4-7, 9-11	Tidal vegetation information for selected estuaries	Messel et al. (various)
The mangrove communities of Darwin Harbour. Technical Report No. R96/7 Resource Capability Assessment Branch, Department of Lands, Planning and Environment	Mangrove maps of Darwin Harbour	Brocklehurst, P. and Edmeades, B (1996)
The mangrove communities of Bynoe Harbour. Draft Report Resource Capability Assessment Branch, Department of Lands, Planning and Environment	Mangrove maps of Bynoe Harbour	Brocklehurst, P. (unpublished)
Mangrove Vegetation in Northern Australia – Volume 1. School of Biological Sciences, University of Sydney		Wells, A.G. (1984)

2.4.2 Mapping Methods

The satellite imagery was processed using ERDAS Imagine 8.4 on a PC with a Microsoft Windows NT operating system. Available bands (see Table 1) were contrast stretched using a linear stretch and break points to highlight the intertidal regions. All water bodies were spectrally masked out using an ETM+ band 4 (near infrared) image. In order to limit the area of the classification to the intertidal coastal wetland environments, the terrestrial land features were masked out manually. The upper limit of the intertidal zone was identified using a false colour composite of ETM+ bands 1, 4 and 5 (through blue, green and red colour guns, respectively) in conjunction with colour aerial photography, topographic maps and field work. The use of brightness and wetness bands of a tasselled cap analysis also assisted in defining the tidal boundary.

The remaining imagery of the intertidal zone was processed using an unsupervised classification procedure. ERDAS Imagine uses the Iterative Self-Organising Data Analysis Technique (ISODATA) classification algorithm in order to create clusters of pixels that are spectrally similar. The ISODATA utility repeats the clustering of the image until either a maximum number of iterations has been performed, or a maximum percentage of unchanged pixels (convergence threshold) has been reached between two iterations (ERDAS 1997). The resulting classes were labelled according to their dominant cover type with the aid of aerial photography. Clumps of pixels less than 0.5 ha were eliminated and the image was smoothed using a three by three pixel, moving kernel.

The classification was converted from raster to vector format using ARC/INFO GIS software. To improve cartographic presentation of the data, the jagged vector boundaries were splined and generalised and polygons with areas under 0.5 ha were excluded.

2.4.3 Field Methods

The computer-based coastal wetland community classification was validated with field work conducted during June and August 2001. Approximately 170 sites were accessed by boat or helicopter. At each site, information on mangrove community floristics and structure was documented. The data recorded included the specific composition of mangroves, dominant genus, estimated density (Projective Foliage Cover – PFC) of each vegetation layer, composition and hardness of substrate, and presence/absence of seedlings, samphires, grasses, algae, leaf litter, roots, ferns, epiphytes, sedges and ponds.

The time available, budget requirements and accessibility to the mangroves limited the amount of field work (see Section 2.4.5). The information collected from the fieldwork was used to aid in the classification of the satellite image and the interpretation of the aerial photography.

2.4.4 Classification Details

Mangroves were classified to the community level based on dominant genus present and canopy density of the whole community. The density of the community was determined by estimating the PFC. A canopy cover of greater than 50% was classified as closed, while less than 50% was identified as open.

The standard Specht (1987) vegetation categories of ‘forest’ and ‘shrub’, which are based on height, were not included in this classification. This is due to the fact that vegetation height cannot be determined from the Landsat ETM+ data.

Only areas subject to tidal inundation were included in this mapping exercise. Excluded classes consisted of permanent pools of water and elevated land containing terrestrial vegetation. Tidally exposed non-vegetated intertidal flats along with sea grass or algal beds were also excluded.

2.4.5 Reliability

A reliability class was assigned to each polygon within the classification based on the amount of ground truth data available (i.e. aerial photography and field data). The reliability classes are as follows:

A	**Highest Reliability**	Complete aerial photography coverage. Fieldwork conducted.
B	**High Reliability**	Complete aerial photography coverage. No fieldwork conducted.
C	**Average Reliability**	No aerial photography available. Fieldwork conducted. OR No aerial photography available. Local cloud cover on satellite imagery.
D	**Reliability Unknown (Further Ground Truthing Required)**	No aerial photography available. No fieldwork conducted. OR No aerial photography available. Local cloud cover on satellite imagery.

2.4.6 Northern Australian Mud Crab Habitat GIS

Along with the tidal coastal wetland communities mapped as part of this study, spatial datasets of foreshore flats and land subject to inundation throughout the NT and northern Qld were included in a GIS.

The foreshore flats spatial dataset was acquired from the TOPO-250K Series 1 GEODATA from Geoscience Australia (formerly AUSLIG). The GEODATA product is primarily sourced from the 1: 250 000 scale National Topographic Map Series, which was completed in 1988. In this series, foreshore flats are defined as that part of the seabed between mean high water and the line of low water (AUSLIG 1994).

The Qld and NT datasets were standardized to remove discrepancies in the classification of coastal wetland habitats. A number of classes in the Qld dataset were amalgamated in order to provide consistency between the two mapping products.

A spatial dataset of field site data and photos was included in the northern Australian mud crab habitat GIS. Field data included all sites visited and photos taken during NT fieldwork, as well as site data available for the Qld mapping. A map template was also included in the GIS.

2.5 Results/Discussion

2.5.1 Description of the Mapping Units

The coastal wetland communities are classified on the basis of the dominant genera present. The actual species mix associated with each class varies from estuary to estuary and even within estuaries. The mapping units used in this study are described in general below. Figures 5 to 16 are given as an illustration of a typical example of the mapping unit. Figure 17 is an example of the hard copy mapping product. Maps are produced at a scale of 1: 100 000 on an A3 paper sheet.

Table 4. Description of habitat classification

CLOSED *RHIZOPHORA*	**FIGURE 5**
Habitat	Occurs along the seaward edge, low in intertidal zone with roots regularly submerged during high tides.
Canopy	Usually dominated by tall, mature *Rhizophora* spp. which form a dense canopy (approximately 6–18 m) with a Projective Foliage Cover (PFC) greater than 50%. Other species that may occur in this community are *Sonneratia alba*, *Avicennia marina*, and *Camptostemon schultzii*.
Shrub layer	Poorly developed or completely absent.
Ground cover	*Rhizophora* spp. stilt roots with a sparse cover of *Rhizophora* spp. seedlings.

CLOSED *AVICENNIA*	**FIGURE 6**
Habitat	Can be found in a diverse range of intertidal environments from the seaward edge (as a pioneer), to accreting banks (as a fringe), to the landward edge.
Canopy	*A. marina*, with occasional *Ceriops* spp., *Rhizophora* spp. and *Sonneratia* spp. forming a dense canopy with a PFC of greater than 50%. Heights vary depending on position within the intertidal zone (taller on seaward edge, shorter on landward edge).
Shrub layer	Seaward edge communities tend to have no shrub layer. Communities further landward may have other species such as *A. corniculatum* or *C. tagal* forming an understorey.
Ground cover	*A. marina* pneumatophores and seedlings and samphires often form a sparse ground cover.

OPEN *AVICENNIA*	**FIGURE 7**
Habitat	Found on the seaward edge as a pioneer and on the landward edge that is only inundated by the highest spring tide.
Canopy	*A. marina* plants form a canopy that has a PFC of less than 50%. Height varies, generally <1 m in areas bordering on salt pans and up to 10 m in pioneering zones.
Shrub layer	Generally absent.
Ground cover	Occasional presence of samphires (on the landward edge) and a sparse coverage of *A. marina* pneumatophores.

CLOSED *CERIOPS*	**FIGURE 8**
Habitat	Generally occurs on erosion banks and towards the upper intertidal limit, on more elevated land. Only inundated by the spring tides.
Canopy	Dominated by *Ceriops* spp., often with *A. marina*, *Bruguiera* spp., *L. racemosa*, *Excoecaria ovalis*. Height of the canopy across sites varies (from approximately 2–10 m) however at an individual site is generally remarkably uniform. PFC greater than 50%. More species diverse on creek banks, more monospecific on saltpan edges.
Shrub layer	Generally absent.
Ground cover	Consists of sparse cover of seedlings and roots of the species present.

OPEN *CERIOPS*	**FIGURE 9**
Habitat	Occurs on the landward edge of the intertidal zone and is inundated by only the high spring tides. This community often surrounds salt pans and is rarely on the water's edge, except on eroding banks.
Canopy	A community dominated by *Ceriops* spp. with occasional *A. marina* emergents. The PFC is less than 50%; height varies from <1 m in the extremely saline areas to approximately 10 m.
Shrub layer	Occasional presence of other species such as *A. corniculatum*.
Ground cover	Consists of seedlings of the species present along with a sparse to open coverage of samphires and grasses.

CLOSED *RHIZOPHORA/AVICENNIA*	**FIGURE 10**
Habitat	Occurs on the seaward edge, generally within a closed *Rhizophora* zone, or on a riverbank towards the mouth of the estuary.
Canopy	A mixed community of *A. marina* and *Rhizophora* spp. together forming a closed canopy with a PFC of greater than 50%. Heights of between 6–18 m are common.
Shrub layer	The understorey may consist of *A. marina* and *Rhizophora* spp.
Ground cover	Roots and seedlings of the canopy species.

CLOSED *AVICENNIA/CERIOPS*	**FIGURE 11**
Habitat	Usually surrounded by salt pans or on the landward edge, in areas only inundated during spring tides.
Canopy	A mixed community of *A. marina* and *Ceriops* spp. forming a canopy with a PFC of greater than 50%. Generally a low community with a canopy of <4 m.
Shrub layer	Other species such as *A. annulata*, *Bruguiera* spp. and *L. racemosa* may be present.
Ground cover	Occasional presence of samphires and seedlings of the species present.

OPEN *AVICENNIA/CERIOPS*	
Habitat	Generally bordering saltpans in areas only inundated during spring tides.
Canopy	A mixed community of *A. marina* and *Ceriops* spp. forming a canopy with a PFC of less than 50%. A low community with a canopy of <3 m.
Shrub layer	Other species such as *A. annulata*, *Bruguiera* spp. and *L. racemosa* may be present.
Ground cover	Occasional presence of samphires and seedlings of the species present.

CLOSED *SONNERATIA*	**FIGURE 12**
Habitat	Occurs as the most seaward community, low in intertidal zone with roots regularly submerged during high tides.
Canopy	Usually dominated by *Sonneratia alba* 10 m tall often forming park-like woodland stands with a PFC greater than 50%. Other species that may occur in this community are *Rhizophora* spp., and *Avicennia marina*.
Shrub layer	Sparse *A. corniculatum* may occur.
Ground cover	*Sonneratia* pneumatophores and seedlings often form a sparse ground cover.

OPEN *SONNERATIA*	**FIGURE 13**
Habitat	Occurs as the most seaward community, low in intertidal zone with roots regularly submerged during high tides.
Canopy	Usually dominated by *Sonneratia alba* up to 10 m tall forming open park-like woodland stands with a PFC less than 50%. Other species that may occur in this community are *Rhizophora* spp., and *Avicennia marina*.
Shrub layer	Sparse *A. corniculatum* may occur.
Ground cover	*Sonneratia* pneumatophores and seedlings often form a sparse ground cover.

CLOSED MIXED	**FIGURE 14**
Habitat	Generally found on the landward edges of mangrove communities and in the upper tidal reaches of creeks and rivers where there is a high freshwater influence.
Canopy	A closed mix (PFC > 50%) in which a variety of the species present in this region may occur without being dominated by one genus in particular. Often reaching heights of 10–20 m.
Shrub layer	Shrub layer often consists of *A. ilicifolius*, *A. speciosum* and *C. pedunculatum*. Juveniles of the various canopy species may also be present. Epiphytes (including orchids and ferns) on the mangrove plants are common.
Ground cover	Seedlings and roots of the various species along with sparse samphires and grasses.

SALINE GRASSLAND	
Habitat	Occurs along the landward edge of the intertidal zone in a hypersaline environment that is only inundated by the highest spring tides. Sometimes extends past the upper intertidal limit into open *Casuarina* communities.
Canopy	Generally absent.
Shrub layer	Absent.
Ground cover	Ranging from sparse to dense coverage of salt couch (*Sporobolus virginicus*) within which a sparse coverage of samphires and sedges may also occur.

SALTPAN	**FIGURE 15**
Habitat	Occurs along the landward edge of the intertidal zone in a hypersaline environment that is only inundated by the highest spring tides.
Canopy	Sparse stunted (<1 m) individuals of various mangrove species may occur (e.g. *A. marina, C. tagal* and *L. racemosa*).
Shrub layer	Some samphire such as *Halosarcia* spp. and *Tecticornia australasica* may be present as very small shrubs.
Ground cover	Commonly an open coverage of samphires. However, may be virtually unvegetated or have an algal covering.

SAMPHIRE-DOMINATED SALT PAN	**FIGURE 16**
Habitat	Occurs along the landward edge of the intertidal zone in a hypersaline environment that is only inundated by the highest spring tides.
Canopy	Generally absent.
Shrub layer	Absent.
Ground cover	Dense coverage of samphires (*Halosarcia* spp. and *Tecticornia australasica*) within which a sparse coverage of salt couch (*Sporobolus virginicus*) and sedges may also occur.

FORESHORE FLATS	
Definition	That part of the seabed between mean high water and the line of low water.

Figure 5. Closed *Rhizophora* on the bank of the Wearyan River

Figure 6. Closed *Avicennia* at Naryampi Creek

Figure 7. Open *Avicennia* on the foreshore near the Daly River

Figure 8. Closed *Ceriops* at Bynoe Harbour

Figure 9. Open Ceriops just north of Fossil Head

Figure 10. Closed *Rhizophora*/*Avicennia* on the Wearyan River

Figure 11. Closed *Avicennia*/ *Ceriops* at the Robinson River

Figure 12. Closed *Sonneratia* on the foreshore at Treachery Point, with closed Rhizophora behind

Figure 13. Open *Sonneratia* on the foreshore at Cape Ford

Figure 14. A closed mixed community with Samphire-dominated saltpan in the foreground, at Limmen Bight

Figure 15. Salt pan at Twin Sisters with a closed mixed community in the background

Figure 16. Samphire-dominated salt pan adjacent to tributary vegetation on the Edward Pellew Island Group

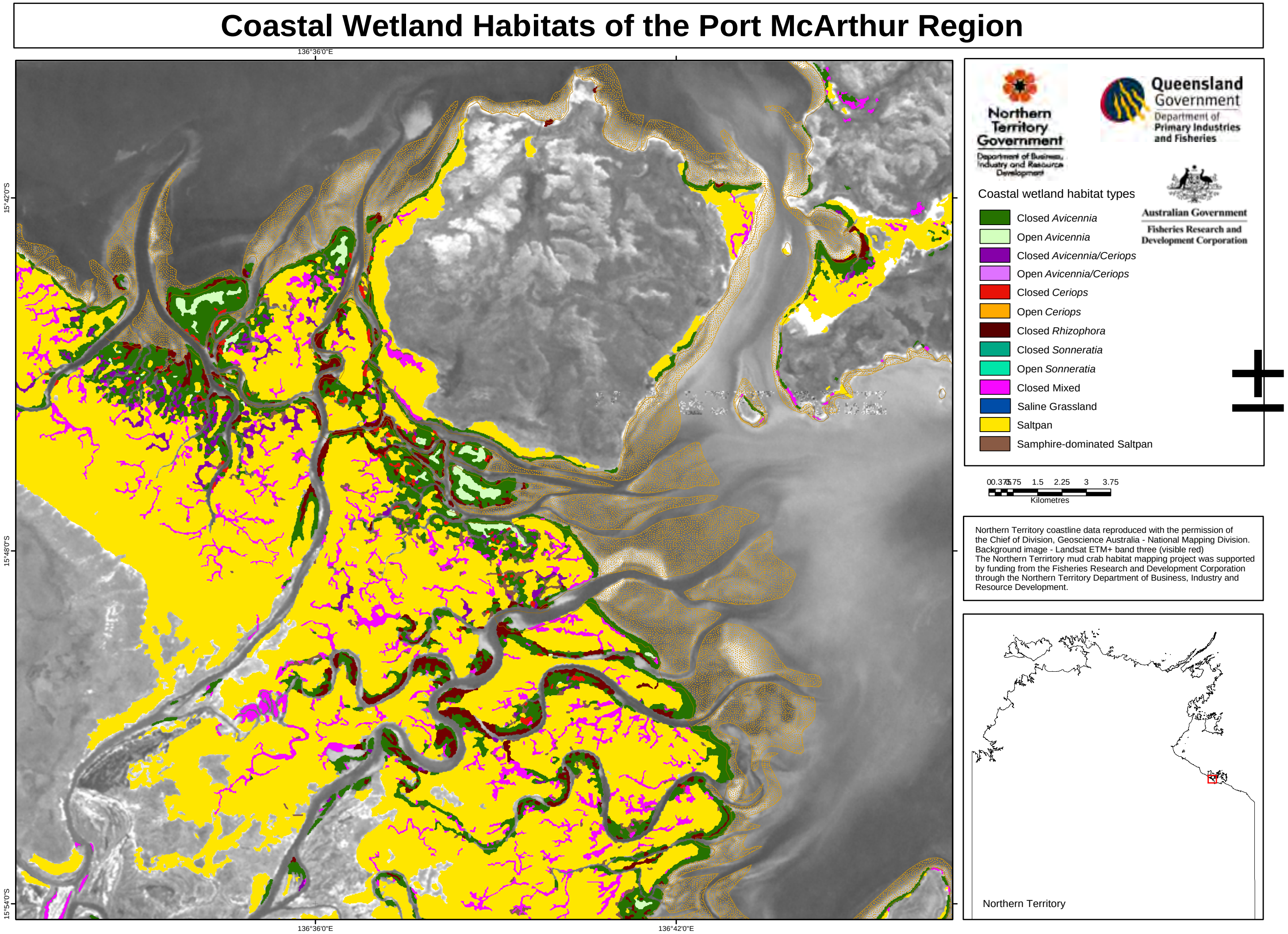

Figure 17. Example of mapping product (not actual size)

2.5.2 Limitations of the Mapping Technique

Some coastal wetland plant species are too spectrally similar to be distinguished by Landsat ETM+ imagery. For example, *Rhizophora stylosa* and *Bruguiera gymnorrhiza* (Family Rhizophoraceae) have very similar foliage and are thus difficult to tell apart from both aerial photography and Landsat ETM+ imagery. Ground truthing and knowledge of positions in the intertidal zone that species typically grow is used to aid in distinguishing classes where species have been confused spectrally.

This mapping technique is also limited by the spatial resolution of the Landsat ETM+ satellite imagery. It is not possible to detect some typical mangrove zones, such as narrow seaward fringes, small mangrove communities within a salt pan or saline grassland or narrow fringing closed mixed communities in upstream locations. Additionally, any communities less than 0.5 hectares are purposefully eliminated in the mapping process to enhance the cartographic representation of the data. The resolution of the satellite imagery and the mapping process produced results that should not be interpreted at scales larger than 1: 100 000.

2.5.3 Reliability

The majority of the tidal coastal wetlands mapped as part of this study were given highest or high reliability. Poor reliability was recorded in those areas for which no aerial photography was available. The main areas of poor reliability include Groote Eylandt, sections of the Tiwi Islands and large portions of Cobourg Peninsula and Van Diemen Gulf.

For some areas of coastal wetland habitats, cloud cover obscured reflectance information in the satellite image. Where this occurred, mapping was undertaken using aerial photography alone. Poor reliability is recorded for those areas where no aerial photography was available.

2.5.4 Metadata

Metadata for the tidal coastal wetlands dataset and the field sites datasets in ANZLIC standard format are included in Appendix 2 and have been submitted for inclusion in the Australian Spatial Data Directory (ASDD).

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3. Estimation of Animal Abundance

3.1 Introduction

The estimation of animal abundance is an important challenge in both theoretical and applied biological sciences (Otis et al. 1978). As such vast amounts of scientific and statistical expertise have been devoted to improving and developing robust assessment methods, particularly over the past 30 years. However, the study of natural aquatic populations is not easy. In some cases, visual counts can be made providing an accurate measure of absolute density for a particular species. For this to occur all animals must be visible at the time of the survey. In reality this is rarely possible, and is especially unlikely in the marine environment, as most aquatic populations are difficult to observe (Hilborn and Walters 1992). This situation is compounded in tropical estuarine environments that are characteristically turbid for most of the year. Fisheries assessments have therefore had to rely heavily on the development of alternative methods to estimate abundance of aquatic species.

The tagging of fish and other aquatic organisms is not a new approach. Mark-recapture techniques (tagging) has long provided important biological information (e.g. growth, movement and in some cases exploitation rates) for many species through tag returns. However, tagging data can also provide much more valuable information. Experiment design and analysis techniques have advanced considerably and robust estimates of population size can be achieved from capture-recapture and removal data. These advances have culminated in the development of a series of models and more recently software that allows for temporal, behavioural and individual heterogeneity in capture and recapture rates. However, for these models to perform with minimal error, certain assumptions must be addressed, and this requires detailed experimental planning.

Seber (1986) acknowledged a long standing problem when converting sample population estimates to density estimates: determining the actual area sampled (the "edge effect" where animals are drawn into the study site). Identifying the actual area of the study site sampled is a difficult task, as the use of baited traps may cause immigration of new animals into the study site, positively biasing the population estimate. This varies among species and is dependent on a number of factors such as the animals' home range, and a mosaic of environmental and behavioural factors. It is therefore important when using baited traps to incorporate a method to monitor animal movement into the study site.

This problem is further complicated by the fact that a species may be found in a variety of habitats. Throughout their broad geographical distribution mud crabs exhibit strong habitat preferences for soft muddy substrates found in estuarine environments such as mangrove-lined streams and mudflat foreshore areas. In order to sample these two distinct habitats, we have developed separate experimental designs that attempt to meet the associated model assumptions. For mangrove-lined streams we introduce a new design combining mark-recapture and depletion techniques, and for the foreshore mud flats we apply the trapping web design developed from DISTANCE sampling theory (Buckland et al. 1993).

As these two methodologies had not previously been applied to fisheries studies, optimum application required preliminary studies. NT Fisheries first developed the depletion mark-recapture method used in this study in 1997 following the 1996 NT mud crab assessment recommendations (Walters et al. 1997). QDPI&F researchers were also present at the 1996 workshop and devised a similar study using a mark-recapture design where depletion methods could also be applied to the data by treating first captures as removals.

David Anderson and Ken Burnham from Colorado State University introduced trapping web theory at a mark-recapture and distance sampling workshop held at the University of Qld, Brisbane in June 2000. The concept was then adapted to the marine environment and the first marine application of this method was trialled by NT Fisheries in October 2000. These preliminary studies conducted by NT Fisheries Group and QDPI&F were precursors to the work presented in this document.

3.2 Mark-Recapture and Depletion Theory

Mangrove-lined streams provide a natural boundary to immigration/emigration simply by having defined edges to the habitat area (i.e. banks) with only the upstream and downstream portion open to influx or escape. This project has focused on developing an experimental design that combines mark-recapture and depletion techniques. This novel design provides a method for assessing the assumption of closure by permitting a measure of the movement of tagged animals into the study site.

Mark-recapture methodology is very comprehensive (Pollock 1991). A simple example of a mark-recapture experiment follows, where a sample of n_1 animals is caught, marked and released. Later a second sample of n_2 animals is captured, of which m_2 have been marked. An intuitive estimator of the population size (N) can be achieved based on the assumption that the ratio of marked to total animals in the second sample should reflect the same ratio in the population (Pollock 1991) and N. is thus estimated as N hat = n_1n_2/m_2 The precision of this estimate can be improved by adding further recapture occasions, provided the population remains closed (i.e. no immigration/emigration). Choosing the sampling duration for such a study is therefore an important factor in the study's success. Otis et al. (1978) recommend that a closed population model requires 5 to 10 sampling periods with a minimum average capture probability of 10 % per period for sound results. Also worth noting for many of the density estimation models, sample sizes in the range of 80-100 individuals have been recommended by various authors (Otis et al. 1978; Burnham et al. 1980; Buckland et al. 1993).

Five general assumptions are recommended for estimating animal abundance using mark - recapture methods;

1. The population is closed (no immigration/emigration).
2. Animals do not lose tags during the experiment.
3. All marks/animals are correctly noted and recorded at each trapping occasion.
4. Each animal has a constant and equal probability of capture on each trapping occasion.
5. All marked animals mix with the unmarked animals and have equivalent recapture probabilities.

The assumption of population closure is perhaps one of the most important. A closed population is one where the population is constant for the duration of the experiment (i.e. no births, deaths, immigration or emigration). This is a strong assumption and in reality has proved difficult to achieve (Otis et al. 1978, White et al. 1982). Pollock (1982) and Seber (1992) expand this further by suggesting that an open population, where migration, births and deaths occur, can sometimes be treated as closed if the study period is short enough. This is the approach we have taken, combined with movement studies to test this assumption.

The two assumptions relating to tag application and recording are often overlooked in large tagging programs. It is important that all personnel involved in conducting the tagging and recording of data are trained in applying tags and recording data. As such the NT Fisheries Group has prepared a training manual for all staff employed on the project (see Appendix 6).

Otis et al. (1978) considers the wide recognition that assumption 4 commonly fails and that accurate population estimation usually requires models that provide for unequal probabilities of capture. Schwarz and Seber (1999) acknowledge the extensive research directed at both examining the effects of departure from assumption 4 on estimates and the modification of various models to allow for such departures. White et al. (1982), Pollock (1991), Chao (1987) and Chao et al. (1992) all provide estimators that do not assume equal catchability.

The final assumption requires that marked animals mix freely with the unmarked population on return and do not become “trap happy” or cluster around the trap. A population that meets this assumption is one where the ratio of marked to unmarked animals remains unchanged.

The removal or depletion method is particularly suitable for estimating fish and aquatic invertebrate populations (Carle and Strub 1978), particularly when it is possible to fish a population intensively over a short period of time (Hilborn and Walters 1992). In a removal study animals are trapped and removed from the population rather than marked and released. On the first and all subsequent occasions all captured animals are removed. The general concept of this form of assessment is to examine how the deliberate removal of the species influences the relative abundance of the remaining population in the depletion study area (Hilborn and Walters 1992).

The two general assumptions for removal studies are equivalent to assumptions 1 and 3 for mark recapture methods.

3.3 Trapping Web Theory

Estimating animal abundance for mudflat foreshore areas requires novel application of a terrestrial sampling method. This method also uses closed population capture-recapture data but needs to account for unknown biases caused by the edge effect, where animals from outside the study site are drawn into the data set. For this method, termed a trapping web, to work the experiment duration must be short to permit the assumption of a closed population and thereby minimising the opportunity for large-scale movement/immigration and recruitment to positively bias the estimate. It is also important that as large a number of traps be used as is practical, to ensure a high probability of capture at the centre of the web.

DISTANCE sampling is a widely-used group of closely related methods using point or line transect data to estimating animal abundance or density (Buckland et al. 1993, Thomas 2002, Borchers et al. 2002). In essence, upon completion of a DISTANCE survey, *n* animals have been detected and their associated distances from the observer are recorded (Buckland et al. 1993). There is a marked tendency for detectability to decrease with increasing distance from the observation point and the analysis incorporates a correction factor based on the distance data to correct for undetected animals (Buckland et al. 1993). Sampling is conducted over a number of consecutive occasions until no new animals are caught near the centre (Buckland et al. 1993). Typically the experiment duration is between three and eight sampling occasions (Buckland et al. 1993).

Anderson et al. (1983) modified this sampling theory and introduced the radial trapping web design. The authors propose that this design eliminates problems associated with most mark-recapture studies, such as accurately measuring effective trapping area and estimating capture probabilities. The method has been widely adopted with various studies examining variations of the method (Link and Barker 1994; Wilson and Anderson 1985; Parmenter et al. 2003). While animals are marked and released only the first capture dataset is required for analyses and subsequent recapture information is used to identify the point in time when all individuals have been marked.

Seber (1986) conveys the benefits of the trapping web design of Anderson et al. (1983) and the nonparametric distance sampling technique of Burnham et al. (1980) as

- the avoidance of a rectangular trapping grid (i.e. accounts for the edge effect);
- trap density near the centre of the web is very high to allow all animals at the centre of the web to be captured with certainty; and
- rigorous methods of analyses are available.

The trapping web design consists of a number of lines of equal length, radiating from a central randomly chosen point. At equal distances along each line are a consistent number of traps. Buckland et al. (1993) suggest a minimum use of at least eight lines of traps. They provide that 'the trapping web was envisioned for use with animals that have some form of home range or territory' and hence 'trap spacing along each line should be determined with respect to the home range of the animal under study'. The spacing should be such that there are 8-12 traps (or more) per home range in the centre of the web (Anderson et al. 1983).

As with all abundance estimation methods a number of assumptions underlie the robustness of DISTANCE analyses. Buckland et al. (1993) state three assumptions are essential for reliable estimation of density from distance sampling. Ordered from most to least critical, these are:

(1) All animals at the centre of the web are captured at least once during the sampling occasions. That is, trapping continues until evidence exists that no new animals are being caught near the centre of the web.

This assumption 'is critical but can be monitored by examining the number of new individuals trapped near the web centre over the trapping occasions'. Alternatively, if at the centre of the web most animals that have been marked and released have subsequently been recaptured then one might conclude that sufficient trapping occasions have been carried out.

(2) Objects are detected at their initial location, prior to any movement in response to the observer.

(3) Distances from the centre of the web to each trap are measured accurately.

Buckland et al. (2001) in assessing the use of trapping web data warns that over estimation of a population's density may occur if the species of interest displays excessive movement near centre of the web. This can be problematic particularly when using baited traps and when trap spacing is too small. "If animals tend to move in home ranges that are small relative to the size of the web and trap spacing then the trapping web is likely to perform well. Alternatively if animals move somewhat randomly over wide areas in relation to the size of the web and trap interval chosen then overestimation may be substantial."

Parmenter et al. (2003) evaluated the accuracy of various models in estimating small mammal density by conducting mark-recapture and trapping web studies on known densities of enclosed rodent populations. When basic assumptions were met the use of web based analytical methods to estimate abundance were recommended over grid based approaches due to the sound theoretical basis of distance sampling techniques.

3.4 Preliminary Studies

In the NT commercial catch and effort data is collected as a summary of monthly fishing activity and while catch can be validated, effort data cannot. An investigation on the effect of lunar cycles on crab abundance was required to ensure abundance estimates were not influenced by the choice of an inappropriate sampling period. Secondly, as trapping web theory had not been applied to the marine environment various configurations of the web design needed to be tested so as to meet analyses assumptions.

3.4.1 Investigation of Lunar Effect on Mud Crab Catch Rates

Commercial catch and effort data for the NT mud crab fishery has been collected since 1983 (Figure 1). The data demonstrate high levels of variation in both catch and effort. Variation in catch can be attributed to strong seasonal patterns with 73% of the reported total catch harvested during the dry season period (May-October) (Hay and Calogeras 2001). This seasonal variation may be partially explained by key biological and environmental factors, such as reproduction and growth and the onset of the monsoon. Variations in effort are more difficult to interpret as NT reported effort is not validated and use of excess pots is a commonly reported offence. Fishery related factors may also impact on the seasonal nature of this fishery such as logistical problems that occur when operating from remote locations during the wet season.

Also worthy of consideration are variations in sex ratios throughout the year. Female mud crabs contribute 60 to 80% of the catch over the northern dry season (May-October), rapidly declining to around 10-20% at the onset of the monsoon. This cyclic pattern demonstrates a significant reduction in the catch of legal sized female mud crabs from the inshore regions of the NT fishery during the later stages of the monsoon season. This supports the work of Hill (1994) suggesting an offshore spawning migration where female mud crabs leave estuaries to seek suitable marine waters to spawn as increased monsoonal rainfall impacts on inshore salinities. (Figure 18).

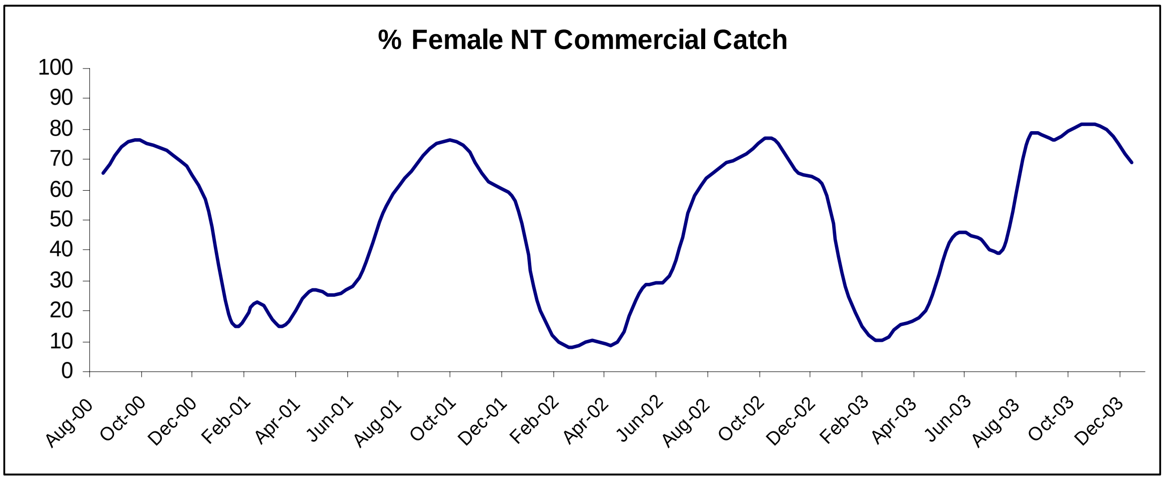

Figure 18. The percentage of female mud crabs in the NT commercial mud crab August 2000-December 2003 (NT commercial catch monitoring)

Investigation of potential lunar variation in mud crab catch rate has not previously been attempted on a finer scale. Anecdotal reports suggest mud crab catch follows the lunar cycle and this required further investigation to determine the most appropriate period of the lunar cycle to conduct abundance estimation studies.

3.4.1.1 Description of Study Site

The GOC is a very large (~370 000 km^2), shallow (<70 m) body of water situated between northern Qld and the NT. In general, the GOC floor slopes very gradually from the coastline, with sinuous gutters of deeper water radiating seaward from the mouth of every major river. The GOC substrate consists primarily of mud and sand (Staunton-Smith et al. 1999), with some of the muddiest areas occurring in the shallow bays and near areas of river discharge (Somers and Long 1994). Intertidal mudflats up to 5 km wide occur throughout the GOC and are most common in the south-west GOC (Conners et al. 1996).

Amongst Australian drainage systems the GOC rivers rate highly in terms of average annual discharge. They are, however, highly dependent on the austral summer monsoonal rains (Munro 1972). Median and mean annual rainfall at Booroloola (nearest rain gauge to the lunar study site) are 731 mm and 790 mm respectively (Conners et al. 1996).

Sea grass beds up to 5 km wide occur throughout the south-western region of the GOC. The sea grass beds are dominated by *Halodule uninervis* and *Halophila ovalis* (Conners et al. 1996). Twenty-six species of mangroves are also known to occur in the coastal fringe of this region (Conners et al. 1996).

The GOC hydrology is dominated by an internal circulation largely isolated from major oceanic currents. Clockwise circulation of coastal waters is evident for most of the year (Church and Forbes 1981). However, this may be reversed in the wet season, particularly during intense north-westerly monsoonal episodes (IMCRA 1998).

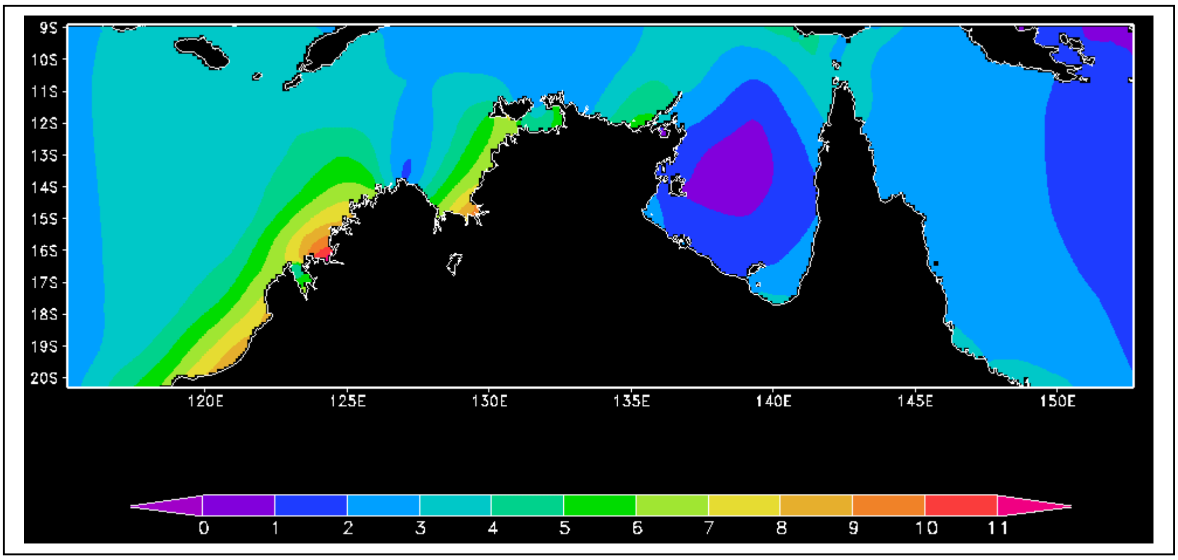

Figure 19. Tidal range in metres (Model ntf_au) for northern Australia. Source: Commonwealth of Australia 2004, Bureau of Meteorology, National Tidal Centre

Tidal range across northern Australia, generally, increases in magnitude in a westerly direction (Figure 19). The Gulf of Carpentaria tidal range can be described as micro-tidal; ranging from 1-2 m offshore and 2-3 m inshore IMCRA (1998). The Gulf of Carpentaria tides are diurnal and the cycle occupies approximately one lunar cycle. The cycle is divided by the neaps into two fortnightly periods. Tides inundate the mudflats regularly, while coastal salt pans are inundated irregularly (spring tides, cyclones) (Conners et al. 1996). The sea surface temperature of the Gulf of Carpentaria is reported to vary 8C° within years (IMCRA, 1998).

3.4.1.2 Methods

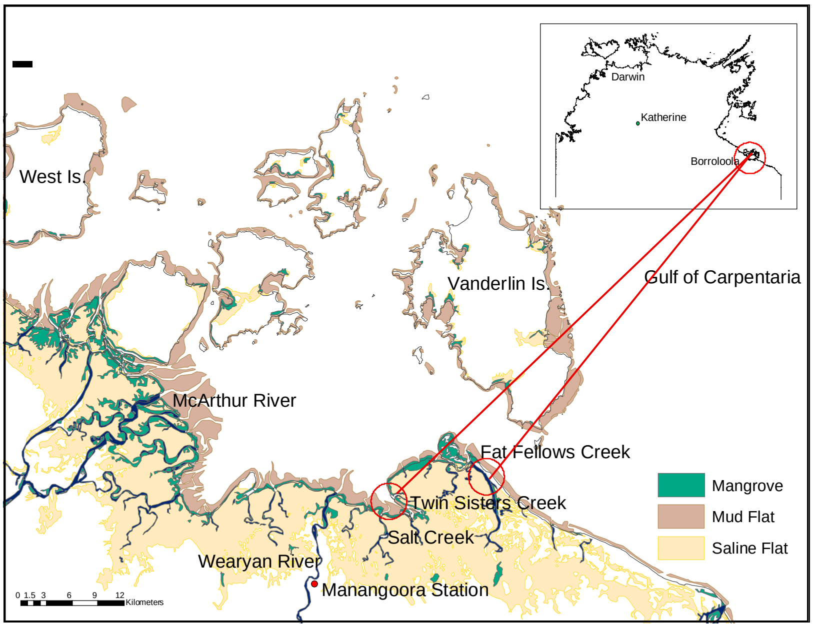

Figure 20. Location of the Gulf of Carpentaria lunar study sites at Salt Creek/Twin Sisters and Fat Fellows Creek

The lunar experiment was conducted from a commercial fishing camp located at Manangoora Station on the Wearyan River in the south-western Gulf of Carpentaria, roughly 1000 km from Darwin (Figure 20 and table 5). The southern Gulf of Carpentaria region is one of the most productive areas of the NT mud crab fishery. The 60 nautical mile grid (NT fishing grid 1536) that encompasses the McArthur River system and Wearyan River produces on average 42% of the total NT commercial catch.

Table 5. Comparative characteristics of the Wearyan River and Fat Fellows Creek (Source: modified from National Land and Water Resources Audit. Estuaries Assessment 2000 http://www.ozestuaries.org/ oracle/ozestuaries/ and CSIRO Simple Estuarine Response model II. http://www.per.marine.csiro.au/serm2))

Character	Wearyan River	Fat Fellows Creek
Longitude	136.86	136.992
Latitude	-15.911	-15.868
Condition	near pristine	near pristine
Classification	river dominated	tide dominated
Sub-classification	tide-dominated delta	tidal flat/creek
Water area (km^2)	7.56	8.81
Entrance width (km)	0.67	1.29
Perimeter (km)	83.96	79.63
Maximum length (km)	32.01	16.35
Catchment area (km^2)	3704	156
Tidal range (m)	2.30	2.30
River Flow (Gl/yr)	174.236	7.338
Tidal period	diurnal	diurnal
IMCRA Class	Pellew Gulf Coast	Pellew Gulf Coast

Two concurrent sampling programs were conducted over a full lunar cycle which extended between the 31 May (first quarter plus one day) and 29 June 2001 (first quarter plus one day). The fishery independent program sampled the mud flat area south east of the Wearyan River, while the fishery dependent program sampled within an adjacent tributary known as Fat Fellows Creek (Study site locations are shown in Figure 3 and description of river characteristics are provided in Table 1). Pots used for both sampling programs were similar and are of the design typically adopted across the NT mud crab fishery (Figure 21).

Figure 21. Typical crab pot used by the NT commercial fishery

For the fishery independent program, NT Fisheries staff set and sampled 60 baited pots daily. The pots, baited with around 0.5 kg red meat (*Macropus* sp), were set on the mud flat areas adjacent to the shoreline at about 100 m apart. To maintain a water depth of between 0.5 m to 3.0 m, the pots were moved perpendicular to the coast according to the amplitude of the tides. In the fishery dependent sampling program, a NT Fisheries staff member accompanied a commercial crabber (licensed to work 60 pots) on normal, daily fishing operations. Bait type, pot location and fishing effort were variable in the fishery dependent program. Bait type was dependent on whatever was at hand, pots were moved to new locations on a regular basis if catch rate dropped and on occasion, tides effectively reduced fishing effort as not all pots were accessible due to low water.

Over the 30 days of sampling the following details of all crabs caught in the baited pots from the two programs were recorded (see Appendix 6 for expanded definitions):

the number of crabs caught per pot;
the sex of each crab;
the carapace width of the crab;
the stage of the moult cycle of the crab;
the stage of sexual maturity of the crab;
the presence or absence of bait in each pot; and
damage (missing limbs, etc.) or evidence of the parasite *Loxothylacus ihlei* .

The position of the pots was recorded for the fishery independent data on a weekly basis with the aid of a GPS.

Crabs (other than those retained by the professional mud crabber as part of normal commercial operations) were tagged and released with the location and details recorded. Crabs were tagged with 50 mm plastic T-bar anchor tags (Hallprint type TBA-2) coloured yellow or orange. With the aid of a Tag-Fast pistol tag applicator, the sequentially numbered tags were inserted into the junction between the dorsal carapace plate and the base of the abdominal flap, slightly off-centre so as to avoid the dorsal abdominal artery (Hill 1975).

The capture of tagged mud crabs was recorded on specific datasheets that were distributed to all mud crab fishers operating in the region. All catch details from the lunar experiment and the subsequent tag returns have been stored in a specifically designed ACCESS database maintained by NT Fisheries.

3.4.1.3 Analyses

Cycles in the catch per unit effort data were tested for, using randomisation tests for periodicity (Manly 1997). First, the time series of catch rates were modelled as a function of sine and cosine terms at different frequencies, and the proportion of the overall variation in catch rate estimated for each frequency. The frequencies examined equated to periodicities ranging between two and 30 days. The original data set was then randomised (with respect to order) a total of 5000 times and the empirical probabilities of observing the pattern of variation were determined.

Calculations were undertaken using S-Plus (Insightful Co., Seattle).

3.4.1.4 Results Lunar Variation in Catch Rate

A total of 8065 *S. serrata* were sampled over the 30 days, with nearly 36% of these crabs tagged and released. A total of 809 tagged crabs were recaptured; (28%) during the study. Out of the combined total catch 74%were male and the mean carapace width of male and female crabs was 160 and 155 mm respectively. Few undersize crabs (<130 mm male, <140 mm female) were captured (<5% total catch), confirming the findings of Knuckey (1999) in demonstrating the NT commercial fishing gears' strong selectivity for legal sized animals (Figure 22).

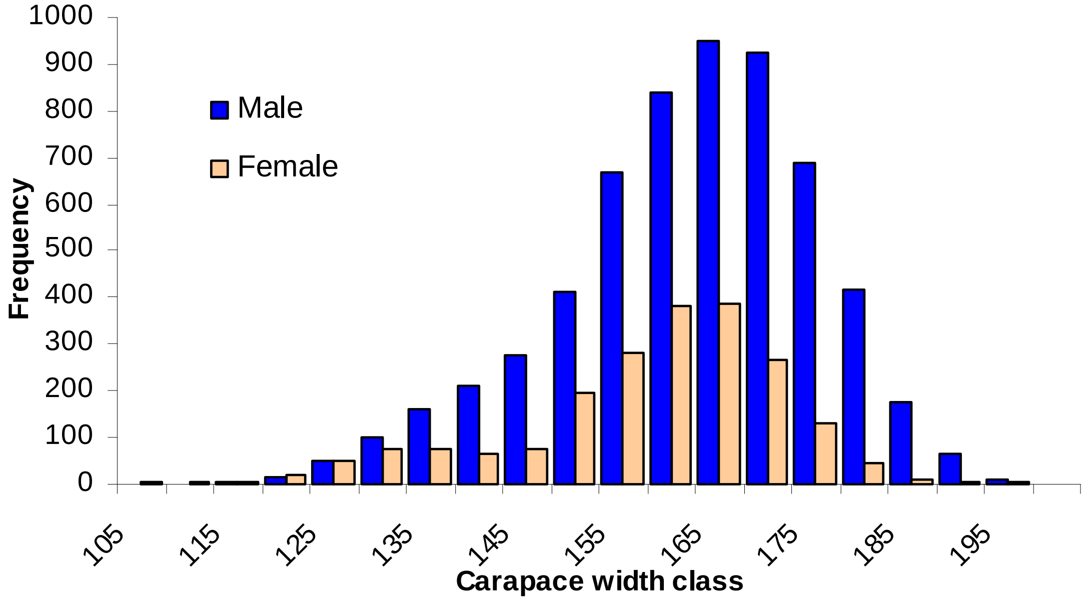

Figure 22. Length frequency of the total catch

The fishery dependent *S. serrata* catch increased in the days following the full moon. However this reflects increased effort as spring tides enable two tides to be fished each day (Figure 23).

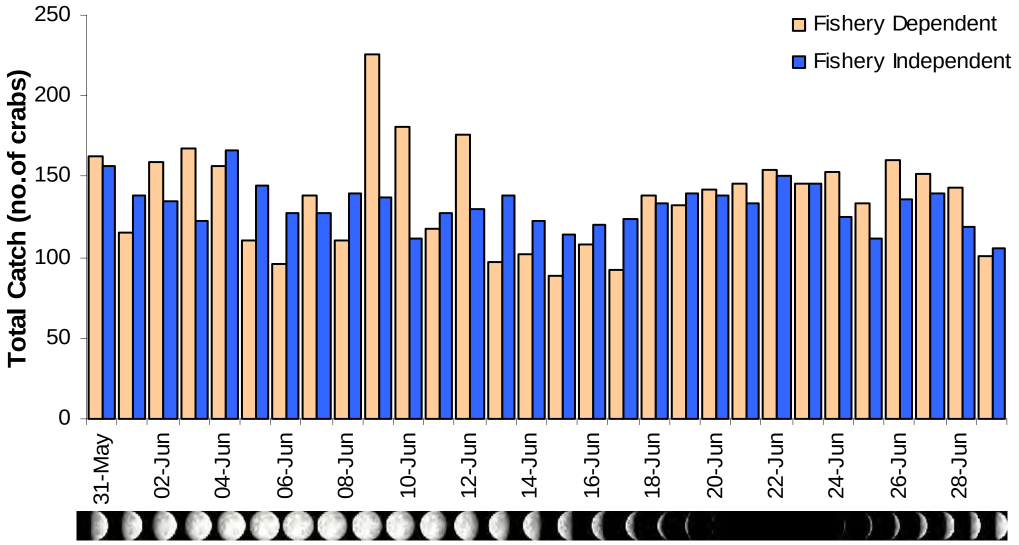

Figure 23. Total number of *Scylla serrata* caught per day for the fishery dependent and fishery independent catches

Over the study phase, CPUE varied between 1.6 and 3.2 crabs per potlift (see Figure 24). Average CPUE over the 30 day period was 2.4 for the fishery dependent data and 2.2 crabs per day per pot for the fishery independent data.

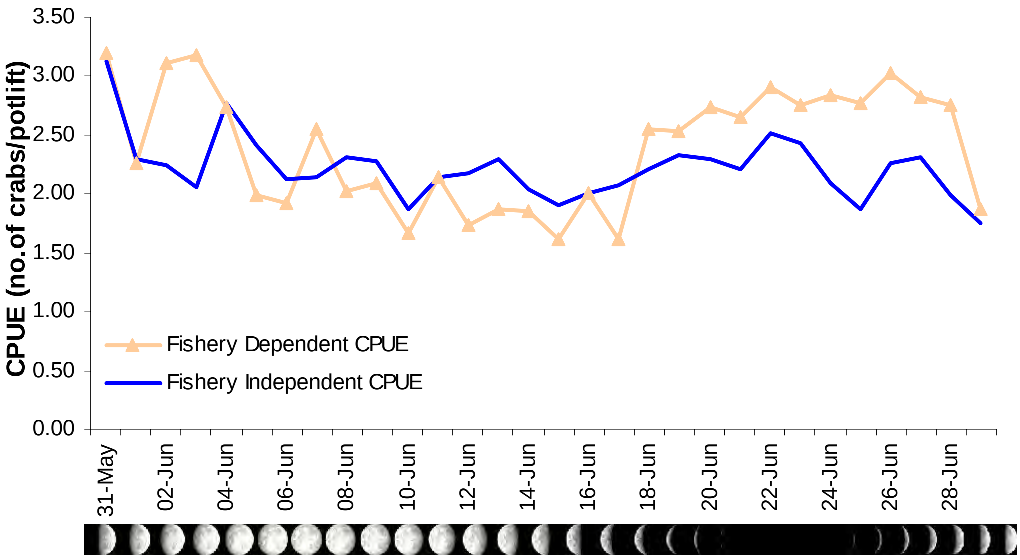

Figure 24. Trend in the fishery independent and fishery dependent CPUE 31 May to 29 June 2001

Results from the S-Plus randomisation test for the fishery independent data are presented in Table 6 and for the fishery dependent data in Table 7. A cycle of 3.8 days explains 26.8% of the variation in the fishery independent data. A cycle of 30 days or greater accounts for 55.3% of the variation in the data for the fishery dependent data.

Table 6. Proportion of variation in fishery independent data explained by cycles of different lengths (cycle length) and the probability of observing this by chance alone (prob.)

	Cycle length (days)	% Prop. var	Rand. mean	Rand. max	Prob.	P. crit.
1	30.0	6.36	0.071	0.392	0.434	0.003
2	15.0	8.54	0.071	0.385	0.321	0.003
3	10.0	6.72	0.070	0.392	0.410	0.003
4	7.5	1.41	0.069	0.467	0.832	0.003
5	6.0	1.41	0.070	0.411	0.843	0.003
6	5.0	0.05	0.071	0.405	0.996	0.003
7	4.3	23.63	0.071	0.415	0.022	0.003
8	3.8	26.80	0.069	0.541	0.012	0.003
9	3.3	3.91	0.070	0.391	0.620	0.003
10	3.0	0.67	0.069	0.477	0.924	0.003
11	2.7	2.36	0.070	0.454	0.745	0.003
12	2.5	0.93	0.070	0.492	0.888	0.003
13	2.3	5.83	0.070	0.452	0.469	0.003
14	2.1	9.59	0.069	0.369	0.269	0.003
15	2.0	1.78	0.018	0.214	0.336	0.003

Table 7. Proportion of variation in fishery dependent data explained by cycles of different lengths (cycle length) and the probability of observing this by chance alone (prob.)

	Cycle length (days)	% Prop. var	Rand. mean	Rand. max	Prob.	P. crit.
1	30.0	55.28	0.071	0.456	0.000	0.003
2	15.0	5.70	0.070	0.699	0.445	0.003
3	10.0	3.26	0.070	0.515	0.632	0.003
4	7.5	3.28	0.067	0.578	0.617	0.003
5	6.0	5.23	0.070	0.520	0.488	0.003
6	5.0	2.22	0.071	0.495	0.734	0.003
7	4.3	0.42	0.072	0.513	0.953	0.003
8	3.8	4.50	0.070	0.544	0.541	0.003
9	3.3	1.42	0.072	0.532	0.822	0.003
10	3.0	1.51	0.070	0.550	0.807	0.003
11	2.7	1.58	0.070	0.433	0.808	0.003
12	2.5	0.46	0.069	0.636	0.940	0.003
13	2.3	8.43	0.071	0.546	0.316	0.003
14	2.1	5.50	0.069	0.489	0.456	0.003
15	2.0	1.22	0.018	0.314	0.400	0.003

3.4.1.5 Discussion

Differences between the fishery dependent and fishery independent catches were observed. Some caution should be observed in interpreting the results obtained from the fishery dependent dataset due to the highly variable nature of commercial fishing activity. Over the sampling period, various bait types were used, pots were moved frequently to new locations as catch rates declined and fishing effort was not consistent. A 30 day cycle was evident. However, this was the maximum period sampled and the cyclic effect may therefore be greater than 30 days.

The fishery independent sampling program showed some evidence of a much shorter cyclic period with 25% of the variation in the data explained by a 3.8 day cycle. A pattern such as this has not been observed before. During the 30 days of this study there was no evidence that lunar patterns influenced mud crab catch rates. This suggests that abundance estimation based on catch rates may be run during any phase of the lunar cycle.

3.4.2 Preliminary Trapping Web Investigation

Using the design represented in Figure 25, four trapping web experiments were conducted on the foreshore areas of the Wearyan River in the southern Gulf of Carpentaria in 2001. Each experiment looked at different configurations of the trapping web design e.g. number of pots, spacing between pots and number of arms. A star picket marked the centre of the web and arms were set by compass bearing and marked with a star picket.

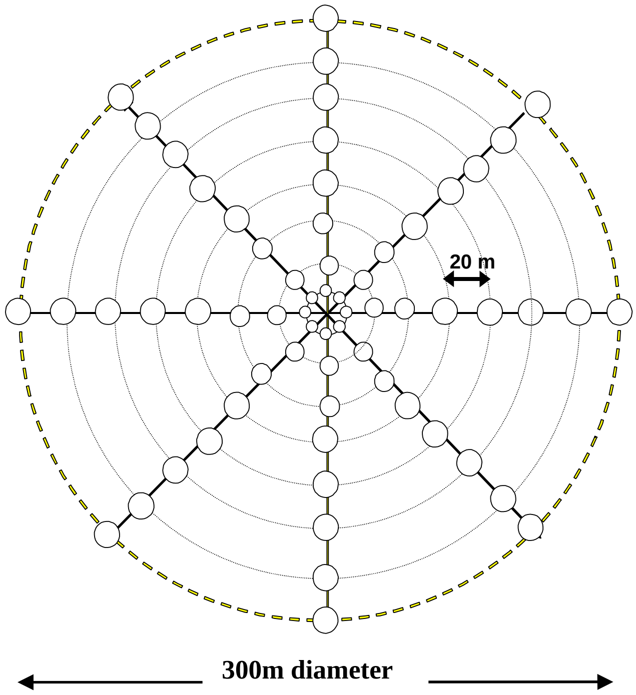

Figure 25. Stylised diagram of the trapping web design - 8 arms x 8 pots utilised by NT Fisheries

Pot spacing between pickets was set using a chainman measuring device, commonly used for measuring distances for geological applications. So as to concentrate traps at the web centre the inner ring of traps was placed at 10 m from the central point and the remaining traps were set at 20 m intervals along each arm of the web creating 8 concentric rings. Crab pots were individually identified by a numbered cattle ear-tag attached near the float. For five days each pot was checked and rebaited every 24 hours with around 500 g fresh red meat (*Macropus* sp.) and re-set in the same location. All crabs caught within the trapping web were sexed, assessed for moult stage, carapace width was measured, and tagged (Hill 1975; Robertson and Piper 1991) using individually numbered T-Bar tags (Hallprint, Australia) before being returned to the water at the point of capture.

3.4.2.1 Trapping Web Design

As this method had not been attempted for crustaceans previously, a number of trials were conducted to provide a design that best met the critical assumptions. A summary of the four trapping web designs tested in 2001 can be found in Table 8.

Table 8. Summary of trapping web designs tested in the southern GOC 2001

Web no.	Date	No pots	No arms	Spacing (m)
1	15/09-19/09/2001	40	8	40
2	15/09-19/09/2001	40	8	60
3	11/10-15/10/2001	30	6	20
4	11/10-15/10/2001	30	6	40

3.4.2.2 Analysis

The trapping web data was analysed using DISTANCE 3.5 software. DISTANCE sampling comprises a number of related methods, which relate to measuring or estimating the distance an animal was detected from a line or point. Distance theory allows for the fact that some of the objects will go undetected and that there is a tendency for detectability to decrease with increasing distance from the observation point. Borchers et al. (2002), in reviewing methods for estimating animal abundance, identify a strength of DISTANCE sampling theory as,"the ability to estimate abundance from a single survey due to the strong (and often reasonable) assumption about detection probability."

The distance sampling theory centres on the measurement or estimation of the detection probability $g(x)$, where the probability of detecting an animal decreases as the distance between the observer and the animal increases. Several flexible models of $g(x)$ can be implemented using DISTANCE. The four available key functions are the uniform, half-normal, and hazard-rate models. A 'series expansion' is used to adjust the fit of the model of distance data. The available series expansions are cosine, simple polynomials, and Hermite polynomials. This fitted function allows the estimation of the proportion of objects missed by the survey. This approach is outlined in detail in the Distance Book (Section 2.4) Buckland et al. (1993).

The recommended analysis strategy when using this software is to select a few models for $g(x)$ that demonstrate the key properties of model robustness, shape criterion, and efficiency.

The software applies Akaike's Information Criterion (AIC) (Akaike 1973) for model selection using a function minimisation framework. AIC is based on the Kullback-Leibler "distance" between two distributions (Thomas et al. 2002; Thomas et al. 1998b). Following the principle of parsimony the model that best fits the data with the fewest number of estimated parameters is selected. A delta AIC (ΔAIC) value of zero indicates the model of best fit and the estimated density of animals is given in number of animals per hectare or kilometre sq. It is generally suggested that the data is truncated to get rid of outliers and improve model fit.

3.4.2.3 Results

Density estimates were further refined by truncating the outer two rings of each web to adjust for the edge effect (immigration from outside the study site) and adjust for positive bias. (Buckland et al. 1993)

Table 9. Results of four trapping web trials from the Wearyan River area, including the model fitted, delta AIC, density per hectare (D), 95% confidence intervals and coefficient of variation (CV)

Web No.	Model	Δ AIC	D/hectare	95% CI		CV
1	Half-normal cosine	0	109.50	74.2	161.6	0.19
1	Uniform cosine	3.8	81.32	52.3	126.4	0.22
1	Half-normal cosine truncate (2)	0	118.10	77.5	179.9	0.21
1	Uniform cosine truncate (2)	4.6	78.02	50.3	120.9	0.22
2	Half-normal cosine	0	40.11	30.17	53.32	0.14
2	Uniform cosine	1.34	40.67	30.51	54.22	0.14
2	Half-normal cosine truncate (2)	0	54.69	35.76	83.64	0.21
2	Uniform cosine truncate (2)	0.14	46.80	32.03	68.39	0.19
3	Half-normal cosine	0	138.48	95.26	201.3	0.19
3	Uniform cosine	0.9	146.31	99.22	215.75	0.19
3	Half-normal cosine truncate (2)	0	258.34	154.62	431.64	0.26
3	Uniform cosine truncate (2)	0.19	238.39	146.08	389.03	0.25
4	Half-normal cosine	3.4	43.06	30.71	60.39	0.17
4	Uniform cosine	0	68.26	42.22	110.35	0.25
4	Half-normal cosine truncate (2)	0	64.62	41.57	100.47	0.23
4	Uniform cosine truncate (2)	1.2	66.60	41.29	107.43	0.25

3.4.2.4 Discussion

A half-normal detection function with cosine smoothing was consistently the best performing DISTANCE model (Table 9). Web No. 3 with 20 m spacing between pots best satisfied the trapping web assumptions. The highest density estimates were achieved utilising pots spaced at 20 m intervals while the lowest were from the pots spaced at 60 m intervals.

From these preliminary results we recommend that trapping web studies for mud crabs use 20m trap spacing with a minimum of 8 lines of pots. To accommodate the need for truncation of outer rings of pots requires a minimum number of eight pots per line, forming the eight concentric rings of the web.

4. Northern Australian Mud Crab Abundance Estimation

Once initial studies were completed two methods were chosen to estimate mud crab abundance in the NT and Qld. Both NT and Qld applied a technique combining depletion and mark recapture studies to estimate crab abundance in mangrove-lined stream habitats and a trapping web design was utilised for the foreshore flat areas. While the study designs applied by the NT and Qld were generally the same, different levels of experimental fishing effort were applied between States.

4.1 Survey Site Selection

4.1.1 Northern Territory

Two locations were selected for the study of mud crab abundance in the NT (Figure 26). The Salt Creek Estuary is located adjacent to the Wearyan River in the southern Gulf of Carpentaria (also the lunar study site see Figure 20) and the second NT site is located adjacent to the Adelaide River, around 60 km east of Darwin (Figure 27).

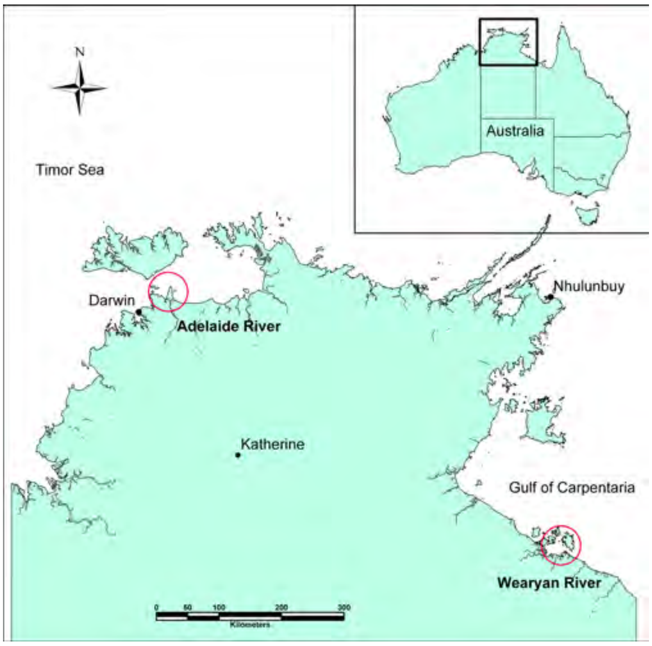

Figure 26. The two NT study sites located adjacent to the Adelaide and Wearyan Rivers

Table 10 describes the characteristics of each of the two sites. The Adelaide River site borders on a large tidally dominated estuary with a tidal range of 6.5 m approximately 4.2 m greater than the Salt Creek/Twin Sisters site located near the Wearyan River. Commercial fishing activity at both study sites demonstrates differences in crab behaviour or habitat preference. Crabs from the Adelaide region tend to be caught from within mangrove-lined stream and river systems while the majority of fishing activity for mud crabs in the Gulf of Carpentaria occurs on the foreshore flats. These differences between sites can most likely be attributed to the tidal range at each site. Tides up to 6.5 m regularly inundate the Adelaide study site while tides up to 2.3 m occur in the southern Gulf of Carpentaria. Hill (1975) reports that crabs prefer sheltered habitat and it is likely that, in areas subject to greater tidal range, mud crabs seek shelter in creeks or rivers particularly during spring tides, while in areas of lesser tidal range crabs burrow and remain within the mud flats habitat.

Table 10. Comparative characteristics of the Adelaide and Salt Creek Estuary. (Source: modified from National Land and Water Resources Audit. Estuaries Assessment 2000. http://www.ozestuaries.org/ oracle/ ozestuaries/ and CSIRO Simple Estuarine Response model II. http://www.per.marine.csiro.au/serm2**)**

Character	Adelaide River	Salt Creek/Twin Sisters Estuary
Longitude	131.214	136.901
Latitude	-12.204	-15.911
Condition	largely unmodified	near pristine
Classification	tide dominated	tide dominated
Sub-classification	tide-dominated estuary	tide-dominated delta
Water area (km²)	53.92	12.33
Entrance width (km)	3.85	3.56
Perimeter (km)	254.83	55.17
Maximum length (km)	68.70	10.18
Catchment area (km²)	7216	928
Tidal range (m)	6.5	2.30
River Flow GL/yr	1468.817	43.653
Tidal period	semi diurnal	diurnal
Imcra class	Beagle-Van Diemen	Pellew Gulf Coastal

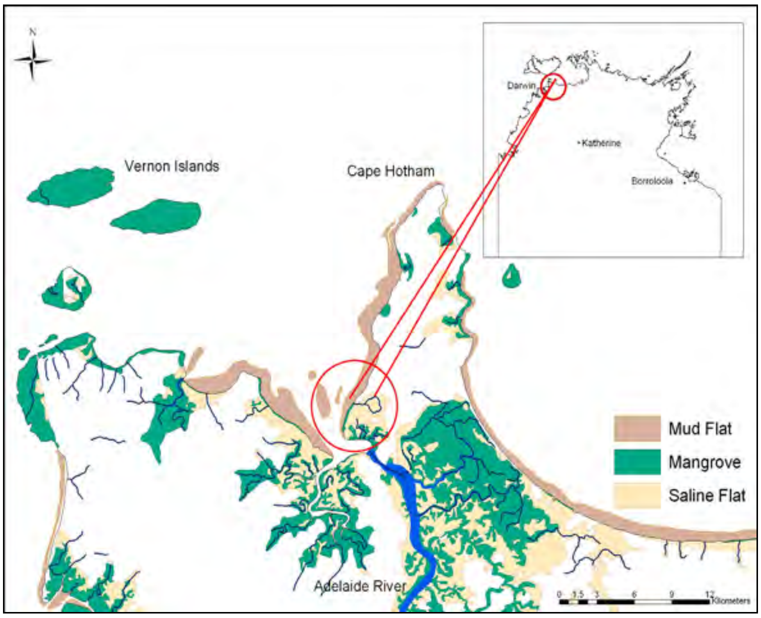

Figure 27. Adelaide River depletion and trapping web study sites

The site chosen for the depletion study at Adelaide River is an unnamed mangrove-lined creek with an approximate average spring high tide width of 30m. The site chosen for the Gulf of Carpentaria region depletion study was Twin Sisters Creek (see Figure 20) with an approximate average spring high tide width of 70 m. Both locations demonstrate historical commercial and recreational mud crabbing activity and have typical areas of the two identified habitat types.

4.1.2 Queensland

The two sites selected to conduct the 2002/03 mud crab surveys in North Qld were Trinity Inlet, Cairns, Qld East coast, and the Norman River, Karumba, Qld GOC coast (Figure 28 and Table 11). Initial pilot surveys in Princess Charlotte Bay and Weipa in 2001 proved these sites to be unsuitable locations, due to a number of unexpected problems.

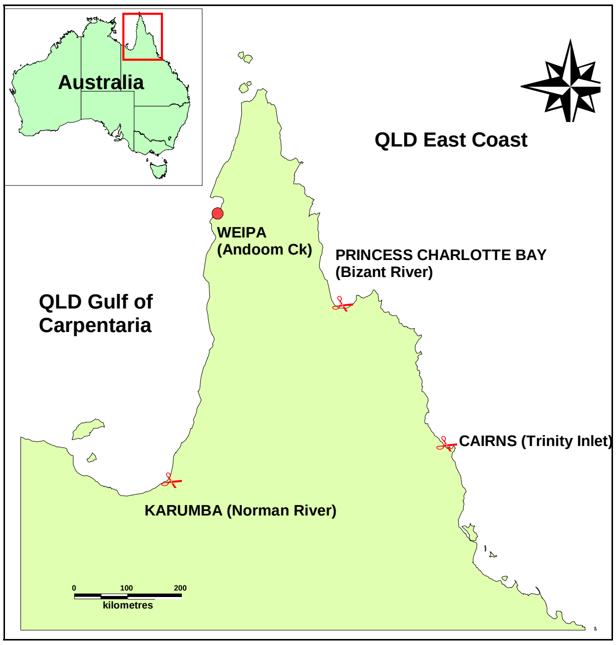

Figure 28. Map of North Qld showing study sites for mud crab surveys (see also Table 12)

Table 11. Comparative characteristics of the Qld Gulf and East Coast study sites (Source: modified from National Land and Water Resources Audit. Estuaries Assessment 2000. http://www.ozestuaries.org /oracle/ ozestuaries/ and CSIRO Simple Estuarine Response model II. http://www.per.marine.csiro.au/serm2)

Character	Qld Gulf of Carpentaria		Qld East Coast	
	Andoom River	Norman River	Bizant River	Trinity River
Longitude	141.88	140.82	144.031	145.785
Latitude	-12.587	-17.463	-14.48	-16.905
Condition	largely unmodified	largely unmodified	Near pristine	modified
Classification	tide dominated	river dominated	tide dominated	Tide dominated
Sub-classification	tidal flat/creek	tide-dom delta	tidal flat/creek	tidal flat/creek
Water area (km^2)	1.89	53.26	3.98	13.46
Entrance width (km)	0.77	1.77	0.48	1.65
Perimeter (km)	26.42	213.89	57.37	80.07
Maximum length (km)	8.34	102.36	19.88	15.01
Catchment area (km^2)	1.72	49588	284	330
Tidal range (m)	2.1	3.3	2.1	2.0
River Flow GL/yr	86.243	2427.828	86.132	470.28
Tidal period	diurnal	diurnal	semi-diurnal	diurnal
Imcra class	West Cape York	Karumba-Nassau	East Cape York	Wet Tropic

The Andoom River foreshore, situated adjacent to Weipa, was selected for the first pilot survey of the trapping web experiment on the Qld Gulf Coast. There had been two successful stream depletion surveys in the Andoom River in the two years prior to this project and the local community was to repeat the depletion exercise at the same time as the proposed foreshore trapping-web trial. The results from the trial, however, showed extremely variable number of crabs captured, with a marked reduction after the first two days. The reason for the sudden drop in the numbers of crabs caught during the survey is unknown, but, it is thought that water temperature and tidal variation may have been contributing factors. Due to this variability in catch the site was assessed as unsuitable.

Karumba was selected as a suitable alternative location for the West Coast site based on strong recommendations from commercial fishers and other fellow fisheries officers familiar with the area. Previous research surveys at this site had also shown consistent catches of crabs.

On the East Coast, the high numbers of crabs caught during pilot surveys in the Bizant River indicated the suitability of the area for future surveys, despite the remote nature of the site. The amount of travelling time required to reach the Bizant River site was considerably less than that to the Andoom River site in Weipa. There was, however, a complication with the pilot trapping web survey. On the fifth and final day of checking the pots, 10 of the 30 crab pots in the trapping web were broken or torn apart by what we suspect were large predators, perhaps turtles or crocodiles, preying on both the bait and the captured mud crabs. Pots were bent out of shape and the entrances and bait bags in most cases were torn open with no bait or crabs remaining.

As this unexpected interference had only been seen on the last day and the damage to the pots was repairable, the site was not ruled out for future surveys. The second survey, however, in May 2002, had to be aborted after 50% of the crab pots at the foreshore site were destroyed on the first night of the survey. The type of damage to the crab pots was identical to that seen previously in 2001. Indigenous rangers in the area suggested that there was a colony of turtles that aggregated in the general area around the sites chosen, and we had observed one turtle while setting the trapping web. Commercial crabbers we interviewed had not had a problem with scavenging. Possibly the high concentration of bait and captive crabs, caused by the high density of pots in the trapping web, was partially the cause of the scavenging we observed. Trinity Inlet in Cairns was selected as a replacement East coast site for the remainder of the 2002 and 2003 surveys. Table 12 outlines the dates, locations and the type of experiment carried out during each of the surveys.

4.2 Data Collection

4.2.1 Northern Territory Data Collection

In the NT the mud crab fishery is strongly seasonal with the majority (73%) of commercial NT catch recorded between May and October each year. Taking this seasonality into account sampling needs to be completed within this period over the dry season.

Three field trips per year over the 2002/03 dry season were conducted at the Adelaide and Wearyan study sites (Table 12). Each fieldtrip consisted of:

An eight-day depletion/ mark recapture experiment using 100 crab pots.
A five day trapping web study using 64 pots in an 8 line x 8 pot array.

The two surveys were run simultaneously.

Commercial crab pots (see Figure 21) are highly selective for legal size mud crabs due to the large mesh size (75 x 25mm) used in their construction (Knuckey 1999). Research pots were constructed using a smaller mesh size (25 x 25 mm) to ensure capture of smaller size classes (Figure 29). The two gear types were utilised at each study site. Due to tidal differences and transport weight restrictions different ratios of commercial to research pots were used at each site. At the Adelaide River site 25% of all gear used were commercial pots and at the remote Wearyan site 25% of gear consisted of research pots.

Figure 29. Typical research crab pot utilised at both study sites

In 2002 all planned work was completed successfully. Unseasonal winds made access to the Wearyan River foreshore flats and the trapping web impossible in June 2002 and the experiment had to be rescheduled and was successfully completed in August 2002.

In 2003 a considerable drop in crab abundance at both study sites was evident, corresponding to a decline in reported commercial catch from both regions (Figure 30). Trapping webs at the Adelaide River foreshore site were abandoned after May 2003 as capture and recapture rates declined to levels that made density estimation and the resources required to run each study unjustifiable. Extremely low crab numbers also resulted in the final NT GOC depletion study to be abandoned after day 3 when only three crabs had been removed from the 2 km study site.

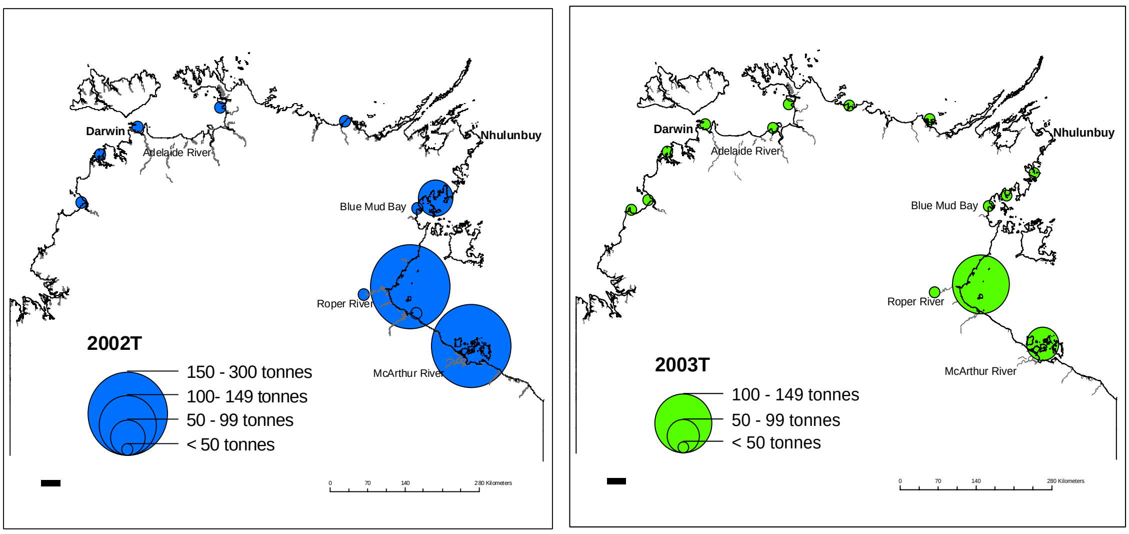

Figure 30. NT mud crab catch by region for 2002 and 2003

Table 12. Summary of NT 2002 and 2003 data collection

Adelaide River				**Wearyan flats/Twin Sisters Creek**			
Date	No pots	Experiment	Completed	Date	No Pots	Experiment	Completed
3-10/5/02	100	Depletion	✔	20-27/05/02	100	Depletion	✔
5-9/5/02	64	Web	✔	22-26/05/02	64	Web	✔
1-8/07/02	100	Depletion	✔	16-23/06/02	100	Depletion	✔
2-6/07/02	64	Web	✔	17/06/02	64	Web	✗
30/7-6/08/02	100	Depletion	✔	25/8-1/09/02	100	Depletion	✔
31/7-4/08/02	64	Web	✔	25-29/08/02	64	Web	✔
				25-29/08/02	64	Web	✔
8/5-13/5/03	100	Depletion	✔	24-29/5/03	100	Depletion	✔
8-12/05/03	64	Web	✔	26-30/5/03	64	Web	✔
19-24/7/03	100	Depletion	✔	21-26/6/03	100	Depletion	✔
20-24/7/03	na	Web	✗	22-26/6/03	64	Web	✔
18-23/9/03	100	Depletion	✔	3-5/8/03	100	Depletion	✗
19-23/9/03	na	Web	✗	3-7/8/03	64	Web	✔

4.2.2 Queensland Data Collection

In following the project design each State was required to conduct three studies per year at each of two sites during 2002-2003. Where possible a Qld mud crab research survey consisted of a 5 day foreshore “trapping-web” and a six day stream “depletion” trapping survey, carried out simultaneously (see Table 13). Following the initial pilot survey work in 2001, seven mud crab surveys were conducted during 2002: one in Princess Charlotte Bay, three at Karumba and three off Cairns.

During 2003 six research surveys were conducted: three off Karumba and three off Cairns. The same general methodology was followed throughout all research surveys to provide six replicate samples in Cairns (Trinity Inlet) and Karumba (Norman River) over the two-year period.

Table 13. Dates and types of experiments carried out at each site over the project's duration

Trip Dates	**Location**	**Sites**	**Survey**
31/05 – 04/06/01	Weipa	Andoom R Foreshore	Trapping Web
26 – 30/10/01	Princess Charlotte Bay	Bizant R Foreshore/ Estuary	Trapping Web
11 – 17/05/02	Karumba	Norman R Foreshore/ 6 Mile Ck	Trapping Web + Depletion
07 – 11/06/02	Princess Charlotte Bay	Bizant R Foreshore/ Estuary	Trapping Web + Depletion
04 – 08/07/02	Karumba	Norman R Foreshore/ 6 Mile Ck	Trapping Web + Depletion
28/07 – 05/08/02	Trinity Inlet	Rolling Bay/Crowley’s Ck	Trapping Web + Depletion
02 – 07/10/02	Trinity Inlet	Rolling Bay/Crowley’s Ck	Trapping Web + Depletion
09 – 15/10/02	Trinity Inlet	Esplanade Foreshore/ Redbank Ck	Trapping Web + Depletion
17 – 23/10/02	Karumba	Norman River Foreshore/ 6 Mile Ck	Trapping Web + Depletion
04 – 11/02/03	Karumba	Norman River Foreshore/ 6 Mile Ck	Trapping Web + Depletion
19 – 24/02/03	Trinity Inlet	Esplanade Foreshore/ Wah Day Ck	Trapping Web + Depletion
03 – 08/03/03	Trinity Inlet	Esplanade Foreshore/ Redbank Ck	Trapping Web + Depletion
19 – 26/03/03	Karumba	Norman River Foreshore/ 6 Mile Ck	Trapping Web + Depletion
01 – 06/04/03	Trinity Inlet	Esplanade Foreshore/ Wah Day Ck	Trapping Web + Depletion
25/05 - 01/06/03	Karumba	Norman River Foreshore/ 6 Mile Ck	Trapping Web + Depletion

4.3 Survey Methods

NT and Qld studies followed similar designs. However survey duration and experimental fishing effort differed between states.

4.3.1 Northern Territory Survey Methods

4.3.1.1 Northern Territory Depletion/Mark Recapture Survey Methods

One hundred baited crab pots were spaced at 20-m intervals, commencing at the creek mouth and alternating along each bank. Pots were individually identified using a numbered cattle ear-tag attached near the float and each pot site was marked using fluorescent flagging tape attached to the most adjacent mangrove tree along the creek bank. For eight days each pot was checked and rebaited every 24 hours with approximately 500 g fresh red meat (*Macropus* sp.) and re-set in the same location. The creek effectively was divided into three zones resulting in a one-kilometre depletion zone enclosed between two 500-m mark-recapture (buffer) zones (Figure 31). The Adelaide River depletion study site had an average width of around 30 m while the GOC depletion river site was around 70 m wide.

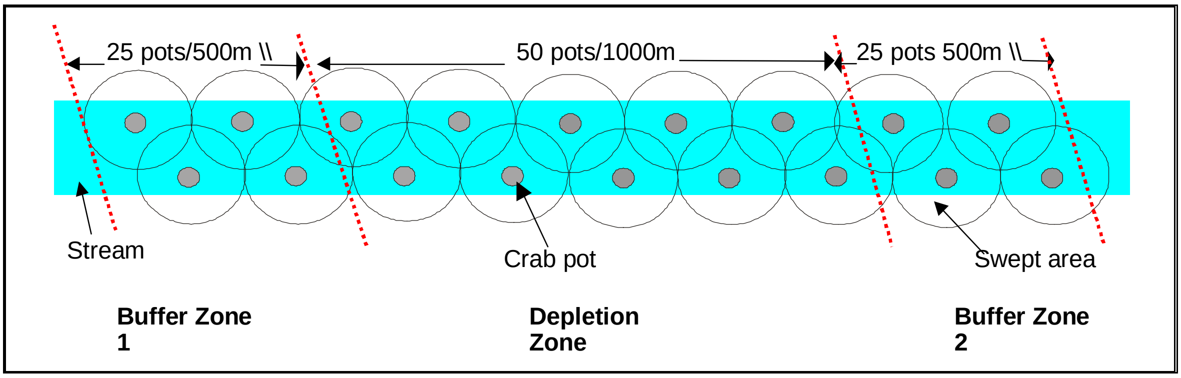

Figure 31. Stylised diagram of depletion experiment including buffer (mark recapture) zones

Pots were systematically checked every 24 hours on the daylight high tide and rebaited. Crabs caught within each buffer zone were sexed, assessed for moult stage, carapace measured, and tagged (Hill 1975; Robertson and Piper 1991) using individually numbered T-Bar tags (Hallprint Australia) before being returned to the water at the point of capture. Crabs caught within the depletion zone were measured, sexed, assessed for moult stage and removed from the study site for the duration of the experiment and returned live to the site on completion of the experiment.

4.3.1.2 Northern Territory Trapping Web Survey Methods

Sixty- four baited crab pots were set in a trapping web design. The trapping web consisted of eight arms of eight crab pots all radiating from a star picket that marked the central point of the web. Once set, the web consisted of eight concentric rings of crab pots (see Figure 25). Pot spacing is uniform for rings 2-8 (set at 20 m) with the inner ring 1 spaced at ½ of this distance to ensure maximum pot saturation at the centre web area. Each web sampled an area of 70650 m^2 or 0.07 km^2. Star pickets marked the end of each arm.

For five consecutive days, pots were systematically checked on the daylight high tide and rebaited. Crabs caught were sexed, assessed for moult stage, carapace was measured, and were tagged (Hill 1975; Robertson and Piper 1991) using individually numbered T-Bar tags (Hallprint Australia) before being returned to the water at the point of capture.

4.3.2 Queensland Survey Methods

Description of Qld survey methods are provided where they differed from those applied in the NT. The design of both the trapping web and the depletion experiments has undergone a number of minor changes. The general design of the web remained constant throughout 2002 and 2003; however, the number of pots and arms had been modified since the initial pilot surveys in 2001. The depletion experiments have consisted of 60 pots throughout the project but the spacing between pots has been modified slightly. Table 14 describes the gear and its deployment used for each of the surveys.

4.3.2.1 Queensland Depletion Mark Recapture Survey Methods

Sixty baited collapsible "Munyana" commercial crab pots (Figure 32) were spaced at 25 m intervals commencing at the creek mouth and alternating along each bank.

Figure 32. Collapsible "Munyana" crab pot utilised during Queensland studies

The total length of the depletion survey site was 1.5 km with each of the three zones broken down into 500 m lengths (Figure 33). Pot numbers correspond with each of the three zones to ensure all crabs caught within the middle 20 pots are removed and those caught within the buffer zones are tagged and immediately released back in their respective locations.

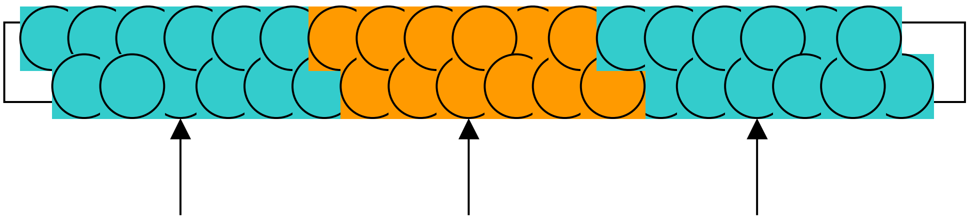

Figure 33. Qld depletion survey design over 1.5 km of stream with each of the three zones broken down into 500 m lengths

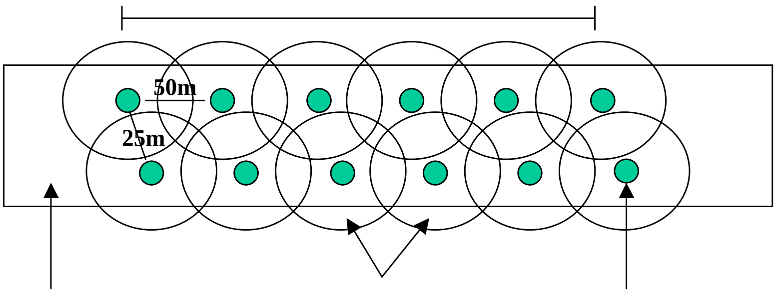

Figure 34. Detail of a 500 m section of depletion survey crab pot placement

The depletion surveys were conducted in river systems which have an average width of no greater than 20 m. The numbered crab pots are staggered evenly up either side of the channel with 50 m spacing between pots on the respective sides (Figure 34).

4.3.2.2 Queensland Trapping Web Surveys

The trapping web surveys, which were carried out on the foreshore sites, used the trapping web as shown in Figure 35. The "web" array consisted of a total of 40 crab pots set in eight separate lines, all spanning out from a central point (Figure 36). Each pot was attached to 8 mm UV treated synthetic rope at 20 m intervals marked with numbered 6-inch floats. The trapping web diameter was 180 m overall, and covered an area of approximately 25446 m^2 or 0.03 km^2.

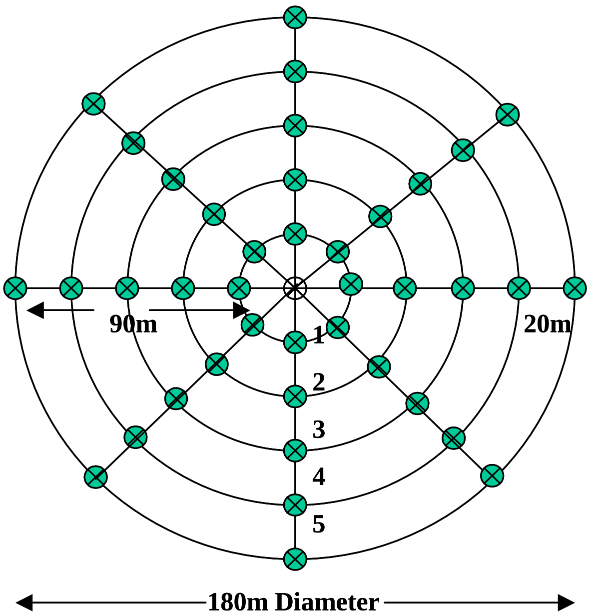

Figure 35. Qld trapping web crab design

Figure 36. The trapping web layout showing the centre buoy and the eight arms attached

Table 14. Variations to the standard gear layout for Qld research mud crab surveys

Trip	Site	Date	Trapping web					Depletion			
			No of Arms	Arm Length (m)	Pots per arm	Spacing (m)	Total Pots	Pots per Buffer zone	Pots in Depletion	Spacing (m)	Total Pots
A*	Andoom River (Weipa)	May/June 2001	6	100	5	20	30				
B*	Bizant River (Princess Charlotte Bay)	October 2001	6	200	5	40	30				
Karumba 1	Norman River (6 Mile Ck/The Oaks)	May 2002	8	100	5	20	40	20	20	50	60
C*	Bizant River (Princess Charlotte Bay)	June 2002	8	100	5	20	40	20	20	50	60
Karumba 2	Norman River (6 Mile Ck/The Oaks)	July/August 2002	8	100	5	20	40	20	20	50	60
Trinity Inlet 1	Cairns (Rolling Bay/Crowley's Ck)	July 2002	8	100	5	20	40	20	20	25	60
Trinity Inlet 2	Cairns (Rolling Bay/Crowley's Ck)	Oct 2002	8	100	5	20	40	20	20	25	60
Trinity Inlet 3	Cairns (Esplanade Foreshore/ Redbank Ck)	Oct 2002	8	100	5	20	40	20	20	25	60
Karumba 3	Norman River (6 Mile Ck/The Oaks)	Oct 2002	8	100	5	20	40	20	20	25	60
Karumba 4	Norman River (6 Mile Ck/The Oaks)	Feb 2003	8	100	5	20	40	20	20	25	60
Trinity Inlet 4	Cairns (Esplanade Foreshore/ Wah Day Ck)	Feb 2003	8	100	5	20	40	20	20	25	60
Trinity Inlet 5	Cairns (Esplanade Foreshore/ Redbank Ck)	March 2003	8	100	5	20	40	20	20	25	60
Karumba 5	Norman River (6 Mile Ck/The Oaks)	March 2003	8	100	5	20	40	20	20	25	60
Trinity Inlet 6	Cairns (Esplanade Foreshore/ Wah Day Ck)	April 2003	8	100	5	20	40	20	20	25	60
Karumba 6	Norman River (6 Mile Ck/The Oaks)	May 2003	8	100	5	20	40	20	20	25	60

* Extra trips to establish the suitability of sites or to test gear configurations

4.4 Data Analysis

Three methods of analyses were used. Mark-recapture and depletion datasets were analysed using program MARK software (Version 3.2) and trapping web datasets were analysed using both DISTANCE sampling software (Version 3.5) and DENSITY software (Version 2.1).

4.4.1 Depletion/Mark Recapture Analysis

All data collected from the NT and Qld mark recapture/depletion studies was analysed using MARK software. Program MARK is a dynamic FORTRAN based windows program that computes the estimates of model parameters via numerical maximum likelihood techniques. Sets of common models are provided, with time effects, group effects, time*group effects, and a null model, including all possible combinations across all parameters. Program MARK is capable of delivering parameter estimates for 47 data types, and both survival estimates for open populations and abundance estimates for closed populations:

For closed populations, MARK estimates the probability of first capture p(*i*) and the probability of recapture c(*i*), along with the number of animals in the population (N). MARK also allows comparisons between groups and the incorporation of time-specific and/or group-specific covariates into the model. At present a total of six different closed capture models are available in MARK.

Data collected in this study was analysed using the Huggins closed capture model (Huggins 1989, 1991). This model permits the estimation of population size when capture probabilities are heterogeneous, by modelling the capture probability in terms of observable covariates, in this case size. The approach used in the Huggins' model is equivalent to the Horvitz-Thompson sampling design, where animals have unequal probability of being included in the sample. To enable detection of differences in size related behavioural patterns, all data was formatted into two groups, small immature animals (<120 mm CW) and large animals (≥ 120 mm CW); those that were mature or would reach maturity within the next moult. Each individual carapace width was also applied as a covariate using the Huggins closed capture model.

Density estimates for small (< 120 mm carapace width) and large (> 120 mm carapace width) crabs in each buffer and depletion zone are presented for NT and Qld for each year (Tables 17, 18 and 34, 35 respectively). Densities were standardised as number of crabs per kilometre of stream and converted to number of crabs per square kilometre. Average density estimates for all crabs and for large crabs, for each year were calculated as the sum of estimates for the buffer zones plus depletion zone for each survey in each year at each site.

4.4.2 Trapping Web Analysis

Two methods are currently available for analysing trapping web data. DISTANCE software and DENSITY software are freeware developed for distribution from the internet.

4.4.2.1 DISTANCE Version 3.5

Analysis of trapping web data using DISTANCE software was described in Section 3.2.2.2.

For both the NT and Qld datasets distance analyses were run using half-normal and cosine detection functions. The probability of detection was determined as the ratio of recapture to new capture of crabs in the innermost ring on each day of the survey, fitted using a linear optimiser routine (XL SOLVER). To account for the effects of immigration from outside the study site (the edge effect) the NT trapping web data was truncated, with data from captures recorded from the outer two rings removed from the analyses. The sampling design adopted by Qld allowed only the data from the outside ring to be removed.

Due to the small sample sizes observed for a number of the 2003 NT trapping web studies, numbers of crabs caught in the inner two rings were pooled and the initial interval distance from the centre of the web was subsequently adjusted from 10 m to 30 m for these analyses.

The density estimates for the foreshore trapping web using DISTANCE are presented for NT and Qld for each year (Tables 22, 23 and 38).

4.4.2.2 DENSITY Version 2.1

Efford (2004) introduces a new and general method for estimating animal density from trapping web data. This approach was developed in response to the common problem of edge effect (also the costly requirement for truncation of data) and the estimation of animal density is not dependent on the trap layout.

At the core of this method is a theoretical model of the trapping process. The estimated population density (*D*) is calculated using both inverse prediction and Monte Carlo simulation. The parameter *D* describes the intensity of animal range centres as a spatial point process. Similar to Distance analyses, a detection function g (d) describes the probability of capture as a decreasing function of distance between the trap and home range centre. To enable these calculations two additional parameters of an individual's capture probability (*g)* are required: the magnitude (g_0), the probability of capture when the trap and range centre coincide and the spatial scale (σ), representing the decline in capture probability with distance. The method also utilises information gained from conventional closed population estimates, population size (*N*), mean capture probability *(p)* and also importantly incorporates the spatial information of the mean distance between successive recaptures *(d)*.

DENSITY analysis is capable of analysing data from any configuration of traps (e.g. grid, web or line) and provides the option to choose from the standard closed-population estimators. The author reports the estimator appears unusually robust and free from bias.

Efford (2003) describes simulation and inverse prediction as "a numerical method for estimating density and two parameters of a spatial detection function from trapping data. Multiple simulations of trap sampling are conducted at vertices of a 'box' that is expected to include the true value in 3-D parameter space. At each iteration a linear model is fitted and inverted to estimate the desired parameters from the input data. The location of the box is adjusted and further simulations conducted until the estimated point lies inside the box. The first simulation box is centred on initial values either provided by the user or calculated with an automatic algorithm The size of the box (default 10%) and number of replicate simulations (default 100) may also be varied."

The assumptions for estimating density by inverse prediction are:

1. The population is closed (i.e. there are no births, deaths or dispersal events during a trapping session).
2. Capture does not affect the pattern of movement of an animal within a trapping session.
3. Tags are not lost, and the identity and location of each recaptured animal is recorded accurately.
4. Traps are set at known locations for a fixed time.
5. Trap placement is random with respect to the location of animal ranges.
6. Animals occupy home ranges that do not change during a trapping session.
7. Home ranges are roughly circular.
8. Home range centres are scattered throughout the area sampled, or home range centres are scattered within a mapped subset of the landscape.
9. The chosen closed population estimator is robust to other variation in capture probability (e.g. temporal variation).

DENSITY analyses use closed population capture-recapture data from trapping web surveys. A graphic interface permits visualisation of spatial movement of individual tagged animals within the study site by individual animal and day of capture. This analysis utilises both capture and recapture data. The software was unable to fit models to the data from trip 25 Wearyan August 2002, due to extremely low recapture rates of 123 captures of 119 animals.

DENSITY technical settings used for analyses included even distribution, Jack-knife estimator for N-hat, a search box of 10% or 20%, 100 simulations per vertex, auto initial values, a convex polygon, population buffer of 130 m for the NT datasets and 100 m for the Qld datasets, density units are reported in km^2, and the random number generator was intrinsic.

DENSITY analyses legend (see tables 22, 23 and 38)

N-hat	Population estimate (hat = estimated)
SeN	Estimated SE (N-hat)
p-hat	Daily capture probability implied by N-hat, given the data
d-bar	Mean distance between successive captures (m) pooled over individuals
sed	SE(d-bar)
Density	Density by inverse prediction (see above for units)
SeD	SE(Density) (prediction SE)
g0	Core trapability estimated by inverse prediction
Sigma	Spatial scale of detection (m) by inverse prediction

For the NT and Qld datasets both half-normal and uniform distributions were run with a logit link function. The density estimates for the foreshore trapping web survey using DENSITY are presented for the NT and Qld for each year (Tables 21, 22 and 37).

4.5 Mud Crab Habitat Analysis

Estimates of the area of mangrove, river, and foreshore for each river system were used in conjunction with the survey crab density results to give estimates of legal-size crab numbers for the NT and Qld Gulf and north-east coasts.

The NT and Qld record mud crab fishery catch and effort statistics at different resolutions: NT commercial catch and effort statistics are recorded by 60 nautical mile grid while Qld QFISH data is reported by 6nm grid. The mapping of mud crab habitat completed and described in Section 2 needed to be modified so that comparisons with each States, commercial catch distribution and trend could be undertaken.

4.5.1 Northern Territory Habitat

The NT component of the habitat mapping data described in Section 2 has been re-calculated by each NT 60 nm fishing grid (Table 20). Using ARCGIS (ESRI © 1999-2002) habitat datasets were projected then merged with the NT fishing grid and values for all habitat types were recalculated using standard area scripts. Additional spatial datasets not included in the QDIP&F mapping product were acquired from the TOPO-250K Series 2 GEODATA from Geoscience Australia (formerly AUSLIG). These hydrography datasets including major rivers and drainage for the NT were projected, merged and then intersected with the NT fishing grid datasets and overlayed with the NT wetlands datasets. The area of tidal rivers and streams was recalculated using standard ARCGIS area and length scripts.

4.5.2 Queensland Habitat

For each major catchment (see Tables 42 and 43) the area of mangrove lined stream and estuary (or “waterways”), and the area of adjacent foreshore mud/flats, was calculated from habitat mapping results (see Section 2). The six nautical mile grid resolution matched that of the QFISH commercial catch and effort logbooks.

The area of foreshore was multiplied by the crab density estimated by “trapping web” for that habitat type and likewise the area of mangrove lined stream/estuary was multiplied by the relevant crab density estimated by the stream depletion surveys. Areas were restricted to the nearest reliable fishing grid that encompassed the river and its catchment (see Table 15 and Figure 37).

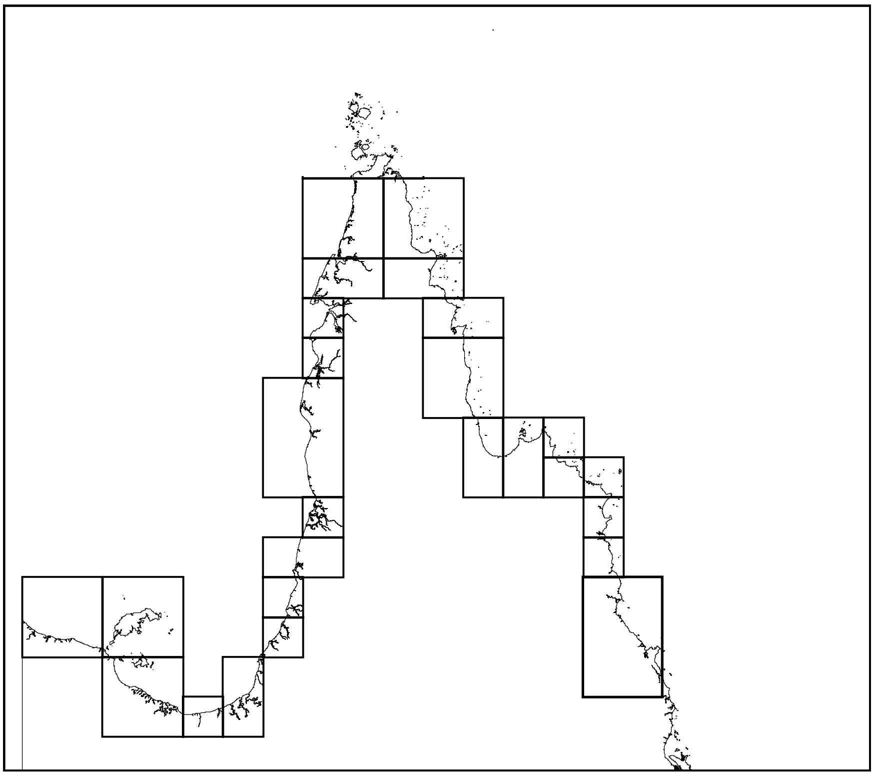

Figure 37. Major catchment areas (grids) used for the Qld habit/catch analysis

Table 15. Latitude and longitude of each major catchment area assessed for crab habitat and potential crab density (refer to Figure 37). Catchment areas are sequential from left to right along the coast from the Western Gulf to Trinity Inlet on the East Coast)

Crab grid name	Latitude (°S)	Longitude (°E)
West Qld Gulf	16.0 to 17.0	138.0 to 139.0
Mornington	16.0 to 17.0	139.0 to 140.0
Burketown	17.0 to 18.0	139.0 to 140.0
Southern Gulf	17.5 to 18.0	140.0 to 140.5
Norman	17.0 to 18.0	140.5 to 141.0
Gilbert	16.5 to 17.0	141.0 to 141.5
Staaten	16.0 to 16.5	141.0 to 141.5
Nassau	15.5 to 16.0	141.0 to 142.0
Mitchell	15.0 to 15.5	141.5 to 142.0
Central Gulf	13.5 to 15.0	141.0 to 142.0
Archer	13.0 to 13.5	141.5 to 142.0
Weipa	12.5 to 13.0	141.5 to 142.0
Pt Musgrave	12.0 to 12.5	141.5 to 142.5
Gulf tip	11.0 to 12.0	141.5 to 142.5
Shelburne Bay	11.0 to 12.0	142.5 to 143.5
Temple Bay	12.0 to 12.5	142.5 to 143.5
Lloyd Bay	12.5 to 13.0	143.0 to 144.0
Cape Sidmouth	13.0 to 14.0	143.0 to 144.0
PCB West	14.0 to 15.0	143.5 to 144.0
PCB East	14.0 to 15.0	144.0 to 144.5
Ninian Bay	14.0 to 14.5	144.5 to 145.0
Jennie R	14.5 to 15.0	144.5 to 145.0
Starke R	14.5 to 15.0	145.0 to 145.5
Cape Bedford	15.0 to 15.5	145.0 to 145.5
Bloomfield	15.5 to 16.0	145.0 to 145.5
Trinity Inlet	16.0 to 17.5	145.0 to 146.0

PCB – Princess Charlotte Bay

5. Results

5.1 Northern Territory

A total of 4251 crabs were captured during the 2002 and 2003 sampling periods and a total of 1196 recaptures were recorded during sampling.

The length frequency distribution plotted by sex for all crabs caught during the study at each of the two NT study sites is provided in Figures 38 and 39. The annual proportion of small and large crabs sampled at each site by gear type is presented in Table 16.

Little difference was observed in the proportion of small and large crabs caught between year and gear type from the Adelaide River study. The GOC data (where 75% of all pots were of commercial large mesh design) demonstrates the strong selectivity of commercial crab pots for large crabs and this changes little over the year. The only contrast in this data can be found for the GOC research pot data where in 2002 35% of the catch was made up of small crabs. In 2003 74% of the total research pot catch was made up of small crabs. This may be a function of reduced recruitment in 2002 and this may help explain the severe drop in GOC commercial catch in 2003.

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Table 16. Proportion of small (<120 mm cw) and large (≥ 120 mm cw) crabs caught by gear type at the two NT study sites 2002 and 2003

Gear Type	Crab carapace width (mm)	Adelaide		Gulf of Carpentaria	
		2002	2003	2002	2003
Commercial pot	% small crabs <120	17.65	14.88	7.65	9.66
	% large crabs ≥120	82.35	85.12	92.35	90.34
Research pot	% small crabs <120	59.09	54.10	35.54	74.44
	% large crabs ≥120	40.91	45.90	64.46	25.56

The two gear types described earlier were deployed in different proportions between study sites. During previous studies at the Adelaide River site, the large mesh and light-weight commercial crab pots were commonly lost, moved or the float submerged due to the large tidal range. To minimise the loss of gear and data, all Adelaide River studies used a 3:1 ratio of research (heavy-small mesh pots) to commercial pots. At the GOC study site, subject to a micro tidal range, a reverse ratio was applied. Of the total pots 75% were of the commercial design and 25% of the alternate research gear type so that comparison of results could be achieved. Subsequently, differences in selectivity were evident with research pots far more selective towards small crabs.

The Adelaide River study site demonstrated similar patterns between years for each gear type in respect to the proportion of small and large crabs available for capture (Table 16). The GOC site also showed similar patterns for commercial pots. The research crab pots' catch of small crabs in 2002 (35%) is less than half of that captured in 2003 (74%) indicating the possibility of reduced recruitment in the Gulf in 2002 and this may explain the reduction in catch (25%) of large crabs in 2003.

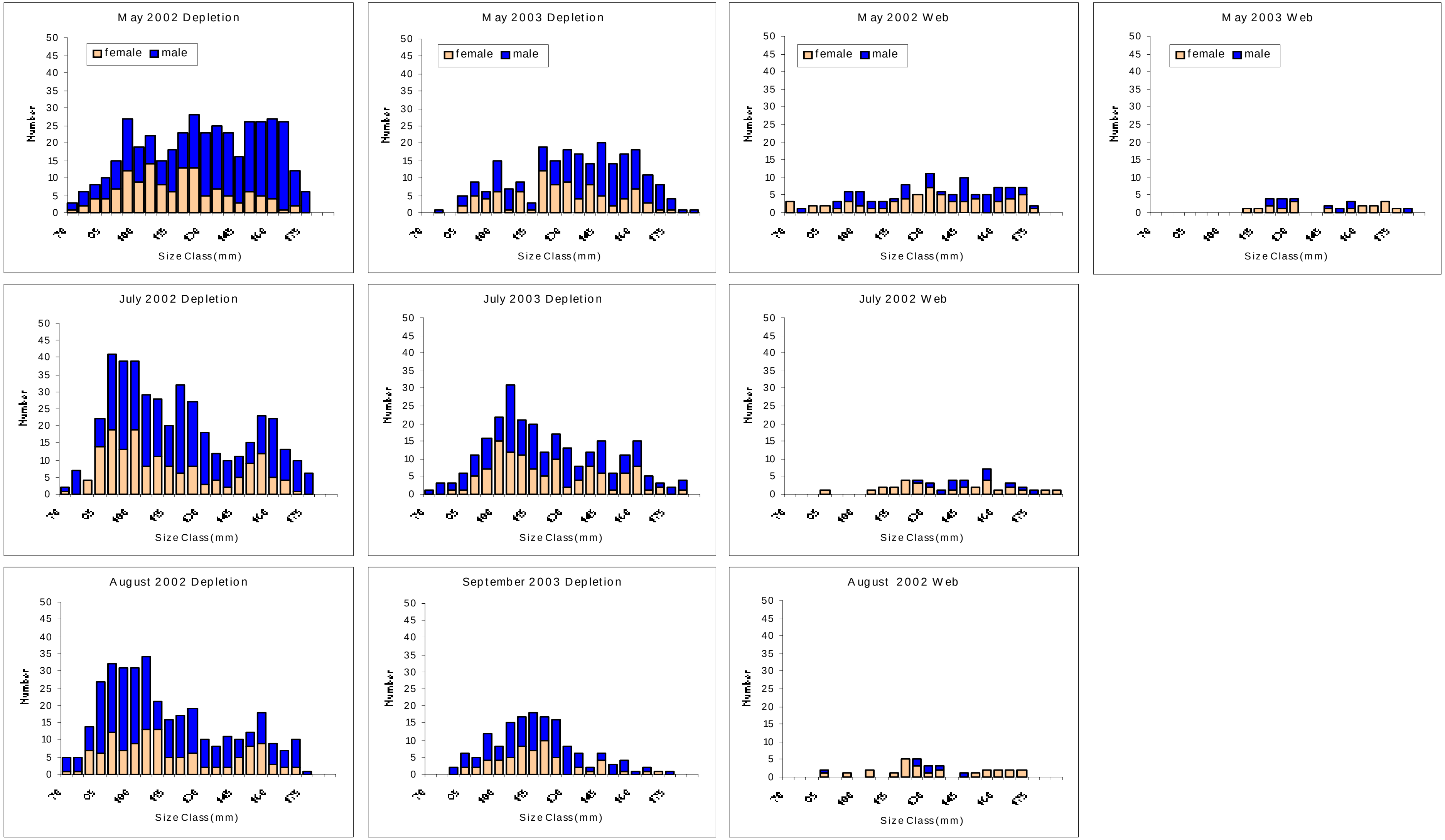

Figure 38. Length-frequency distribution of male and female mud crabs from Adelaide River depletion and web studies 2002-2003

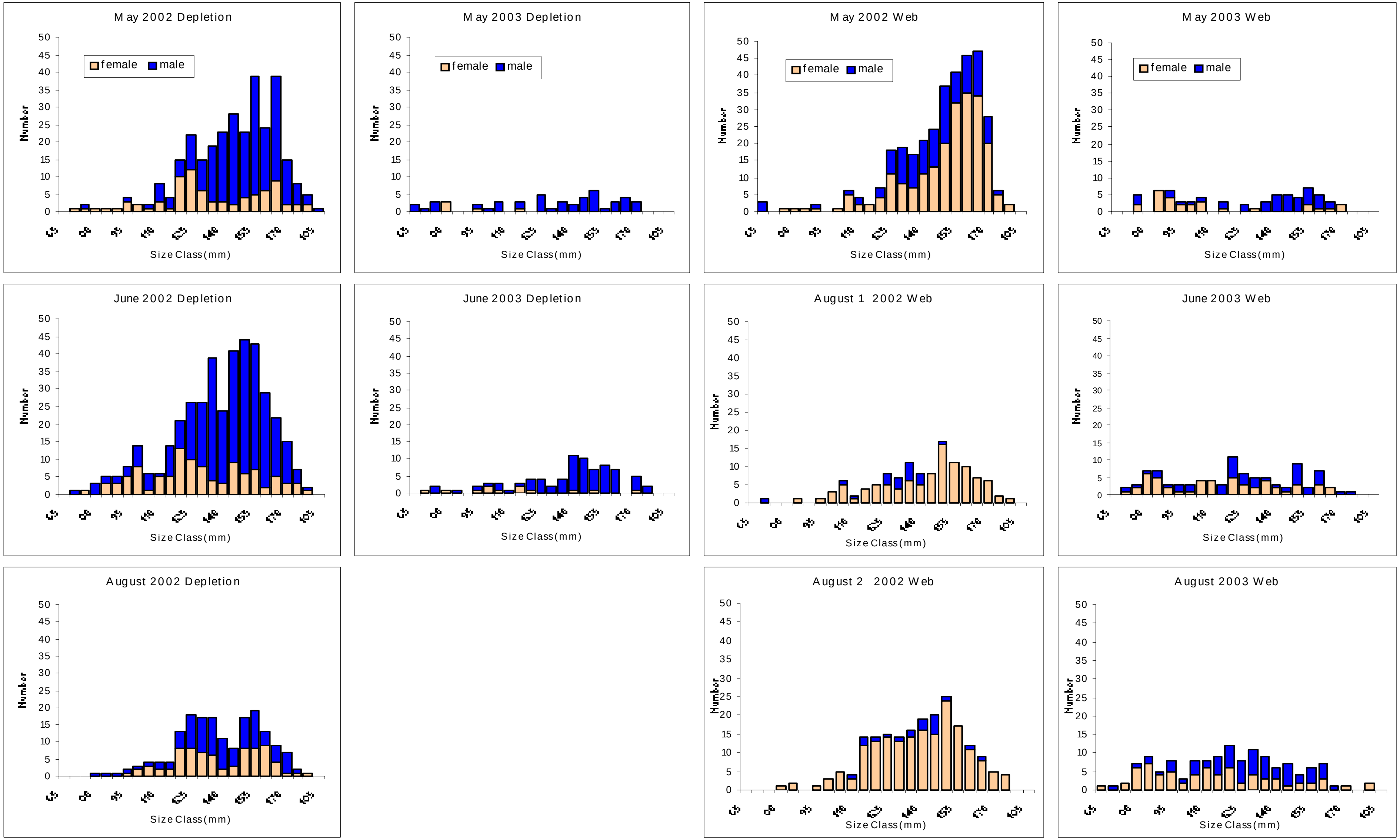

Figure 39. Length-frequency distribution of male and female mud crabs from Gulf of Carpentaria depletion and web studies 2002-2003

Table 17. Adelaide River population estimates of crabs <120 mm and ≥ 120 mm, standard error and lower and upper confidence limits for buffer 1 (B1), depletion (D) and buffer 2 (B2)

Year	Site	Date	Zone	No. marked		MARK	Estimated # crabs <120 mm				Density	Estimated # crabs ≥ 120 mm				Density
				<120 mm	≥ 120 mm	model	N hat	s.e	LCL	UCL	km^2	N hat	s.e	LCL	UCL	km^2
2002																
	Adelaide 1	5-12/05/02	B1	27	81	p(.)c(g*t)	40.91	8.61	31.55	69.49	2727.3	122.72	23.26	96.05	196.68	8181.3
			D	91	79	p(size) c=0	126.78	17.157	105.67	178.28	4226.0	80.45	1.377	79.30	85.98	2681.7
			B2	49	84	p(.)c(g)	60.51	5.95	53.44	78.88	4034.0	103.74	9.31	92.20	131.51	6916.0
	Adelaide 2	1-8/07/02	B1	30	72	p(.) c(g)	39.35	5.67	33.12	58.00	2623.3	94.44	12	80.39	131.97	6296.0
			D	143	63	p(size) c=0	250.97	48.86	189.33	394.60	8365.7	67.75	3.01	64.51	77.88	2258.3
			B2	83	42	p(.) c(g)	117.22	17.14	96.53	169.52	7814.7	59.32	9.3	48.43	88.65	3954.7
	Adelaide 3	30/7/02--7/08/02	B1	36	58	p(.) c(g)	54.68	11.79	42.00	94.10	3645.3	88.09	18.24	68.05	148.08	5872.7
			D	115	41	p(size) c=0	164.03	29.94	131.31	262.81	5467.7	41.65	1.06	41.07	47.10	1388.3
			B2	81	19	p(.) c(g)	100.93	10.5	88.55	133.59	6728.7	23.67	3.25	20.37	34.98	1578.0
2003																
	Adelaide 4	8-13/05/03	B1	8	36	p(.) c(g)	8.60	0.9	8.07	13.03	573.3	38.71	2.5	36.58	48.58	2580.7
			D	41	81	p(size) c=0	50.77	6.18	44.13	71.48	1692.3	88.62	4.37	83.68	102.65	2954.0
			B2	21	46	p(.) c(g)	24.52	2.8	21.89	34.88	1634.7	53.70	5.19	48.32	71.53	3580.0
	Adelaide 5	19-24/07/03	B1	29	30	p(.) c(.)	32.95	2.48	29.70	41.35	2196.7	33.05	2.54	30.73	42.65	2203.1
			D	74	46	p(small*t + size, large(.) c=0	77.05	3.66	74.48	93.44	2568.3	47.10	1.07	46.10	51.87	1570.1
			B2	40	37	p(.)c(g)	50.88	6.96	43.46	74.29	3392.0	47.07	6.51	40.16	69.07	3138.0
	Adelaide 6	18-23/09/03	B1	30	15	p(.) c(.)	32.36	2.23	30.49	41.32	2157.3	16.18	1.4	15.19	22.23	1078.7
			D	48	24	p(size) c=0	54.21	4.4	49.78	69.71	1807.0	25.15	1.34	24.19	31.09	838.3
			B2	20	14	p(g) c(.)	29.17	11.47	21.37	81.42	1944.7	14.06	0.26	14.00	15.77	937.3

Table 18. Wearyan River population estimates of crabs <120 mm and ≥ 120 mm, standard error and lower and upper confidence limits for buffer 1 (B1), depletion (D) and buffer 2 (B2)

Year	Site	Date	Zone	No. marked		MARK	Estimated # crabs <120 mm				Density	Estimated # crabs ≥ 120 mm				Density
				<120 mm	≥ 120 mm	model	N hat	s.e	LCL	UCL	km^2	N hat	s.e	LCL	UCL	km^2
2002	Wearyan 1	20-27/05/02	B1	10	101	p(.) c(g)	17.98	6.14	12.10	40.40	513.7	181.64	50.32	127.20	349.19	5189.7
			D	19	123	p(small*t, large(.) c=0	20.99	0	20.99	20.99	299.9	215.75	53.73	155.29	389.24	3082.1
			B2	8	41	p(.) c(g)	12.68	4.67	8.92	31.90	362.3	65.01	20.42	46.66	142.98	1857.4
	Wearyan 2	16-24/06/02	B1	21	98	p(.) c(t)	29.54	5.2	23.79	47.08	844.0	137.83	20.1	113.68	199.22	3938.0
			D	48	153	p(size) c=0	107.78	38.55	66.82	237.93	1539.7	179.20	11.29	164.66	211.86	2560.0
			B2	13	69	p(.) c(t)	19.69	5.1	14.76	38.35	562.6	104.48	22.55	80.33	180.14	2985.1
	Wearyan 3	25-30/08/02	B1	7	35	p(.) c(.)	8.69	1.89	7.29	16.87	248.3	43.44	6.88	37.08	69.20	1241.1
			D	17	54	p(size) c=0	27.90	9.94	19.37	67.09	398.6	60.31	4.57	55.77	76.50	861.6
			B2	3	57	p(.) c(.)	3.24	0.53	3.02	6.26	92.6	61.64	3.48	58.25	74.17	1761.1
2003																
	Wearyan 4	24-29/05/03	B1	3	15	p(.) c(t)	3.50	0.93	3.05	8.50	100.0	17.51	3.16	15.37	31.95	500.3
			D	14	10	p(size) c=0	15.95	2.9	14.23	30.16	227.9	10.45	0.89	10.04	15.32	149.3
			B2	2	7	p(.) c(g)	2.00	0.07	2.00	2.44	57.1	7.02	0.13	7.00	7.90	200.6
	Wearyan 5	21-26/06/03	B1	6	36	p(.) c(.)	6.16	0.43	6.01	8.72	176.0	26.67	1.02	26.08	31.72	762.0
			D	14	29	p(small*t+size,large(.)c=0	14.00	0.004	14.00	14.01	200.0	29.19	0.49	29.01	32.07	417.0
			B2	1	6	p(.) c(.)	1.04	0.21	1.00	2.48	29.7	6.24	0.65	6.01	10.16	178.3

Results of analysis of the NT depletion data for small (<120 mm cw) and large (>120 mm cw) mud crabs are provided in Tables 16 and 17. The analysis process provides an interesting insight into mud crab behaviour. In general, the model selected was the most parsimonious, where the delta AIC suggested that the model was similar to a more complex model but with a larger number of parameters, unless the more complex model returned significantly improved variance for the estimate. The analysis consistently resulted in the selection of two different models in describing the capture probability for small and large crabs caught within the mark-recapture (buffer) and the depletion zones. For both study sites and years the capture probability (p) for crabs caught within buffer zones (where tagged animals were returned to the water at point of capture) was consistently best described by the models p(.) corresponding to the capture probability of small and large crabs which remained constant throughout each study. Recapture probabilities (c) for buffer zones resulted in either c(.), c(g) or c(t) correspond to probability of recapture for small and large crabs c(.) which remain constant for all crabs during the study. Selection of c(g) indicated that probability of recapture was influenced by group (in this case large crabs) or c(t) where the probability of recapture changes with time.

For the depletion zone (where there were no recaptures) the models that consistently best described the capture probability were, p (size) c=0 and p ((small*t, large (.)) c=0, indicating that the probability of capture is primarily influenced by crabs larger than the mean size or the probability of capture of small crabs increases over time, and remains constant for large crabs. c=0, denotes that there was no recapture probability as there were no recaptures.

A closed population is a key assumption of mark-recapture and depletion data analyses. For this to be true, movement between buffer and depletion zones needs to be minimal Table 18 documents the total number of crabs tagged in buffer zones and the percentage of total number tagged that were subsequently recaptured in the depletion zone.

Table 19. Number of crabs tagged during each study in buffer zones and percentage that moved into depletion zone

Site	Year	Month	Total Number crabs tagged		No. tags moved	
			Buffer1	**Buffer 2**	**Depletion**	**% movement**
Adelaide	2002	May	97	130	8	3.52
Adelaide	2002	July	93	114	4	1.93
Adelaide	2002	Aug	84	89	4	2.31
Adelaide	2003	May	40	63	2	1.94
Adelaide	2003	July	58	75	0	0.00
Adelaide	2003	sep	41	33	1	1.35
Gulf of Carpentaria	2002	May	100	44	4	2.78
Gulf of Carpentaria	2002	June	110	74	17	9.24
Gulf of Carpentaria	2002	Aug	37	57	2	2.13
Gulf of Carpentaria	2003	May	15	9	0	0.00
Gulf of Carpentaria	2003	June	32	7	1	2.56

Movement of tagged animals into the depletion zone was low with an average of 1.8% total tagged animals having moved into the depletion zone at the Adelaide River site and 3.3% movement at the GOC site. During the GOC (June 2002) study over 9% of tagged crabs moved into the depletion zone. Examination of the data indicates that all 17 crabs were intermoult males, greater than 120 mm carapace width. A pattern of movement involving one sex, all of similar physiological condition, may indicate the onset of a biological function such as moulting. These crabs were removed from the study site and stored alive at camp. While no moulting activity was observed, it was unlikely that a crab would moult once removed from water.

To avoid over estimation of crab abundance all tagged animals that moved into the depletion zone were not included in the depletion zone catches during analyses.

Table 20. Mean annual estimate (N-hat) and density (km^2) of small (<120mm) and large (>120mm) mud crabs estimated from mark-recapture and depletion stream survey data

Site	Date	Zone	MARK	Crabs <120 mm		Crabs ≥ 120 mm	
			Model	N-hat	Density/km^2	N-hat	Density/km^2
		Buffer 1	p(.)c(g)	44.98	2998.67	101.75	6783.33
Adelaide	2002	Depletion	p(size) c=0	180.59	6019.78	63.28	2109.44
		Buffer 2	p(.)c(g)	92.89	6192.44	62.24	4149.56
		Buffer 1	p(.) c(g)	24.64	1642.44	29.31	1954.16
Adelaide	2003	Depletion	p(size) c=0	60.68	2022.56	53.62	1787.47
		Buffer 2	p(.) c(g)	34.86	2323.78	38.28	2551.78
Wearyan	2002	Buffer 1	p(.) c(g)	18.74	535.33	120.97	3456.29
		Depletion	p(size) c=0	52.22	746.05	151.75	2167.90
		Buffer 2	p(.) c(g)	11.87	339.14	77.04	2201.24
Wearyan	2003	Buffer 1	p(.) c(g)	4.83	138.00	22.09	631.14
		Depletion	p(size) c=0	14.98	213.93	19.82	283.14
		Buffer 2	p(.) c(g)	1.52	43.41	6.63	189.43

Table 21. Average density of mud crabs per km^2 per region per year, estimated for stream habitat for all crabs and large crabs (CW >120)

Region	Year	Crabs	Lower confidence level	Mean	Upper confidence level
Adelaide	2002	All	8115.88	9417.74	10719.61
		Large only	1695.89	**4347.44**	6998.99
	2003	All	3318.7	4094.06	4869.38
		Large only	1643.02	**2097.80**	2552.58
Wearyan	2002	All	2295.95	3148.65	4001.36
		Large only	1777.43	**2608.48**	3439.53
	2003	All	196.24	499.69	803.13
		Large only	104.54	**367.90**	631.27

Estimates of mud crab density obtained from the foreshore flat areas using trapping web surveys are provided in Table 22 and estimates of crab density from foreshore areas for crabs >120 mm are provided in Table 23. The tables provide a comparison of results from the two analysis methods used in this study, DISTANCE and DENSITY software. The major data difference between the two analysis methods is DISTANCE uses only first capture information while DENSITY utilised both capture and recapture information. Both the uniform and half normal detection function models were applied for each of the analysis methods. DISTANCE was able to resolve all the analyses using both detection function models. However DENSITY preferred the uniform detection function and could not resolve trip 25 Wearyan August 2002 using either detection function. This failure in analyses was due to the placement of the trapping web too close to the shoreline, resulting in excessive movement of crabs when the tide moved in and out across the mud flats resulting in extremely low recapture rates. Generally, the estimated crab densities provided by DISTANCE were slightly higher that those from DENSITY, but both methods provide results of similar magnitude and give reasonable and valid estimates of mud crab density.

Table 22. Trapping web density estimates (km²) for all crabs for the two study areas. DISTANCE analyses results, ΔAIC and AIC model selection, Density/km² and upper and lower confidence levels. DENSITY analyses results D/km² and capture probability (g0) magnitude and spatial scale (home range) sigma (m). See Section 4.4.2.2

DISTANCE										DENSITY									
Trip #	**Site**	**Date**	**Detection Model**	**ΔAIC**	**AIC**	**D/km²**	**D LCL**	**D UCL**	**D CV**	**Detection**	**N-hat**	**seN**	**p-hat**	**d-bar**	**sed**	**D/km²**	**seD**	**g0**	**Sigma**
17	Adelaide	May-02	uniform cosine	0	209.06	2552.50	1755	3711	0.189	Uniform	281.88	23.86	0.0993	103.4	12.8	1164.26	722	0.002	262.68
	River		half normal cosine	0	209.15	2455.80	1611	3745	0.214	Halfnormal	281.88	23.86	0.0993	103.4	12.8	1526.47	538	0.003	129.79
22	Adelaide	Jul-02	uniform cosine	0.353	65.711	719.86	344	1508	0.365	Uniform	95.47	13.95	0.1257	86.1	18.3	634.51	268	0.005	138.37
	River		half normal cosine	0	65.358	675.27	305	1493	0.393	Halfnormal	95.47	13.95	0.1257	86.1	18.3	NA	NA	NA	NA
24	Adelaide	Aug-02	uniform cosine	0	61.341	363.08	229	576	0.459	Uniform	66.66	11.52	0.129	66.6	15	655.27	229	0.008	91.81
	River		half normal cosine	2	63.341	363.15	146	906	0.224	Halfnormal	66.66	11.52	0.129	66.6	15	619.56	251	0.015	49.14
Adelaide 2002 Average			**uniform cosine**			**1457.79**				**Uniform**						**818.01**			
30	Adelaide	May-03	uniform cosine	0	42.175	**428.89**	244	753	0.548	Uniform	73.1	12.3	0.0903	94.1	31.8	**617.03**	513	0.002	186.59
	River		half normal cosine	2	44.175	428.98	142	1298	0.267	Halfnormal	73.1	12.3	0.0903	94.1	31.8	NA	NA	NA	NA
Adelaide 2003 Average						**NA**										**NA**			
19	Wearyan	May-02	uniform cosine	0.67	789.96	7194.20	5572	9289	0.13	Uniform	847.21	41.38	0.0928	112.9	8.6	3279.19	392	0.001	408.19
	River		half normal cosine	0	789.29	7225.50	5568	9377	0.133	Halfnormal	847.21	41.38	0.0928	112.9	8.6	3311.73	498	0.002	328.29
25	Wearyan	Aug-02	uniform cosine	0	201.42	1060.80	683	1647	0.223	Uniform	343.83	26.29	0.0715	103.8	34.3	NA	NA	NA	NA
	River		half-normal cosine	0.32	201.74	986.80	628	1551	0.229	Halfnormal	343.83	26.29	0.0715	103.8	34.3	NA	NA	NA	NA
26	Wearyan	Aug-02	uniform cosine	0.95	432.66	3251.30	2184	4839	0.203	Uniform	467.38	30.82	0.1087	66.7	9.6	4880.47	760	0.001	92.94
	River		half-normal cosine	0	431.71	4103.80	2587	6509	0.236	Halfnormal	467.38	30.82	0.1087	66.7	9.6	4769.81	807	0.012	48.84
Wearyan 2002 Average			**uniform cosine**			**4130.03**				**Uniform**						**4079.83**			
32	Wearyan	May-03	uniform cosine	0.06	144.61	1442.10	915	2272	0.228	Uniform	160.31	18.11	0.1035	96.9	19.2	926.61	564	0.003	188.43
	River		half normal cosine	0	144.55	1398.10	839	2329	0.257	Halfnormal	160.31	18.11	0.1035	96.9	19.2	891.94	346	0.005	103.64
34	Wearyan	Jun-03	uniform cosine	0.64	210.45	2901.00	1735	4852	0.262	Uniform	234.82	21.84	0.0886	67.8	13.8	3572.64	1058	0.003	94.28
	River		half normal cosine	0	209.81	3854.90	2116	7022	0.307	Halfnormal	234.82	21.84	0.0886	67.8	13.8	3523.69	1245	0.006	50.77
36	Wearyan	Aug-03	uniform cosine	0	275.74	7508.50	4253	13255	0.292	Uniform	356.28	26.8	0.0825	77.9	21.9	5425.37	934	0.002	118.23
	River		half normal cosine	0.08	275.82	5869.20	3610	9543	0.249	Halfnormal	356.28	26.8	0.0825	77.9	21.9	5727.00	3433	0.004	61.9
Wearyan 2003 Average			**uniform cosine**			**4253.83**				**Uniform**						**3308.21**			

Table 23. Trapping web density estimates (km^2) for crabs ≥ 120 mm for the two study areas. DISTANCE analyses results, ΔAIC and AIC model selection, Density/km^2 and upper and lower confidence levels. DENSITY analyses results D/km^2 and capture probability (g0) magnitude and spatial scale (home range) sigma (m) see Section 4.4.2.2

DISTANCE crabs ≥120 mm										DENSITY crabs ≥120 mm									
Trip #	Site	Date	Detection Model	ΔAIC	AIC	D/km^2	D LCL	D UCL	D CV	Detection	N-hat	seN	p-hat	d-bar	sed	D/km^2	seD	g0	Sigma
17	Adelaide	May-02	uniform cosine	0.1	116.24	1147.4	635.8	2071	0.297	Uniform	175.7	18.93	0.1116	116.6	12.8	482.22	89.6	0.002	547.96
	River		half normal cosine	0	116.14	1062.5	582.8	1937	0.302	Halfnormal	175.7	18.93	0.1116	116.6	12.8	NA			
22	Adelaide	Jul-02	uniform cosine	0.04	42.74	673.85	326.5	1391	0.342	Uniform	79.87	12.75	0.1202	104.5	21.3	312.20	212.0	0.005	141.98
	River		half normal cosine	0	42.70	697.52	277.5	1754	0.443	Halfnormal	79.87	12.75	0.1202	104.5	21.3	356.81	310.8	0.004	159.21
24	Adelaide	Aug-02	uniform cosine	0	34.503	217.85	117.6	403.5	0.289	Uniform	43.14	8.72	0.1437	66.2	16.6	435.54	174.4	0.009	91.36
	River		half normal cosine	2.00	36.504	217.89	65.22	728	0.592	Halfnormal	43.14	8.72	0.1437	66.2	16.6	397.40	160.6	0.016	49.44
Adelaide 2002 Average			**uniform cosine**			**659.29**				**Uniform**						**409.99**			
30	Adelaide	May-03	uniform cosine	0	32.171	**336.99**	176.1	645	0.302	Uniform	60.88	11.25	0.0953	94.1	31.8	**468.85**	588.3	0.002	184.02
	River		half normal cosine	2.00	34.172	337.05	94.88	1197	0.618	Halfnormal	60.88	11.25	0.0953	94.1	31.8	NA	NA	NA	NA
Adelaide 2003 Average						**NA**										**NA**			
19	Wearyan	May-02	uniform cosine	0.5	720.68	6281.2	4770	8271	0.14	Uniform	772.4	39.52	0.0948	114.7	8.5	2518.45	329.9	0.001	537.88
	River		half normal cosine	0	720.18	6273.7	4746	8293	0.142	Halfnormal	772.4	39.52	0.0948	114.7	8.5	NA	NA	NA	NA
25	Wearyan	Aug-02	uniform cosine	0	143.07	428.52	317.9	577.6	0.149	Uniform	280.79	23.77	0.0727	103.8	34.3	NA	NA	NA	NA
	River		half-normal cosine	0.4	143.47	590.09	338.2	1030	0.282	Halfnormal	280.79	23.77	0.0727	103.8	34.3	NA	NA	NA	NA
26	Wearyan	Aug-02	uniform cosine	1.63	332.67	3232.7	1860	5619	0.284	Uniform	372.48	27.5	0.1138	70.3	10.1	3500.07	535.9	0.006	100.7
	River		half-normal cosine	0	331.04	3031.7	1777	5172	0.274	Halfnormal	372.48	27.5	0.1138	70.3	10.1	3313.51	640.3	0.012	54.02
Wearyan 2002 Average			**uniform cosine**			**3244.64**				**Uniform**						**3009.26**			
32	Wearyan	May-03	uniform cosine	0	64.367	299.06	188.7	474.1	0.224	Uniform	75.45	11.8	0.1352	110.7	19.2	283.44	91.6	0.003	364.68
	River		half normal cosine	0.654	65.021	460.27	201.3	1052	0.411	Halfnormal	75.45	11.8	0.1352	110.7	19.2	296.08	100.3	0.004	207.88
34	Wearyan	Jun-03	uniform cosine	0	99.776	767.18	396.3	1485	0.332	Uniform	105.17	14.81	0.1122	64.2	14.3	1119.80	393.8	0.007	89.46
	River		half normal cosine	0.04	99.819	1320.1	484.4	3598	0.52	Halfnormal	105.17	14.81	0.1122	64.2	14.3	1120.46	364.3	0.013	47.27
36	Wearyan	Aug-03	uniform cosine	0	108.61	508.41	359.7	718.6	0.172	Uniform	168.24	18.56	0.087	115.8	33	679.75	241.0	0.001	996.18
	River		half normal cosine	1.48	110.09	629.8	325.8	1218	0.333	Halfnormal	356.28	26.8	0.0825	77.9	21.9	997.08	624.1	0.001	3171.4
Wearyan 2003 Average			**uniform cosine**			**524.88**				**Uniform**						**694.33**			

5.1.2 Northern Territory Mud Crab Habitat

The two areas chosen for the NT study fall within NT fishing grids 1231 (Adelaide River region) and 1536 (McArthur River region). Each of these regions has historically demonstrated both commercial and recreational mud crab fishing activity. Each grid covers a 60-nm square, or 111.12 km^2. The estimated area of identified habitat type for grids 1231 and 1536 are provided in Table 24. Catch, effort and CPUE history for all NT fishing grids that demonstrate more than five active licences per annum are presented in Table 24 and the area of each identified habitat for each NT fishing grid is presented in Table 26.

Table 24. Area of habitat type in km^2 for grids 1231 and 1536 identified from satellite imagery

Site	Logbook grid	Foreshore flatskm^2	Tidal river/streams km^2	Total
Adelaide	1231	98.41	37.65	136.07
Wearyan	1536	250.39	36.11	286.5

Table 25. Catch, effort and CPUE history for NT fishing grids 1435/1535 Roper River, 1536 McArthur - Wearyan River, 1335/36 Blue Mud Bay, 1230 Darwin/Bynoe Harbour and 1231 Adelaide River 1985-2003

	1435/1535			1536			1335/36			1230			1231		
	tonnes	potlifts	cpue	tonnes	potlifts	cpue	tonnes	potlifts	cpue	tonnes	potlifts	cpue	tonnes	potlifts	cpue
1985	1.81	4090	0.44	40.12	61355	0.65				2.5156	5035	0.50	29.44	94772	0.31
1986	6.18	14172	0.44	39.24	79850	0.49	nfp	nfp	0.29	7.7056	27089	0.28	18.15	57290	0.32
1987	32.32	63654	0.51	34.13	76325	0.45				12.5669	44875	0.28	28.78	94170	0.31
1988	46.18	88115	0.52	25.15	71280	0.35				10.1566	58560	0.17	22.22	107238	0.21
1989	80.38	143160	0.56	30.57	45600	0.67				14.6981	53015	0.28	41.74	153947	0.27
1990	22.27	61740	0.36	38.70	84720	0.46				30.5188	161808	0.19	33.39	118012	0.28
1991	46.95	128580	0.37	47.11	89700	0.53				21.9792	112175	0.20	9.79	47933	0.20
1992	52.85	115920	0.46	86.16	181060	0.48	nfp	nfp	0.35	12.2507	70856.4	0.17	11.34	70522	0.16
1993	51.15	126821	0.40	119.92	241920	0.50	11.295	25.025	0.45	8.6579	42968	0.20	11.13	40030	0.28
1994	55.36	144215	0.38	84.94	279805	0.30	nfp	nfp	0.49	11.2118	44305	0.25	15.05	58480	0.26
1995	74.83	186010	0.40	112.97	257026	0.44	12.02	20.88	0.58	15.74	49837	0.32	22.54	79110	0.28
1996	169.25	285950	0.59	290.02	375955	0.77	nfp	nfp	0.57	9.57	29469	0.32	20.10	55710	0.36
1997	152.85	268902	0.57	245.25	311520	0.79	nfp	nfp	0.77	6.19	21120	0.29	56.93	145134	0.39
1998	134.30	222000	0.60	218.32	453270	0.48	34.38	42795	0.80	9.59	31292	0.31	37.57	139140	0.27
1999	199.90	254940	0.78	283.00	390720	0.72	115.04	114660	1.00	35.87	52380	0.68	63.14	93480	0.68
2000	277.29	225120	1.23	500.99	434460	1.15	73.30	64860	1.13	49.34	79290	0.62	80.86	128274	0.63
2001	400.18	325935	1.23	451.64	398220	1.13	126.08	74032	1.70	32.15	54155	0.59	98.47	137610	0.72
2002	310.67	403980	0.77	288.55	403085	0.72	76.50	81420	0.94	15.14	38380	0.39	38.07	120135	0.32
2003	117.45	254280	0.46	82.44	216420	0.38	78.40	153810	0.51	36.60	121100	0.30	16.99	58700	0.29

Note nfp = Not for publication data confidential due to <5 fishers submitting returns for these years.

Table 26. NT coastal habitat by NT fishing grid (see appendix 3) in km^2

Vegetation/Habitat	NT Fishing GRID															
Class	**1032**	**1130**	**1131**	**1132**	**1133**	**1134**	**1135**	**1136**	**1230**	**1231**	**1232**	**1234**	**1235**	**1236**	**1329**	**1330**
Closed Avicennia	0.12	24.36	51.11	26.60	21.56	4.96		0.08	17.39	103.90	42.09	67.15	7.81	20.11	6.08	26.27
Closed Ceriops	1.77	76.83	36.76	112.10	30.45	7.33	4.72	0.68	199.67	53.09	0.16	19.37	71.88	57.36	6.54	1.21
Closed Mixed	0.41	89.55	33.56	21.64	10.41	3.78	5.28	0.14	139.51	75.25	45.01	75.84	129.13	55.17	12.85	8.99
Closed Rhizophora	0.06	287.57	132.73	156.14	27.24	2.91	7.18	3.78	33.05	41.47	18.89	35.04	36.53	50.30	1.81	2.91
Closed Avicennia/Ceriops	0.01	35.34	21.82	13.23	2.10				0.52	13.68	4.55	1.74	2.31	2.76	0.29	
Closed Sonneratia		2.24	0.28	1.68		0.07			14.28	2.20	6.00	0.46	4.87	3.65	1.24	0.90
Open Avicennia		1.23	2.34	2.96	1.12	0.09			4.95	8.94	8.53	2.48	0.24	4.13	1.21	13.15
Open Avicennia/Ceriops			0.06	3.06												
Open Ceriops		0.44	0.00						0.05			0.03		0.12		
Open Sonneratia		0.77	0.33	4.32		0.01			0.65		0.88	0.42	0.41	0.40		
Saline Grassland		0.50	0.00						0.18	4.56			0.16	0.78		
Sedgeland			0.00						1.56							
saltpan	0.29	44.73	99.36	215.98	64.56	5.60	2.37	0.32	64.17	243.76	231.05	208.44	224.70	114.66	11.36	41.11
Samphire-dominated saltpan		1.05	2.37	2.92	3.51	0.20	1.24		1.87	9.80	9.40	8.29	16.84	2.79	0.71	7.39
water and terrestrial	0.09	7.78	8.04	65.77	6.99	0.61	0.29	0.06	10.11	35.61	46.76	36.80	19.96	5.75	0.43	4.96
Foreshore mud flats	3.04	142.19	63.05	148.03	55.24	13.89	31.79	5.57	254.98	98.41	15.71	110.62	65.45	107.23	61.76	137.37
CLASS	**1335**	**1336**	**1428**	**1429**	**1430**	**1435**	**1436**	**1528**	**1529**	**1530**	**1535**	**1536**	**1537**	**1636**	**1637**	**1638**
Closed Avicennia	52.00	29.07	0.58	83.87	0.07	36.45	0.78	0.08	42.58	0.23	14.10	65.91	1.87		9.32	0.29
Closed Ceriops	5.96	3.65		18.73		7.92	0.40				4.54	1.49			0.22	
Closed Mixed	3.82	1.38		113.09	1.37	50.89	0.16		11.62	0.08	18.05	48.76	2.93		5.25	0.20
Closed Rhizophora	12.04	21.76		23.23		6.84	0.75		7.27		4.18	16.66	0.68		1.95	
Closed Avicennia/Ceriops	6.72	7.06		0.02		6.77					10.77	7.47	0.48		2.40	
Closed Sonneratia				3.89												
Open Avicennia	3.38	3.59	1.35	67.95	0.04	4.95	0.09	0.10	68.83		0.60	5.12	0.01		0.50	
Open Avicennia/Ceriops																
Open Ceriops	0.72						0.05								0.17	
Open Sonneratia																
Saline Grassland						0.78										
Sedgeland	23.09	18.10														
saltpan	277.86	26.58	147.78	1207.9	6.44	694.23	0.76	51.28	648.01	1.22	309.12	672.67	79.96	18.73	252.33	6.36
Samphire-dominated saltpan	2.68	0.31		1.74		51.56			4.30			5.84		0.02	0.58	
water and terrestrial	3.01	0.26	7.91	39.60	0.08	50.68	0.04	1.80	36.65		10.88	26.04	5.50	1.13	21.35	0.40
Foreshore mud flats	0.11	66.54	49.25	275.14		87.08	5.24		8.25	3.45	130.13	250.39	51.75		10.20	

5.1.3 Cluster Analysis of Grids Based on Habitat Composition

Similarities in the habitat composition of grids were analysed using a clustering algorithm. Variables included mud flats, closed *Avicennia* sp., closed *Avicennia* sp. and *Ceriops* sp., closed *Ceriops* sp., closed mixed, closed *Rhizophora* sp., closed *Sonneratia* sp., open *Avicennia* sp., open *Avicennia* sp. and *Ceriops* sp., open *Ceriops* sp., open *Sonneratia* sp., saline grassland, salt pan, samphire dominated salt pan and sedge.

The analyses was performed on the area of each habitat type (in square kilometres) present in each NT fishing grid (See Appendix 3). The complete linkage procedure (furthest neighbour) was used to determine naturally distinct "clumps" (Figure 40). All data used was measured on the same scale so joining measures were based on Euclidean distances.

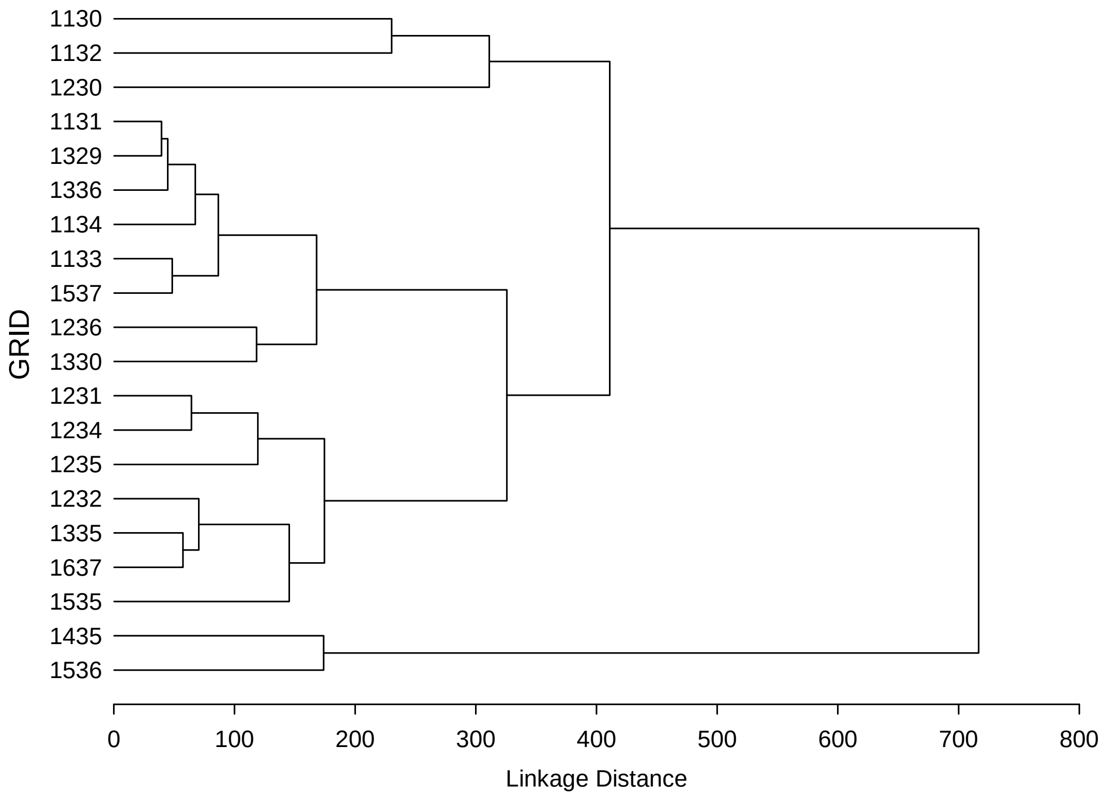

Figure 40. Cluster analyses of habitat associations between NT fishing grids

Two grids that have historically recorded the greatest NT fishing activity and catch demonstrate significant difference from any other grid-habitat type (grids 1536 McArthur/Wearyan River and 1435 Roper River) (Figure 40). Grids 1130 (Bathurst Island), 1132 (Cobourg Pennisula) and 1230 (Bynoe Darwin) are also grouped, identified with similar characteristics but differing significantly from other areas. Two other major groupings are evident grids 1131 to 1330 and 1231 to 1535.

In light of the distinct separation of the two study areas, density estimates obtained for the McArthur-Wearyan site (grid 1536) were used for the Gulf of Carpentaria region that encompasses grids 1435 and 1536. Density estimates from the Adelaide River study site in grid 1231 were used to multiply up catches for all other grids using the meso-scale regionalisation (IMCRA 1998, see Appendix 4).

5.1.4 Relative Abundance Estimates for Northern Territory Mud Crabs

Relative abundance estimates for all crabs as well as large crabs (those ≥ 120 mm carapace width) were calculated from MARK-recapture/depletion data for mangrove lined streams using MARK software and from the trapping web data from foreshore flats using DISTANCE and DENSITY software (Tables 17, 18 and 19). Estimates were calculated for all crabs as well as large crabs (≥ 120mm CW) to provide an indication of the potential population of legal sized crabs based on the assumption that crabs ≥ 120 mm were already or would reach legal size within the next moult.

Abundance estimates in numbers were derived by multiplying the average annual density estimate for each region by the corresponding area of habitat, mud flats for trapping web data and for the MARK-recapture and depletion data by the area of mangrove lined streams and creeks.

Table 27. Total estimated number and predicted abundance of for all crabs and large crabs (≥120 mm) for the tidal stream (MARK) and foreshore flats (DISTANCE) for NT Grids 1231 (Adelaide River) and 1536 (the McArthur/Wearyan Rivers) compared to the commercial catch (tonnes) for 2002 and 2003

Grid	Year	Size	Tidal stream estimate n	Foreshore estimate n	Predicted (number)	Predicted (t)	Commercial catch (t)	Estimated % removed
1231	2002	All	354561.77	143390.60	497952.37	404.54		
		large	163686.69	64884.00	228570.69	185.69	38.07	20.5
	2003	All	154144.20	42121.60	196265.80	151.69		
		large	78984.78	33164.90	112149.68	86.68	19.01	21.9
1536	2002	All	113694.23	1034109.60	1147803.83	783.03		
		large	94189.16	812424.50	906613.66	618.49	288.55	46.7
	2003	All	18043.25	1064907.51	1082950.76	701.10		
		large	13284.63	131424.56	144709.19	93.77	82.44	88.0

Table 28. Total estimated number and predicted abundance of for all crabs and large crabs (≥120 mm) for the tidal stream (MARK) and foreshore flats (DENSITY) for NT Grids 1231 (Adelaide River) and 1536 (the McArthur/Wearyan Rivers) compared to the commercial catch (tonnes) for 2002 and 2003

Grid	Year	Size	Tidal stream estimate n	Foreshore estimate n	Predicted (number)	Predicted (t)	Commercial catch (t)	Estimated % removed
1231	2002	All	354561.77	80503.50	435065.27	353.45		
		large	163686.69	40349.20	204035.89	165.76	38.07	23.0
	2003	All	154144.20	60722.00	214866.20	166.07		
		large	78984.78	46141.90	125126.68	96.71	19.01	19.7
1536	2002	All	113694.23	1021339.70	1135033.93	774.32		
		large	94189.16	753487.80	847676.96	578.29	288.55	49.9
	2003	All	18043.25	828289.20	846332.45	547.92		
		large	13284.63	173853.10	187137.73	121.27	82.44	68.0

For each region density estimates for foreshore flats and rivers were combined and multiplied by the mean NT crab weight per region from commercial catch monitoring data (Table 29) to gain a final estimate in tonnes. Separate estimates were calculated using both MARK + DISTANCE (Table 27) and MARK + DENSITY (Table 28). The estimated crab abundance at both sites reflects the reduction in commercial catch over the two years of the study. The next stage in this work was to assess how these estimates perform over the entire fishery. It would be reasonable to assume that areas of similar habitat should carry similar numbers of crabs. However, some error could be expected due to the large scale at which the multipliers are being applied. Also fishing effort is not consistently applied across all fishing grids and without conducting additional fishery independent surveys it is difficult to assess whether final predicted estimates reasonably describe broad spatial application.

In the NT, commercial fishers' data can only be released if greater than five fishers have operated within each grid over the year. Within this constraint the reported commercial catch for 2002 and 2003 compares favourably with the predicted estimates of total tonnage of large crabs (Tables 30 and 31). In 2003, as catch and catch rates declined two NT Gulf of Carpentaria grids predicted catch exceeded the reported catch. Blue Mud Bay (grid 1336) predicted catch was 24.82 –32.1 tonnes while actual catch data cannot be released the reported catch was larger than that predicted. Such a scenario is possible when a species exhibits a rapid growth rate and new recruits enter the fishery in pulses throughout the year as they reach legal size or catch and effort locations are not accurately recorded.

Likewise in 2002 and 2003 the Roper River grid 1435 commercial catches exceeded the predicted catches. However, this is most likely to involve confusion in reporting the actual grid from which that catch was harvested. In 2003 the Roper region recorded 27% of the total NT fishery effort. The majority of fishers from this region all camp at the Roper River landing and, to maintain reasonable catches they must travel large distances each day to check their pots. For example, the adjacent grid 1535 is 40 km from the Roper mouth and yet this grid reported nil catch in 2003. The predicted catch for this region was around 60 tonnes.

The NT Fisheries Group monitors the commercial catch from four regions in the NT for biological changes in catch composition. Each month a series of biological data from a random sample of 100 crabs is collected. Table 29 presents mean weight for NT mud crabs from four regions. Declines in mean weight are evident across the fishery and this reflects decline in the NT mean mud crab size.

Table 29. Mean weight (g) and carapace width (CW) mm for mud crabs from four NT regions for 2002 and 2003

Area	Grid	Mean weight (g)		Mean CW (mm)	
		2002	**2003**	**2002**	**2003**
Adelaide River	1231	812.4	772.9	157.1	156.5
Blue Mud Bay	1335/36	717.9	646.7	153	152.2
McArthur River	1536	682.2	647.4	151	150.0
Roper River	1435	692.3	619.2	152.5	150.5
Annual mean		**714.4**	**660.2**	**152.9**	**151.6**

Table 30. Estimated habitat area (km^2) x mud crab density/ km^2 (x Wearyan River density estimates) and commercial catch (t) by NT fishing grid for the NT Gulf of Carpentaria (see Appendix 4 IMCRA Meso-scale Region Pell 13 Pellew), 2002 and 2003

Grid	**Area**	**Tidal stream area**	**Mud flat area**	**Year**	**Waterway estimate**	**Mud flats estimate**	**Mud flats estimate**	**Total est number**	**Total est number**	**Predicted tonnes**	**Predicte d tonnes**	**Commercial catch**
		km ^{2}	km ^{2}		MARK number	DISTANCE number	DENSITY number	MARK + DISTANCE	MARK+ DENSITY	MARK + DISTANCE	MARK+ DENSITY	Tonnes *
1335	Walker River	10.96	0.11	2002	28586.8	370.9	344.0	28957.7	28930.8	20.8	20.8	<5 lic
				2003	4031.9	60.0	79.4	4091.9	4111.3	2.6	2.7	<5 lic
1336	Blue Mud Bay	9.35	66.54	2002	24389.5	215913.1	200249.9	240302.6	224639.4	172.5	161.3	63.52
				2003	3439.9	34927.9	46203.9	38367.8	49643.8	24.8	32.1	36.70
1435	Roper River	52.78	87.08	2002	137679.7	282533.2	262037.0	420212.9	399716.7	290.8	276.6	296.66
				2003	19418.6	45704.9	60460.1	65123.5	79878.7	40.3	49.4	133.10
1436	Limmen Bight	7.78	5.24	2002	20295.7	17015.3	15780.9	37311.0	36076.6	25.7	24.8	0
				2003	2862.5	2752.5	3641.2	5615.1	6503.7	3.9	4.5	0
1535	Limmen River	50.30	130.13	2002	131198.5	422210.7	391581.7	553409.2	522780.3	380.7	359.7	<5 lic
				2003	18504.5	68300.3	90350.1	86804.8	108854.6	59.7	74.9	0.00
1536	McArthur R	36.11	250.39	2002	94189.2	812424.5	753487.8	906613.7	847676.9	618.3	578.1	288.55
				2003	13284.6	131424.6	173853.1	144709.2	187137.7	93.8	121.3	82.44
1537	Robinson R	5.49	51.75	2002	14323.5	167912.8	155731.7	182236.3	170055.2	125.4	117.0	0
				2003	2020.2	27163.0	35932.2	29183.2	37952.4	20.1	26.1	0
1637	Calvert River	35.41	10.20	2002	92359.7	33098.7	30697.5	125458.3	123057.2	86.3	84.7	0
				2003	13026.6	5354.3	7082.9	18380.9	20109.5	12.6	13.8	<5 lic
Total Gulf of Carpentaria		**208.18**	**601.45**	**2002**	**543022.5**	**1951479.2**	**1809910.6**	**2494501.7**	**2352933.1**	**1720.5**	**1622.9**	**677.86**
				2003	**76589.0**	**315687.5**	**417602.7**	**392276.5**	**494191.7**	**257.9**	**324.8**	**304.17**

Table 31. Estimated habitat area (km^2) x mud crab density/ km^2 (x Adelaide River density estimates) and commercial catch (t) (where >5 licences) by NT fishing grid for the regions surrounding Darwin corresponding to IMCRA Meso-scale Region ANB 18 Anson-Beagle, for 2002 and 2003

Grid	Area	**Tidal stream area**	**Mud flats area**	**Year**	**Waterway estimate**	**Mud flats estimate**	**Mud flats estimate**	**Total est number**	**Total est number**	**Predicted tonnes**	**Predicte d tonnes**	**Commercial catch**
		km^2	km^2		MARK number	DISTANCE number	DENSITY number	MARK + DISTANCE	MARK+ DENSITY	MARK + DISTANCE	MARK+ DENSITY	Tonnes*
1329	Anson Bay	6.96	61.76	2002	30277.0	40717.1	25320.6	70994.1	55597.6	48.84	38.25	0
				2003	14609.7	20812.2	28955.7	35421.9	43565.5	24.37	29.97	<5 lic
1330	Daly R	52.14	137.37	2002	226662.8	90565.3	56319.5	317228.2	282982.3	218.25	194.69	<5 lic
				2003	109373.1	46291.6	64405.0	155664.7	173778.0	107.10	119.56	<5 lic
1230	Bynoe Harbour	24.93	254.98	2002	108381.1	168107.9	104540.6	276489.0	212921.7	190.22	146.49	15.14
				2003	52297.8	85926.8	119548.9	138224.6	171846.7	95.10	118.23	36.78
1231	Adelaide R	37.65	98.41	2002	163686.7	64884.0	40349.2	228570.7	204035.9	185.60	165.68	38.07
				2003	78984.8	33164.9	46141.9	112149.6	125126.6	86.69	96.72	19.01
Total Darwin Region		**121.68**	**552.53**	**2002**	**529007.53**	**364274.44**	**226529.87**	**893281.97**	**755537.40**	**642.92**	**545.11**	**54.16**
				2003	**255265.37**	**186195.52**	**259051.51**	**441460.89**	**514316.88**	**313.26**	**364.49**	**57.81**

Note* Predicted tonnes calculated from NT commercial fishery monitoring data (see table 28). Average weight of mud crab for 2002 and 2003 for Grids 1231, 1335/36, 1435, and 1536. All other grids calculated at total fishery average weight.

Table 32. Estimated habitat area (km^2) x mud crab density/ km^2 (x Adelaide River density estimates) and commercial catch (t) by NT fishing grid for the NT Arnhem – Wessels Coast (IMCRA Meso-scale Region AWS 15 Arhnem-Wessels) for 2002 and 2003 where >5 licences

Grid	Area	**Tidal stream area**	**Mud flats area**	**Year**	**Waterway estimate**	**Mud flats estimate**	**Mud flats estimate**	**Total est number**	**Total est number**	**Predicted tonnes**	**Predicte d tonnes**	**Commercial catch**
		km^2	km^2		MARK number	DISTANCE number	DENSITY number	MARK + DISTANCE	MARK+ DENSITY	MARK + DISTANCE	MARK+ DENSITY	Tonnes*
1133	Goulburn Island	21.86	55.24	2002	95014.0	36422.2	22649.7	131436.2	117663.7	90.4	81.0	0
				2003	45847.7	18616.9	25901.4	64464.6	71749.1	44.4	49.4	<5 lic
1134	Goomadeer River	0.55	13.89	2002	2383.8	9156.5	5694.1	11540.4	8078.0	7.9	5.6	<5 lic
				2003	1150.3	4680.3	6511.6	5830.6	7661.9	4.0	5.3	0
1135	Castlereigh Bay	0.44	31.79	2002	1916.0	20961.2	13035.1	22877.3	14951.1	15.7	10.3	0
				2003	924.6	10714.1	14906.4	11638.7	15831.0	8.0	10.9	0
1136	English Co.–WesseI Is.	2.59	5.57	2002	11281.2	3673.2	2284.2	14954.4	13565.5	10.3	9.3	0
				2003	5443.6	1877.5	2612.2	7321.1	8055.8	5.0	5.5	0
1234	Maningrida	47.03	110.62	2002	204456.0	72931.2	45353.5	277387.3	249809.5	190.8	171.9	0
				2003	98657.5	37278.1	51864.6	135935.6	150522.1	93.5	103.6	<5 lic
1235	Buckingham Bay	47.43	65.45	2002	206213.9	43152.7	26835.2	249366.5	233049.0	171.6	160.3	0
				2003	99505.7	22057.1	30687.7	121562.8	130193.4	83.6	89.6	0
1236	Nhulunbuy	24.70	107.23	2002	107383.9	70692.9	43961.5	178076.9	151345.5	122.5	104.1	0
				2003	51816.7	36134.0	50272.8	87950.7	102089.5	60.5	70.2	<5 lic
Total Arhem Wessels Coast		**144.60**	**389.80**	**2002**	**628648.9**	**256990.0**	**159813.3**	**885638.9**	**788462.3**	**609.3**	**542.5**	**<5 lic**
				2003	**303346.0**	**131358.1**	**182756.8**	**434704.0**	**486102.8**	**299.1**	**334.4**	**<5 lic**

Table 33. Estimated habitat area (km^2) x mud crab density/ km^2 and commercial catch (t) by NT fishing grid for the far Western NT region (IMCRA CAB 21 Cambridge-Bonaparte) Kakadu/ Coburg regions (IMCRA VDG 17 and COB 58) and Tiwi Islands (IMCRA TIW 16) where >5 licences

Grid	Area	**Tidal stream area**	**Mud flats area**	**Year**	**Waterway estimate**	**Mud flats estimate**	**Mud flats estimate**	**Total est number**	**Total est number**	**Predicted tonnes**	**Predicte d tonnes**	**Commercial catch**
		km^2	km^2		MARK number	DISTANCE number	DENSITY number	MARK + DISTANCE	MARK+ DENSITY	MARK + DISTANCE	MARK+ DENSITY	Tonnes*
1529	Upper Victoria R	253.41	8.25	2002	1101670.3	5439.7	3382.8	1107110.0	1105053.1	761.7	760.3	0
				2003	531596.0	2780.5	3868.4	534376.4	535464.4	367.7	368.4	0
1429	Victoria/Keep R	170.15	275.14	2002	739696.9	181394.6	112803.1	921091.5	852500.0	633.7	586.5	0
				2003	356930.6	92718.2	128997.6	449648.8	485928.3	309.4	334.3	0
Total far Western NT		**423.6**	**283.4**	**2002**	**1841367.2**	**186834.3**	**116185.9**	**2028201.5**	**1957553.1**	**1395.4**	**1346.8**	**0**
				2003	**888526.6**	**95498.6**	**132866.1**	**984025.2**	**1021392.7**	**677.0**	**702.7**	**0**
1132	Mini Mini	76.1	148.0	2002	330630.5	97593.2	60689.9	428223.7	391320.4	294.6	269.2	<5 lic
				2003	159541.2	49883.8	69402.8	209425.1	228944.0	144.1	157.5	<5 lic
1232	VDG/Kakadu	162.7	15.7	2002	707430.6	10355.0	6439.5	717785.7	713870.1	493.8	491.1	0
				2003	341361.0	5292.9	7363.9	346653.9	348724.9	238.5	239.9	<5 lic
1032	Croker Island	0.2	3.0	2002	1028.5	2002.8	1245.5	3031.3	2273.9	2.1	1.6	0
				2003	496.3	1023.7	1424.3	1520.0	1920.5	1.0	1.3	0
Coburg /Kakadu		**239.0**	**166.8**	**2002**	**1039089.6**	**109951.0**	**68374.8**	**1149040.6**	**1107464.4**	**790.5**	**761.9**	**<5 lic**
				2003	**501398.5**	**56200.4**	**78191.0**	**557599.0**	**579589.5**	**383.6**	**398.8**	**<5 lic**
1130	Bathurst Island	117.9	142.2	2002	512608.9	93747.3	58298.2	606356.2	570907.2	417.2	392.8	0
				2003	247352.4	47918.1	66667.8	295270.5	314020.2	203.1	216.0	0
1131	Melville Island	41.5	63.0	2002	180347.6	41567.5	25849.4	221915.1	206197.0	152.7	141.9	0
				2003	87024.3	21246.8	29560.5	108271.1	116584.7	74.5	80.2	0
Tiwi Islands		**159.4**	**205.2**	**2002**	**692956.5**	**135314.8**	**84147.6**	**828271.3**	**777104.2**	**569.9**	**534.6**	**0**
				2003	**334376.7**	**69164.9**	**96228.3**	**403541.6**	**430605.0**	**277.6**	**296.3**	**0**

5.2 Queensland

The length frequency distributions plotted by sex for all crabs caught during the study at each of the two Qld study sites are provided in Figures 41 and 42.

Analysis of the depletion surveys is presented in Tables 34, 35, 36 and is summarised in Table 37. The magnitude of crab density estimates for the “mangrove lined waterways” (Table 37) was consistent with that from the DENSITY analysis of the foreshore trapping web (Table 38). Based on these estimates, the foreshore mudflats were as productive as the stream habitat. This is biologically reasonable, or at least feasible, for productive mudflats adjacent to mangrove streams. As with the foreshore estimates there was a strong decline in mud crab density in 2003 compared with 2002 in the Karumba, but there was no such decline in Trinity Inlet (Table 37). The results from the foreshore trapping web density analysis using DENSITY and DISTANCE are presented in Table 38. On first inspection the Qld density estimates from both analysis programs appear high, with DISTANCE estimates being an order of magnitude higher than those provided by the DENSITY program.

The highest crab density estimated by DENSITY was 12939.2 crabs per km^2 (Table 38 Karumba 1). This is approximately 1.3 crabs per $100m^2$ or 1 crab per 10 metres in all directions. Biologically this is not an unreasonable density for a highly productive area of mudflat in the peak season. The lowest crab density estimated was 1345.4 crabs per km^2 (Table 38, Trinity Inlet 2) which approximates to 1 crab per 100 m in all directions.

DENSITY analysis failed to resolve the web data for trapping webs Karumba 4, Karumba 6 and Trinity Inlet 1. This was most probably due to violations of the underlying assumptions of the analysis: that the web diameter was large enough to encompass the animals’ home range. Observation of mud crabs in the field suggested that they were foraging extensively, moving up and down the slope with the tide (see also Hill 1978; Gribble and Thorne 1998). The sites for the trapping web were chosen to ensure that no part of the trapping web would dry out at low tide, but it is more than likely that crabs moved extensively through the trapping web as the tide flooded the adjacent coastal mangroves. Efford (2003) reports that failure of DENSITY analyses “may also be caused by sparse data. When the number of recaptures is less than about 20, the algorithm becomes less robust, however with some manipulation of search settings the software will usually yield an estimate of density, albeit one with wide confidence limits”.

The DISTANCE program provided estimates for all the Qld trapping webs; however, its estimates were 10 times the DENSITY estimates of crabs per km^2 (Table 38); which was at the limit of what could be considered as biologically reasonable. The trend in the estimates between years, however, does follow those seen in other independent data sets, particularly from the commercial harvest statistics. There was an apparent decline in mudcrab density in 2003 compared with 2002 for Karumba, but there was no such decline at Trinity Inlet.

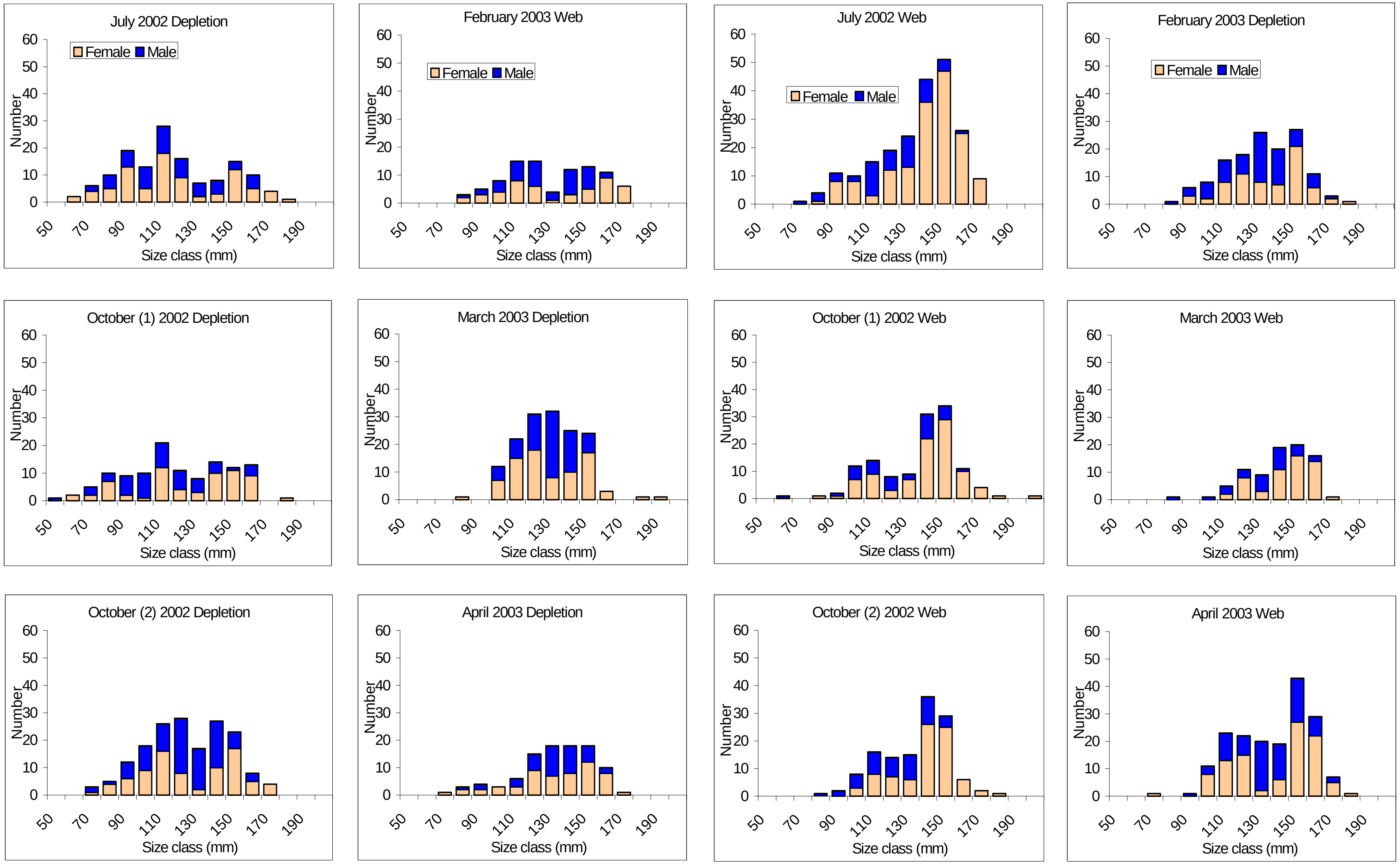

Figure 41. Length-frequency distribution of male and female crabs from Trinity Inlet depletion and web studies 2002 – 2003

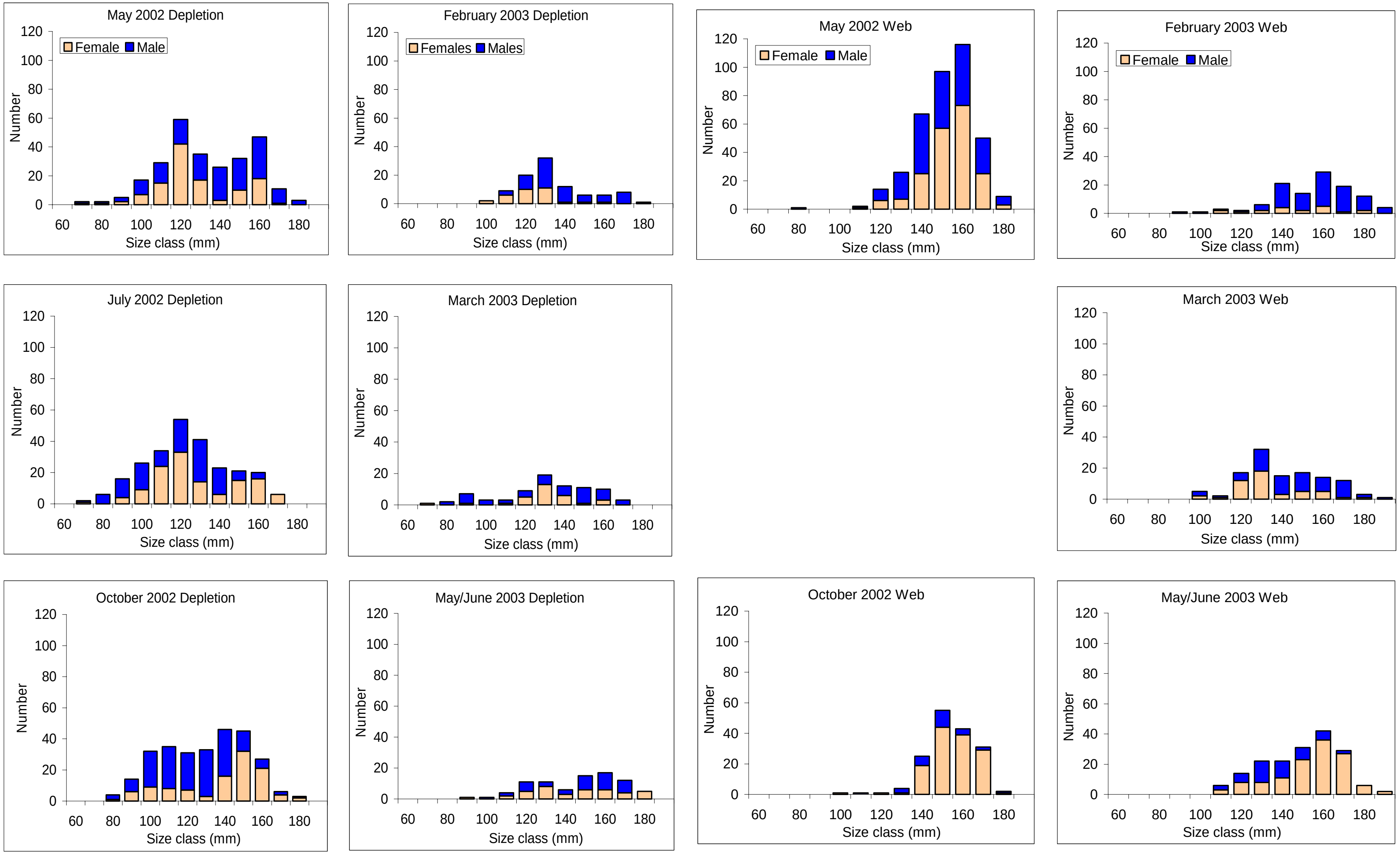

Figure 42. Length-frequency distribution of male and female crabs from Karumba depletion and web studies 2002 – 2003

Table 34. Trinity Inlet population estimates of crabs <120 mm and ≥ 120 mm, standard error and lower and upper confidence limits for buffer 1 (B1), depletion (D) and buffer 2 (B2)

Year	Date	Trip	Zone	No. marked		MARK	Estimated # crabs <120 mm				Density	Estimated # crabs ≥ 120 mm				Density
				<120 mm	≥120 mm	Model	N-hat	s.e	LCL	UCL	km^2	N-hat	s.e	LCL	UCL	km^2
2002	Jul-Aug	Trinity Inlet 1	B1	27	18	p(.) c(g)	38.72	10.06	29.73	77.26	3872	25.81	6.98	19.74	53.05	2581
			D	22	21	p(size) c=0	29.35	10	22.99	76.66	2935	21.4	0.73	21.04	25.3	2140
			B2	29	22	{p(.) c(g)	33.3	3.5	30.06	46.42	3330	25.26	2.82	22.75	36.12	2526
2002	Oct	Trinity Inlet 2	B1	35	27	p(.)c(g)	44.95	7.05	37.85	69.74	4495	34.68	5.64	29.12	54.84	3468
			D	11	15	p(size) c=0	13.45	4.17	11.25	35.06	1345	15.6	0.99	15.06	20.69	1560
			B2	19	22	{p(.)c(g)	24.31	4.76	20.18	42.89	2431	28.15	5.39	23.4	49.02	2815
2002	Oct	Trinity Inlet 3	B1	16	39	p(.)c(g)	19.73	3.18	16.88	31.88	1973	48.09	6.63	41.52	71.71	4809
			D	31	37	p(size) c=0	111.96	106.9	42.3	611.1	11196	42.8	5.4	38.24	64.27	4280
			B2	17	31	p(.)c(g)	21.12	3.6	17.94	35.02	2112	38.52	5.94	32.92	60.46	3852
2003	Feb	Trinity Inlet 4	B1	14	44	p(.) c(g)	17.24	2.82	14.75	28.12	1724	54.2	7.19	46.94	79.4	5420
			D	13	42	p(size) c=0	16.71	4.48	13.58	36.79	1671	53.86	9.12	45.11	87.14	5386
			B2	6	21	p(.) c(g)	6.74	1.12	6.09	12.26	674	23.61	2.82	21.46	35.65	2361
2003	Mar	Trinity Inlet 5	B1	15	34	p(.) c(g)	23.93	8.29	16.91	56.86	2393	54.24	17.66	38.63	122.46	5424
			D	11	35	p(size) c=0	12.44	1.94	11.19	21.6	1244	73.54	54.34	39.96	334.53	7354
			B2	9	49	p(.) c(g)	12.67	3.38	9.79	26.03	1267	68.99	14.59	54.56	120.94	6899
2003	Apr	Trinity Inlet 6	B1	5	31	p(.) c(g)	6.41	1.75	5.21	14.38	641	39.73	7.74	32.96	69.86	3973
			D	6	25	p(size) c=0	6.46	0.96	6.04	11.86	646	28.14	3.3	25.58	42.02	2814
			B2	5	21	p(.) c(g)	7.21	2.91	5.31	20.76	721	30.29	10.31	22.61	74.76	3029

Table 35. Karumba population estimates of crabs <120 mm and ≥ 120 mm, standard error, lower and upper confidence limits for buffer 1 (B1), Depletion (D) and buffer 2 (B2)

Year	Date	Trip	Zone	No. Marked		MARK	Estimated # crabs <120 mm				Density	Estimated # crabs ≥ 120 mm				Density
				<120 mm	≥120 mm	Model	N-hat	s.e	LCL	UCL	km^2	N-hat	s.e	LCL	UCL	km^2
2002	May	Karumba 1	B1	8	67	p(.) c(g)	10.23	2.09	8.47	18.57	1023	85.64	11.41	73.17	123.32	8564
			D	21	76	p(size) c=0	39.53	19.54	24.4	121.92	3953	126.56	32.95	91.76	238.25	12656
			B2	26	70	p(.) c(g)	32.55	4.26	28.04	46.98	3255	87.62	9.7	76.43	118.32	8762
2002	Jul	Karumba 2	B1	14	73	p(.) c(g)	15.96	1.76	14.43	22.88	1596	83.2	5.98	76.52	102.58	8320
			D	29	50	p(g) c(.)	53.36	30.64	32.61	193.33	5336	53.94	3.24	50.96	66.12	5394
			B2	47	74	p(.) c(g)	67.05	10.94	54.37	101.53	6705	105.57	16.46	86.08	156.53	10557
2002	Oct	Karumba 3	B1	11	70	p(.) c(g)	11.69	0.92	11.09	16.03	1169	74.39	3.09	71.26	85.22	7439
			D	46	79	p(size) c=0	76.58	29.35	46.96	179.61	7658	78.52	6.91	70.89	101.14	7852
			B2	46	79	p(.) c(g)	66.8	11.32	53.67	102.43	6680	114.73	18.45	92.78	171.66	11473
2003	Feb	Karumba 4	B1	1	32	p(.) c(g)	1.01	0.1	1	1.67	101	32.31	0.64	32.03	35.85	3231
			D	6	33	p(size) c=0	6.4	0.8	6.03	10.85	640	33.73	1.07	33.09	38.97	3373
			B2	5	27	p(.) c(g)	5.12	0.37	5.01	7.43	512	27.67	1.01	27.08	32.68	2767
2003	Mar	Karumba 5	B1	6	25	p(.) c(g)	6.04	0.21	6	7.43	604	25.17	0.45	25.01	27.87	2517
			D	4	13	p(size) c=0	4.13	0.49	4.01	7.31	413	13.03	0.17	13	14.2	1303
			B2	8	27	p(.) c(g)	8.05	0.24	8	9.61	805	27.18	0.46	27.01	29.9	2718
2003	May	Karumba 6	B1	2	33	p(.) c(g)	2.26	0.58	2.02	5.56	226	37.32	3.95	33.94	52.89	3732
			D	3	25	p(size) c=0	22.31	40.8	4.5	251.31	2231	51.4	34.07	28.79	208.8	5140
			B2	2	27	p(.) c(g)	2.21	0.51	2.01	5.21	221	29.83	2.94	27.53	42.13	2983

Table 36. Density estimates averaged per year for each region from the depletion surveys

Site	Date	Zone	MARK	Crabs <120 mm		Crabs ≥ 120 mm	
			Model	N-hat	Density/km^2	N-hat	Density/km^2
		Buffer 1	{p(.) c(g)	12.63	1263	81.08	8108
Karumba	2002	Depletion	p(size) c=0	56.49	5649	86.34	8634
		Buffer 2	{p(.) c(g)	55.47	5547	102.64	10264
		Buffer 1	p(.) c(g)	3.1	310	31.6	3160
Karumba	2003	Depletion	p(size) c=0	10.95	1095	32.72	3272
		Buffer 2	p(.) c(g)	5.13	513	28.23	2823
Trinity	2002	Buffer 1	p(.) c(g)	34.47	3447	36.19	3619
Inlet		Depletion	p(size) c=0	51.59	5159	26.6	2660
		Buffer 2	p(.) c(g)	26.24	2624	30.64	3064
Trinity	2003	Buffer 1	p(.) c(g)	15.86	1586	49.39	4939
Inlet		Depletion	p(size) c=0	11.87	1187	51.85	5185
		Buffer 2	p(.) c(g)	8.87	887	40.96	4096

Table 37. Average density of mudcrabs per km^2 per region per year, estimated for stream habitat for all crabs and large crabs (CW >120)

Region	Year	Crabs	Lower confidence level*	Mean density (km^2)	Upper confidence level*
Karumba	2002	All	10299.24	13154.67	16010.09
		Large only	7296.61	**9001.89**	10707.17
	2003	All	2555.30	3724.11	4892.92
		Large only	2293.02	**3084.89**	3876.76
Trinity Inlet	2002	All	4155.55	6857.78	9560.00
		Large only	2299.92	**3114.56**	3929.19
	2003	All	4254.67	5960.11	7665.55
		Large only	3361.56	**4740.00**	6118.44

*Upper and lower 95% confidence intervals around the mean density estimate from MARK

Table 38. Trapping web density estimates (km^2) for all crabs for the two study areas. DISTANCE analyses results, ΔAIC and AIC model selection, Density/km^2 and upper and lower confidence levels. DENSITY analyses results D/km^2 and capture probability (g0) magnitude and spatial scale (home range) sigma (m). see section 4.4.2

			DISTANCE								**DENSITY**					
Trip #	Site	Date	Detection Model	D/km^2	D LCL	D UCL	Detection Model	N-hat	seN	p-hat	d-bar	sed	D/km^2	seD	g0	Sigma
1	Karumba	May 2002	Half normal cosine	46311.0	30672	69924	Uniform	676.00	41.30	0.1538	53.6	3.6	12939.2	1223.3	0.0124	74.56
3	Karumba	Oct 2002	Half normal cosine	7363.5	3923	13821	Uniform	282.00	25.44	0.1596	83.0	6.1	1751.3	150.88	0.0044	323.41
	2002 Average			**26837.3**									**7345.2**			
4	Karumba	Feb 03	Half normal cosine	5873.9	2531.7	13628	Uniform	485.00	131.52	0.0491	88.9	12.9	NA	NA	NA	NA
5	Karumba	Mar 03	Half normal cosine	4816.3	2561.4	9056	Uniform	549.00	143.02	0.0481	63.3	15.4	8052.1	4435.8	0.0027	96.31
6	Karumba	May 03	Half normal cosine	12685.0	6853.2	23481	Uniform	918.00	217.14	0.0414	102.4	11.5	NA	NA	NA	NA
	2003 Average			**7791.73**									**NA**			
1	Trinity Inlet	Jan 02	Half normal cosine	5524.1	2999.7	10173	Uniform	488.00	42.68	0.0820	82.8	5.5	NA	NA	NA	NA
2	Trinity Inlet	Oct 02	Half normal cosine	20550	10437.0	40462	Uniform	198.00	15.07	0.2061	77.6	6.0	1345.4	272.76	0.0070	212.90
3	Trinity Inlet	Oct 02	Half normal cosine	23512	13179	41945	Uniform	433.00	83.31	0.0707	75.0	14.4	3496.9	2301.0	0.0025	169.18
	2002 Average			**16528.7**									**2421.1**			
4	Trinity Inlet	Feb 03	Half normal cosine	9568.4	3921.6	23346	Uniform	174.00	23.82	0.1391	55.8	9.2	3119.6	650.31	0.0104	79.38
5	Trinity Inlet	Mar 03	Half normal cosine	10573.0	6118.9	18268	Half normal	225.00	44.75	0.0916	79.3	13.4	1395.9	1428.4	0.0046	129.53
6	Trinity Inlet	Apr 03	Half normal cosine	35234.0	19433	63882	Uniform	285.00	19.04	0.1667	69.7	5.1	2896.7	772.37	0.0080	134.31
	2003 Average			**18458.5**									**2470.7**			

5.2.1 Relative Abundance Estimates for Queensland Mud Crabs

The range of crab density estimates for all area/year combinations was wide for both stream and foreshore habitats; therefore these relative abundance estimates should be taken as indicative rather than exact.

Objective 1 of this study produced a GIS of tidal wetlands and foreshore flats in Northern Australia (FRDC 2000/142 Objective 1 CD). Combining that data for Qld with the data from Table 37 and 38, total number of crabs was estimated for regions and across the state.

Only the area of “mangrove lined stream/estuaries” (area of mangrove-lined watercourse) and “foreshore flats” were used in these estimates. The “area of watercourse” within each 6' x 6' chart grid within 5km of the coast was calculated to provide the area of mangrove lined estuary, river and larger stream area. However some small creeks/streams would be excluded from this calculation (Clare Bullock, QDPI&F CHRIS program, pers com).

The area of foreshore flat in km^2 was summed within a coastal 6' x 6' chart grid. Given that there will be estimate errors in the calculation of the area of habitat types, and these will compound any estimate errors from the density surveys, the values derived will underestimate the range in total relative abundance possible. Again these values should be taken as indicative not exact.

Estimates of the area of the foreshore flats and watercourse area was summed for each coastal 6'x 6' chart grid for Karumba (Table 39) and Trinity Inlet (Table 40). Karen Danaher and Clare Bullock, QDPI&F CHRIS program supplied habitat area data as per objective 1 of the current project.

Table 39. Area of habitat type in km^2 for Karumba, identified from satellite imagery

Karumba	Logbook 6’ Grid	Foreshore flats km^2	Stream area km^2	Water course km^2
	AD17-24	4.09	0.26	2.88
	AD17-23	1.09		
	AD17-19	5.96		
	AD18-3	1.73	1.57	7.46
	AD18-4		1.69	9.81
	AD18-5		2.54	8.24
	AD18-10		1.94	3.90
	Total	12.88	8.00	32.30

Table 40. Area of habitat type in km^2 for Trinity Inlet, identified from satellite imagery

Trinity Inlet	Logbook 6’ Grid	Foreshore flats km^2	Stream area km^2	Water course km^2
	H16-23	3.62	0.46	7.42
	H16-24	3.11		
	H16-18	5.06	0.57	1.51
	H16-19	2.67		
	H17-3		0.09	0.48
	H17-8		1.03	0.50
	Total	14.46	2.15	9.91

Simply multiplying the area of habitat in km^2 (Table 38 and 39) by the number of crabs per km^2 for each habitat type, estimated by the research surveys (Table 34 and 35), gives the total number of mud crabs per habitat type for Karumba and Trinity Inlet (Tables 41a and 41b).

Table 41a. Method 1 (MARK plus DENSITY estimates) Total number of mud crabs from the summed area of the two major mud crab habitat types in Karumba and Trinity Inlet for the years 2002 and 2003.

Region	Year	Size	Watercourse estimate n	Foreshore estimate n	Predicted (number)	Predicted (t)*	Commercial catch (t)	Estimated % removed
Karumba	2002	All	424895.8					
		large	517126.1	94606.8	611732.9	611.7	117.4	19.19
	2003	All	345841.5					
		large	158041.5	103711^	261752.5	261.8	65.9	25.17
Trinity In	2002	All	38418.7					
		large	94739.6	35009.8	129749.4	129.7	10.6	8.17
	2003	All	38938.3					
		large	75965.6	35726.8	111692.4	111.7	10.7	9.58

Note: Conversion from number to weight based on "1 legal crab = 1 kg", historically used by the QFISH logbook program database. No adjustment has been made for undersize or female crabs. And,
^ 2003 foreshore estimate from Karumba March 2003 survey – software unable to resolve Feb and May 2003 surveys.

Table 41b. Method 2 (MARK plus DISTANCE estimates) Total number of mud crabs from the summed area of the two major mud crab habitat types in Karumba and Trinity Inlet for the years 2002 and 2003 (Mark© plus DISTANCE© estimates)

Region	Year	Size	Watercourse estimate n	Foreshore estimate n	Predicted (number)	Predicted (t)*	Commercial catch (t)	Estimated % removed
Karumba	2002	All	424896					
		large	517126	345664	862791	862.8	117.4	13.61
	2003	All	345842					
		large	158042	100358	258399	258.4	65.9	25.50
Trinity In	2002	All	38418.7					
		large	94739.6	239005	333745	333.7	10.6	3.18
	2003	All	38938.3					
		large	75965.6	266910	342876	342.9	10.7	3.12

* Conversion from number to weight based on "1 legal crab = 1 kg", historically used by the QFISH logbook program database, no adjustment has been made for undersize or female crabs.

The estimates do not account for ongoing growth of juvenile crabs into the size classes vulnerable to capture by the depletion and web surveys. For rapidly growing highly productive species, such as mud crabs, it is possible to annually harvest more than the instantaneous biomass estimate made at any one time in a year.

5.2.2 Commercial Logbook Data

The comparison of commercial logbook CPUE from Karumba and Trinity Inlet shows a pronounced drop in the first four months of the year between 2002 and 2003 for the Karumba region. There is no comparable drop in CPUE in the Trinity Inlet area (Figures 43 and 44).

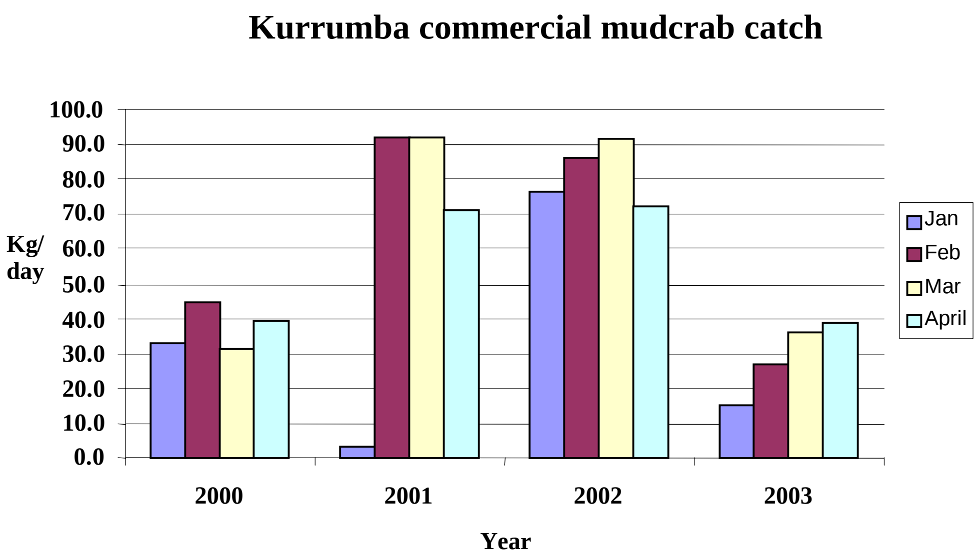

Figure 43. Commercial catch rate (CPUE) of mud crab for the first four months of the season in the 6' grids corresponding to Karumba, southern Gulf of Carpentaria

There was a 50% decline in numbers caught in the Karumba region between 2002 and 2003, corresponding to the decline seen in the stream depletion research surveys for these years in this area. In comparison there was no similar decline for the catch in Trinity Inlet in any of these three data sources between 2002 and 2003.

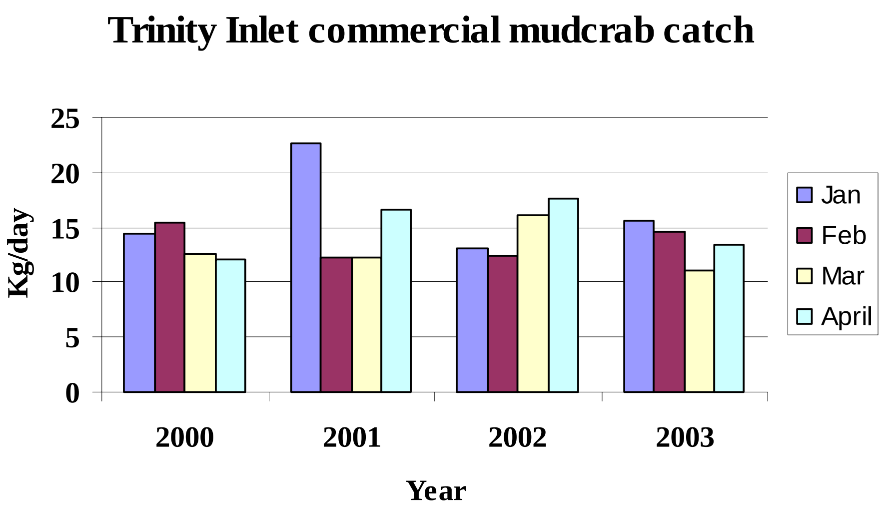

Figure 44. Commercial catch rate (CPUE) of mud crab for the first four months of the season in the 6' grids corresponding to Trinity Inlet, northern Qld East Coast

5.2.3 Reported recaptures from Queensland Infofish Services

Of the over 4,000 crabs tagged during the research surveys, only 35 tag returns were recorded from the recreational fishery based OZFISH program, with seven crabs recaptured twice and the other 28 recaptured only once. Twelve tags were returned from the Trinity Inlet survey tagging and 21 from the Karumba surveys. The maximum distance moved at either site was 8 nautical miles (but only six returns had sufficient information for this calculation). Four tagged crabs moved up river from release point, two moved "east along shore", and 11 were recaptured in the same area as release. The remaining 17 reports provided insufficient information on recapture location.

One tag was returned from a Sydney restaurant, the crab having been bought from the Qld fish market. One was returned from a buyer in Karumba and a further one tagged crab was returned from Townsville, having been given to the person returning the tag by a recreational fisher (from the Cairns area).

In contrast to the 0.9% reported recapture rate by the OZFISH program, the survey team recaptured and re-released 36% of the tagged crabs within the area of survey, either during a survey or during a subsequent survey in the same area. If returns from buyers and restaurants are ignored, the overall picture from the tagging component is one of relatively localised crab movement.

5.2.4 Assessment of Crab Abundance Based on Major Catchments

An extrapolation of the mud crab density estimates for mangrove-lined waterways and foreshore mud/sand flats was made for the major catchments on the Qld Gulf and East Coast (see Tables 41a and 41b). Estimates were made up of the DENSITY foreshore mud/sand flat crab density (Table 37), added to the MARK mangrove-lined waterway density estimates for large crabs (Table 36), derived from the Karumba surveys for the Qld Gulf of Carpentaria, and the Trinity Inlet surveys for the Northern East Coast. The 2002 commercial mud crab catch, extracted from the QDPI&F CHRIS database for each catchment, has been provided in the tables as a reference.

In all cases the estimated number of crabs was higher than the reported commercial catch of mud crabs. Only near centres of highest human population is the reported catch close to the estimated number of large crabs potentially available for harvest. Total number of crabs estimated for the Gulf coast in 2002 was 10770281.67 or 10770.3 t given each large sized crab is 1 kg (conversion rate used in Qld commercial catch and effort logbook database). The commercial catch in 2002 for the Qld Gulf was 173.9 t or 1.6% of the estimated numbers available.

The total number of crabs estimated for the Qld northern East Coast was 829427.3 or 829.4 t given each large sized crab is 1kg. The actual commercial catch was 35.8 t or 4.3% of the estimated numbers available. On both coasts this exploitation rate would seem to be very low for a high value seafood product.

Table 42. Estimates of mud crab numbers based on habitat area for the major catchments of the Qld Gulf of Carpentaria

Crab Grid Name	Latitude (°S)	Longitude (°E)	Area waterway (km^2)	Area foreshore (km^2)	Year	Estimate of waterways MARK No. of large crabs	Estimate of foreshore DENSITY No. of crabs	Predicted number	Predicted tonnes	Commercial catch*
					2002	156092.77	279891.76	435984.53	436.0	0
West Qld Gulf	16.0 to 17.0	138.0 to 139.0	17.34	38.11	2003	53491.99	**			
					2002	101451.30	913642.14	1015093.44	1015.1	3.5
Burketown	17.0 to 18.0	139.0 to 140.0	11.27	124.39	2003	34766.71	**			
					2002	75615.88	629828.48	705444.36	705.4	6.3
Southern Gulf	17.5 to 18.0	140.0 to 140.5	8.4	85.75	2003	25913.08	**			
					2002	615549.24	458035.43	1073584.67	1073.6	119.6
Norman	17.0 to 18.0	140.5 to 141.0	68.38	62.36	2003	210944.78	**			
					2002	221536.51	242722.23	464258.74	464.3	15.7
Gilbert	16.5 to 17.0	141.0 to 141.5	24.61	33.04	2003	75919.14	**			
					2002	153932.32	414475.05	568407.37	568.4	5.8
Staaten	16.0 to 16.5	141.0 to 141.5	17.1	56.43	2003	52751.62	**			
					2002	182558.33	20747.74	203306.07	203.3	<5 boats
Nassau	15.5 to 16.0	141.0 to 142.0	20.28	2.82	2003	62561.57	**			
					2002	634003.11	100574.33	734577.44	734.6	4.4
Mitchell	15.0 to 15.5	141.5 to 142.0	70.43	13.69	2003	217268.80	**			
					2002	1137568.84	231540.18	1369109.02	1369.1	0.3
Central Gulf	13.5 to 15.0	141.0 to 142.0	126.37	31.52	2003	389837.55	**			
					2002	259164.41	239635.22	498799.63	498.8	<5 boats
Archer	13.0 to 13.5	141.5 to 142.0	28.79	32.62	2003	88813.98	**			
					2002	951139.70	797006.65	1748146.35	1748.1	2.9
Weipa	12.5 to 13.0	141.5 to 142.0	105.66	108.51	2003	325949.48	**			
					2002	655157.55	530738.68	1185896.23	1185.9	4.7
Pt Musgrave	12.0 to 12.5	141.5 to 142.5	72.78	72.26	2003	224518.29	**			
					2002	404454.92	363308.93	767763.85	767.8	<5 boats
Gulf tip	11.0 to 12.0	141.5 to 142.5	44.93	49.46	2003	138604.11	**			
					2002	5548134.86	5222147	10770281.67	10770.3	173.9^
Total Qld Gulf			616.33	710.96	2003	1901310	**			

*Due to confidentiality catch cannot be reported where there is less than 5 boats ^total includes grids with less than 5 boats

** Insufficient data to reliably estimate Qld Gulf foreshore abundance of crabs in 2003, (Note Table41a "software unable to resolve Feb and May surveys."

Table 43. Estimates of mud crab numbers based on habitat area for the major catchments of the Qld Northern East Coast

Crab Grid Name	Latitude (°S)	Longitude (°E)	Area waterway (km^2)	Area foreshore (km^2)	Year	Estimate of waterways MARK No. of large crabs	Estimate of foreshore DENSITY No. of crabs	Predicted number	Predicted tonnes	Commercial catch*
Shelburne Bay	11.0 to 12.0	142.5 to 143.5	4.68	19.96	2002	14576.14	48321.22	62897.36	62.9	<5 boats
					2003	22183.20	49310.74	71493.94	71.5	
Temple Bay	12.0 to 12.5	142.5 to 143.5	4.97	13.61	2002	15479.36	32957.61	48436.97	48.4	<5 boats
					2003	23557.80	33632.52	57190.32	57.2	
Lloyd Bay	12.5 to 13.0	143.0 to 144.0	9.54	20.59	2002	29712.90	49848.27	79561.17	79.6	<5 boats
					2003	45219.60	50869.06	96088.66	96.1	
Cape Sidmouth	13.0 to 14.0	143.0 to 144.0	1.51	41.2	2002	4702.99	99755.35	104458.34	104.5	<5 boats
					2003	7157.40	101798.12	108955.52	109.0	
PCB West	14.0 to 15.0	143.5 to 144.0	7.88	65.71	2002	24542.73	159100.39	183643.12	183.6	<5 boats
					2003	37351.20	162358.42	199709.62	199.7	
PCB East	14.0 to 15.0	144.0 to 144.5	9.78	3.94	2002	30460.40	9527.5	39987.90	40.0	12.7
					2003	46357.20	9722.6	56079.80	56.1	
Ninian Bay	14.0 to 14.5	144.5 to 145.0	1.13	2.69	2002	3519.45	6501.67	10021.12	10.0	<5 boats
					2003	5356.20	6634.81	11991.01	12.0	
Jennie R	14.5 to 15.0	144.5 to 145.0	5.76	16.59	2002	17939.87	40175.41	58115.28	58.1	<5 boats
					2003	27302.40	40998.12	68300.52	68.3	
Starke R	14.5 to 15.0	145.0 to 145.5	5.42	5.7	2002	16880.92	13793.1	30674.02	30.7	12.4
					2003	25690.80	14075.55	39766.35	39.8	
Cape Bedford	15.0 to 15.5	145.0 to 145.5	4.03	18.36	2002	12551.68	44448.77	57000.45	57.0	<5 boats
					2003	19102.20	45358.98	64461.18	64.5	
Bloomfield	15.5 to 16.0	145.0 to 145.5	3.32	3.47	2002	10340.34	8400.54	18740.88	18.7	<5 boats
					2003	15736.80	8572.57	24309.37	24.3	
Trinity Inlet	16.0 to 17.5	145.0 to 146.0	24.23	24.93	2002	75465.79	60362.62	135828.41	135.8	10.7
					2003	114850.20	61598.72	176448.92	176.4	
		Total North East Coast	82.27	236.74	2002	256234.85	573192.5	829427.31	829.4	35.8^
					2003	389959.80	584930.2	974890.02	974.9	

*Due to confidentiality catch cannot be reported where there is less than 5 boats ^total includes only grids with 5 boats or more

6. Discussion

Objective one of this project has been successfully completed with the mud crab habitat of Qld and NT mapped and compiled into a GIS database.

An investigation of lunar effect on catch rates was also completed to gain some understanding on the way in which the lunar cycle and tides affect catch rates. This was important as in the Top End it is recommended that trapping studies be carried out during smaller neap tides, so that pot loss and excessive movement does not bias results. Analysis of the fishery dependent dataset provided little evidence of catch rates following a lunar pattern however this was due to the highly variable nature of the fishing operation, where bait type and levels of fishing effort vary according to availability and various daily routines. The variation in the fishery independent dataset was best explained by a 3.8-day cycle in catch rates, again showing little support for a lunar cycle. While the study was only conducted over one 30-day period, we conclude that conducting this work during neap tides was unlikely to bias abundance estimation results.

Mark recapture and trapping web survey designs adopted by the NT and Qld during this study deliver realistic estimates of local crab abundance. A significant reduction in reported commercial catch and catch rates has occurred throughout the entire NT and Qld Gulf fisheries and this indicates the possibility of a large-scale ecosystem influence/response on recruitment, at least in the Gulf.

Major differences in the studies conducted in Qld and the NT include the use of different fishing gear and study design layout. Different fishing gears are commonly used in each State and gear was chosen so comparisons with commercial catch could be made. The depletion and mark-recapture studies differed between States in two ways: the NT study utilised 100 crab pots and covered a 2 km section of tidal mangrove creek and the Qld study used 60 crab pots and covered 1.5 km section of creek. Trapping web layout chosen by the NT used 64 crab pots with a web diameter of 300 m and the Qld design used 40 crab pots with a 180 m diameter.

Abundance estimates obtained from the mark-recapture and depletion studies from each State provided similar numbers of captures and estimates and confidence intervals that were of similar magnitude, demonstrating no real preference for either design. This is particularly promising as both States recorded declining numbers in catch at each study site in 2003 and the design and software continued to provide acceptable results from very low numbers of captures and recaptures.

Trapping web analysis provided some evidence that a reduction in the size of the area sampled and small numbers of captures/recaptures may fail some of the underlying analysis assumptions. Two analysis methods were tested during this study. DISTANCE software uses only first capture information and DENSITY software uses both capture and recapture information. Intuitively an analysis using all the available information would prove more robust; however DISTANCE is the standard, well-regarded analysis method and DENSITY is a new and relatively untested method.

In comparison, estimates obtained from DISTANCE and DENSITY analysis of the NT trapping web surveys were of similar magnitude, generally followed similar trends and provided reasonable and valid estimates of mud crab density. DISTANCE was able to resolve all the NT analyses and DENSITY was capable of resolving all but one NT survey. This failure in analyses was due to the placement of the trapping web too close to the shoreline, resulting in excessive movement of crabs when the tide moved in and out across the mud flats and therefore, extremely low recapture rates. Generally, the estimated crab densities provided by DISTANCE were slightly higher that those from DENSITY.

The estimates of crab density from the Qld trapping web array surveys varied considerably in terms of the analysis method used (DENSITY and DISTANCE) and between years and sites for each method. Part of this variability can be explained by environmental forcing factors that applied differently on the Gulf and East Coasts, and can be interpreted as real changes in the abundance of mud crabs. As noted in the Results Section, there was an obvious downward trend in stream depletion estimates of crab numbers at the Karumba site from 2002 to 2003, but this trend was not shown in the crab numbers at the Trinity Inlet site. The 95% confidence intervals for the Karumba density estimates (Table 36) were wide but did not overlap, which indicated that the decline was statistically significant and that there was also high variability in estimates. The trapping web estimates of crab numbers suffered similar levels of variability and low numbers of replicates; however, the Karumba foreshore data shows the same downward trend as the stream depletions (Table 37) in the same areas. This trend was reflected in both the DENSITY and DISTANCE estimates from the trapping web surveys, although the magnitude of the estimates differed.

A second component of the variability in the trapping web array surveys, particularly in the arrays where DENSITY failed to resolve the analysis (Table 37), was likely due to failure of the underlying assumptions for trapping web analysis. While robust, the method is sensitive to movement of crabs through the web and to very low numbers of animals captured, or a combination of both factors. During the 2002 and 2003 Qld surveys crabs were noted moving to and from the tidal mudflat/foreshore; hence the web sampled only part of this population, present only at a particular stage of the tide. Another source of uncertainty, related to the first two, is the possibility that the area utilised by resident crabs was significantly larger than the trapping web, hence making estimates non-representative of the population or at the very least increasing the range of uncertainty about the estimate. Of the two methods applied to analyse the Qld mud crab trapping web data, the DENSITY method provided better biologically reasonable estimates. DISTANCE estimates appeared to be unacceptably high, given available commercial catch statistics and the level of commercial and recreational fishing effort that is known to be applied to mud crab populations in Karumba and Trinity Inlet (see Tables 41a and 41b).

When relative abundance estimates from the two NT study sites were multiplied up by the estimated area of habitat in each corresponding fishing grid, results confirmed previous assessment findings and followed commercial catch trends. The Gulf of Carpentaria remains the most significant region for the NT mud crab fishery responsible for 77% of the total NT catch in 2003. Comparison of the reported commercial catch to the estimated abundance of mud crabs in 2003 confirmed the high levels of exploitation 70-90% reported by Walters et al. (1996). This study estimated that the Gulf of Carpentaria fishery removed > 93 % of adult mud crabs in 2003. The next most important region, the Adelaide River/Darwin region was responsible for 14% of the NT total catch in 2003 and the remaining catch is reported from the from the Arnhem and Cobourg /Mini Mini regions. Removals of around 19-23 % were estimated for the Adelaide River/Darwin region in 2003 and no estimates were attempted for the remaining regions as catch data remains confidential.

The two NT study areas demonstrated differences in abundance patterns between habitat types. Over the two-year study period, the majority of crabs caught at the Adelaide River study site (89%) were captured within the creek habitat. This could be the result of high tidal movement in this area, encouraging crabs to seek refuge in sheltered creeks. This pattern was not evident for the GOC, where tidal range is considerably smaller and similar patterns in abundance were observed in both the Gulf creeks (48%) and Gulf foreshore flat (52%) habitats. A similar difference in habitat preference by gender was evident for both study sites. Male mud crabs dominated the creek catches at both the Adelaide (63% male) and Gulf (73% male) River sites. At the two foreshore sites, females dominated the catch contributing 62% of the Adelaide River foreshore catch and 68% of the total Gulf catch.

When abundance estimates from the two Qld study sites were multiplied by the corresponding area of habitat, it was estimated that around 25% adult (male only) crabs were removed from the Karumba fishery in 2003. At the Trinity Inlet site, it was estimated that around 3-8% of adult crabs were removed in 2003. These figures do not take into account the recreational harvest, which in Qld is thought to at least equal the commercial harvest and this would effectively double the removal estimates.

In conclusion, when estimated abundance from each study site was extrapolated across each State's entire fishery the estimates appear to be unrealistically high, when compared with the reported commercial catch from each region. While it appears reasonable to extrapolate abundance estimates up to adjacent local regions some caution needs to be applied when interpreting the extrapolated results over broader spatial scales. Tagging studies were conducted at only two sites in each State and where these results have been applied across other regions, it is very likely that the actual carrying capacity may differ from the sites examined in each State. Also the presence of habitat deemed suitable for mud crabs may not necessarily indicate that mud crabs are present, as each location may have its own mud crab "carrying capacity", dependent on micro-habitat factors that are not captured by broad scale habitat mapping. Improving the uncertainty around estimates for regions not surveyed during this study can be achieved by undertaking additional surveys in areas of key interest.

6.1 Benefits and Adoption

The method utilised for assessing coastal wetlands at a regional scale has proven to be cost effective and highly accurate (approximately 90%). The use of Landsat ETM+ gives the ability to select imagery captured at specific times (e.g. ideally during the dry season at low tide). The complete coverage of imagery reduces the amount of field data required for accurate mapping. The digital map product output is easily integrated with other data in a GIS and analysed with accurate quantitative assessments.
The creation of a set of decision support rules to interpret the digital classification of the satellite imagery using aerial photography and field data enables the method to be used by other operators (e.g. Bruinsma 2001 and Danaher 1995a), and to be applied to other locations.

In Qld the tidal coastal wetlands dataset has benefited coastal planning and management through the provision of comprehensive coastal wetland information. The dataset provides a baseline for future monitoring and in facilitating further research into the interactions between fauna and habitat (including this project). With the aid of the Qld Fisheries Service's online Coastal Habitat Resources Information System (CHRISweb, http://chrisweb.dpi.qld.gov.au/chris), researchers can now view the distribution of coastal wetland habitat types and link this to fish catch data to explore fish/habitat interactions.

Additionally, the dataset has been applied to the protection of representative coastal wetland habitats throughout Qld through the spatial analysis of the digital dataset with respect to the Interim Marine and Coastal Regionalisation for Australia: a national classification for marine and coastal environments (IMCRA Technical Group 1998) and the network of Fish Habitat Areas (a form of Marine Protected Area) (de Vries et al. 2002).

Similar applications of the NT dataset to natural resource and coastal management are now possible, with the added advantage of a compatible dataset being available for Qld. The identification and quantification of coastal habitats in the NT will benefit a broad range of northern Australian inshore fisheries, including mud crab. It will also provide a baseline dataset for broader application across a variety of natural resource management issues. As in Qld, critical habitat identification will provide valuable input for future decision making and planning processes such as the development of Marine Protected Areas.

This method of assessing mud crab abundance provides an additional tool for fishery assessment, particularly as in this case, when a component of the catch and effort data cannot be validated. High levels of unreported effort in the NT hamper effective evaluation of fishing activity and the additional information gained from this work has proved important in the most recent assessment of the fishery. An additional and important benefit to be gained from the intensive tagging studies undertaken during this project are better understanding of the mud crab's population dynamics and improved estimates of various parameters used for fishery assessment such as growth, recruitment, and selectivity.

The methods developed from the research described in this document would be particularly useful in some of the regions where little fishing activity has been reported and where elevated levels of crab abundance were predicted. This would benefit fishery stakeholders, particularly commercial operators, who have suffered declining returns over the past two years, in providing key information regarding the potential for any future development in this fishery.

All of the components of this work are also transferable to other fisheries and jurisdictions. For example, southern rock lobster scientists from TAFI are currently testing trapping web methods.

6.2 Further Development

Further studies to examine the linkages between habitat and its influence on mud crab abundance at a finer scale would enhance and build on the outcomes of this project. For example, estimates may be improved by gaining an understanding of micro-scale habitat and environmental interactions, such as the influence of tidal amplitude on substrate structure. The dynamic structure of the tidal wetlands GIS permits the addition of new datasets, as they become available. This is one of the real strengths of a GIS, in not being a static entity and allowing additional layers to be added and updated.

The delivery of the Qld habitat mapping dataset into a web-based application has proved extremely successful. The Coastal Habitat Resources Information System (CHRIS) is a resource centre for Qld coastal fish habitat, fisheries resources and environmental datasets (layers) developed by QDPI&F and other agencies. CHRIS web can be accessed through the QDPI&F website (http://chrisweb.dpi.qld.gov.au/chris/ and provides an excellent means of extending the product to the general public and fishery stakeholders. A recommended further development for this project would be to mirror the CHRIS web site adding the NT tidal wetland dataset and perhaps additional catch and effort datasets to a web based application accessed through the DBIRD website.

The uncertainty surrounding the relatively unfished regions of the NT and Qld and the high-predicted catches for some of these regions requires additional investigation. It is reasonable to assume that the scale at which estimates were extrapolated across these regions introduces some error and localised surveys at key sites of interest would assist in clarifying this problem.

6.3 Planned Outcomes

The completion of Objective 1 of this project has resulted in the compilation of a GIS. This is available in CD format for ease of distribution. It was planned that the identification and quantification of marine and coastal habitat types from satellite imagery and interpretation of aerial photography would benefit a broad range of northern Australian inshore fisheries, including mud crab and provide baseline data for broader application across a variety of natural resource management issues. For example, critical habitat identification will be invaluable in the development of any MPAs with a view to protecting juvenile mud crab and other species nursery areas as well as areas of high productivity.

The completion and release of the GIS of coastal NT and Qld wetlands provides the necessary baseline datasets to fulfil this outcome.

Secondly, methodology was developed to estimate mud crab abundance. In planning this component of the project we identified the planned outcome would be that “assessments and management of Australia's mud crab fisheries would be based on an understanding of annual stock size by region. Provision of information such as this, which is of a predictive nature, is far more useful for management purposes than logbook (CPUE) data alone. As such, we anticipate that this assessment technique will provide a means to increase the value of CPUE data, setting up a benchmarking process which will ultimately assist in making informed management decisions.”

Results of the work undertaken during this project indicate very high levels of fishing mortality for the NT GOC, confirming the most recent assessment that fishing mortality for mud crab in the NT is too high and that the fishery is under duress. Negotiations regarding changes to the NT mud crab management arrangements are under way.

7. Conclusion

The mapping of coastal wetland habitats using remote sensing techniques has provided a complete broad-scale coverage of coastal wetlands in the NT and Qld and is a significant achievement. This mapping exercise has been extremely cost effective with a high degree of reliability. The GIS will prove to be an important resource for coastal and natural resource management issues.

The development of methods to estimate mud crab abundance across two habitat types provides the first broad scale estimates of mud crab stock size in northern Australia. The tagging study designs developed during this research and the analyses methods outlined in this document provide biologically reasonable estimates of local mud crab abundance. Study site selection and an understanding of animal movement patterns are two important factors for consideration when planning mud crab abundance surveys. For areas that have no recorded mud crab catch history additional targeted surveys would reduce uncertainty surrounding the extrapolation of the density estimates.

The method also grants the opportunity to extract additional and important information from the intensive tagging studies. Such data can provide better understanding of the population dynamics of the species of interest through the attainment of improved estimates of parameters required for fishery assessment, such as growth, recruitment, and selectivity.

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Appendix 1. Acknowledgements

NORTHERN TERRITORY

This work could not have taken place without the support of the FRDC and the NT and Qld Fisheries agencies.

We recognise and thank the commercial fishers who allowed NT and Qld Fisheries staff to invade their fishing grounds and camps. Carrying out this scale of work in remote locations requires a real community spirit and we thank all those from the crabbers camps at Manangoora Station and the Adelaide River particularly for their good advice and assistance over the past nine years. This assistance includes numerous good stories and rescues from bogs, fogs, mud flats, break downs, bush welding , boats misbehaving, BBQ's in the rain and generally waiting around for the tide.

A big thank you to the legendary NT mud crab fishery icons and characters such as the Wearyan mob: Roy James Wright, Roy James Junior, the late Lloyd Wright, Jason Khan, Neil and Yvonne Bradley, Alan, Anne and Shane Sluggett, and from the Adelaide River crew Mike Fraser, Nigel Fraser, Lloyd Beck and David and Chou Tran, not to mention all the Cambodian and Vietnamese crabbers spread throughout the Gulf of Carpentaria who will not allow us to leave their camps without sampling multitudes of great food and good cheer.

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Wayne Dries	Kate Seidel
Chris Errity	Richard Sellers
Paul Exley	Steve Sly
Bill Flaherty	Nick Spanswick
Steve Gibson	Monica Thompson
Darren Grigg	Jeanne Vorsatz
Chris Ham	

QUEENSLAND HABITAT MAPPING

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QUEENSLAND ABUNDANCE ESTIMATION

The Qld component of the project would not have been possible without the assistance of the many commercial, recreational, charter fishers and tackle shops who provided information and feedback from the tagging program.

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Finally, many thanks to Ash and Cheryl Colahan from ‘Ash’s Cabins’ in Karumba for putting us up in their accommodation and for the use of their facilities including freezers for our countless cartons of bait.

Appendix 2. Full Metadata Listing

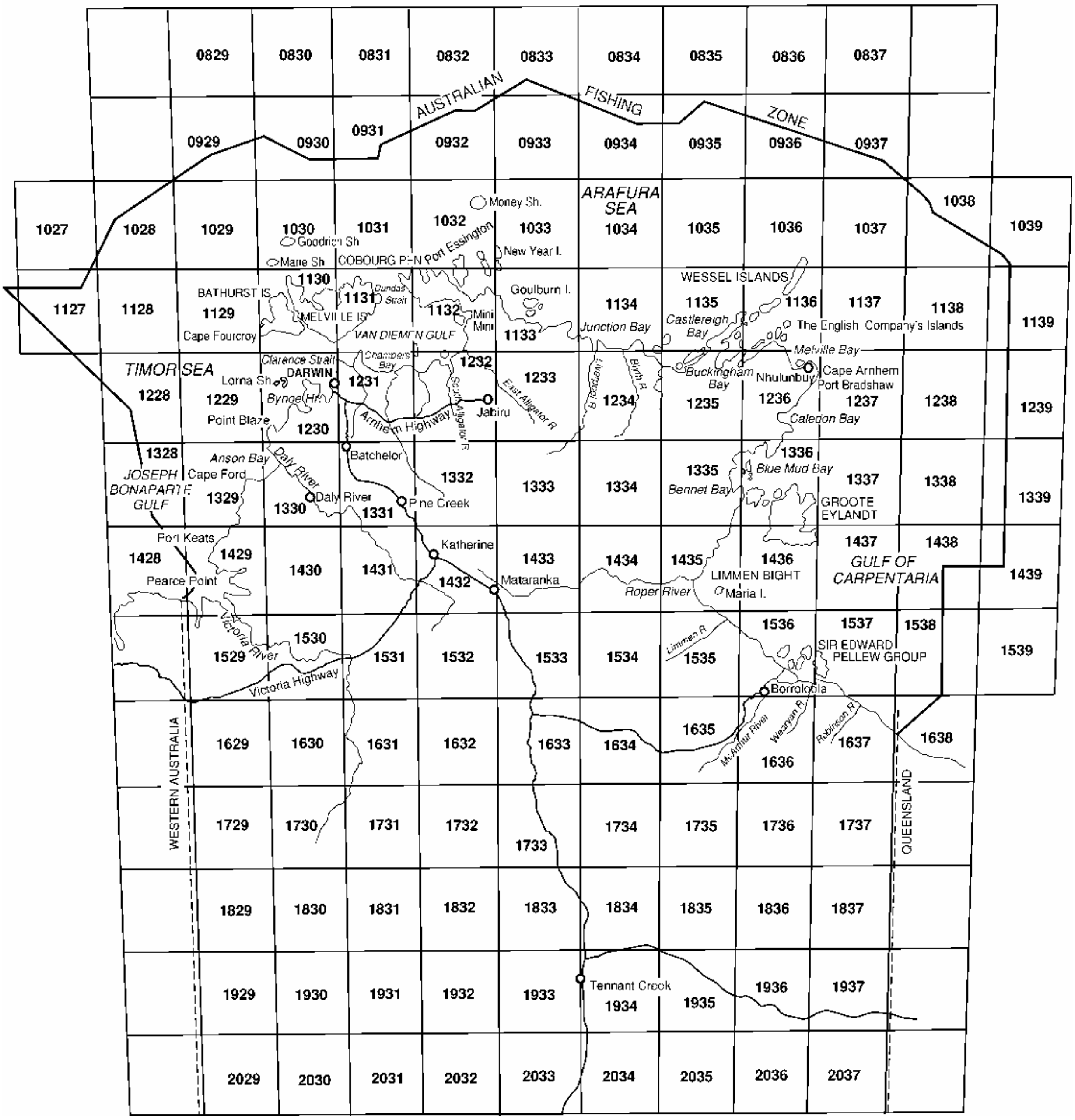
NT Coastal Wetlands.

Category		Dataset details
	Title	NT Coastal Wetlands
	Legal Owner	State of Qld through Department of Primary Industries
	Custodian	Qld Fisheries Service - Assessment and Monitoring Unit
	Jurisdiction	Australia
Description	Abstract	A coastal wetland community classification produced as the first phase of the FRDC funded project, Methods for monitoring the abundance and habitat of the northern Australian mud crab, Scylla serrata. The Landsat ETM+ derived classification includes mangroves and salt marsh communities.
	Search Word(s)	Mangroves, salt marshes, Remote Sensing, Habitat
	Geographic Extent Name(s)	NT Coast
	Geographic Extent Polygon	129 -17, 138 -17, 138 -11, 129 -11
	Coordinates	North:-11 South:-17 East:138 West:129
	Beginning date	1 February 2001
	Ending date	2 August 2002
Dataset Status	Progress	Complete
	Maintenance and update frequency	Not planned
Access	Stored Data Format	DIGITAL - ARC/INFO Export (.e00), DIGITAL - ARC/INFO
	Available Format Type	DIGITAL - ARC/INFO, DIGITAL - ARC/INFO Export (.e00)
	Access Constraint	QFS data - release outside QFS on completion of a data agreement
Data Quality	Lineage	Landsat ETM+ imagery processed using unsupervised classification procedure. Classes labelled with 1: 50 000 aerial photography. See report for further details including Landsat ETM+ and aerial photography details. The "Landsat Source Data" field indicated the base imagery processed to produce mapping in that area.
	Positional Accuracy	Base data Landsat ETM+ imagery. Problems with the positional accuracy of Landsat imagery at the Zone 52/53 boundary and the WA border required that mapping be registered to NT coastline data.
	Attribute Accuracy	Various. Reliability field indicates the reliability of the attribute assigned based on the level of ground truth data available. A - highest reliability, B - high reliability, C average reliability, D - reliability unknown, further ground truthing required. See report for more details.
	Logical Consistency	As no evidence to the contrary has been ascertained, it is considered that this dataset is logically consistent.
	Completeness	The dataset is complete.
Contact Information	Contact Organisation	Qld Fisheries Service - Assessment and Monitoring Unit
	Contact Position	Remote Sensing Officer
	Mail Address	Level 2 80 Ann Street
	Locality	Brisbane
	State	Qld
	Country	Australia
	Postcode	4001
	Telephone	07 3224 8112
	Facsimile	07 3224 2805
	Electronic Mail	fishdatacoordinator@dpi.qld.gov.au
Other	Scale	1: 100 000

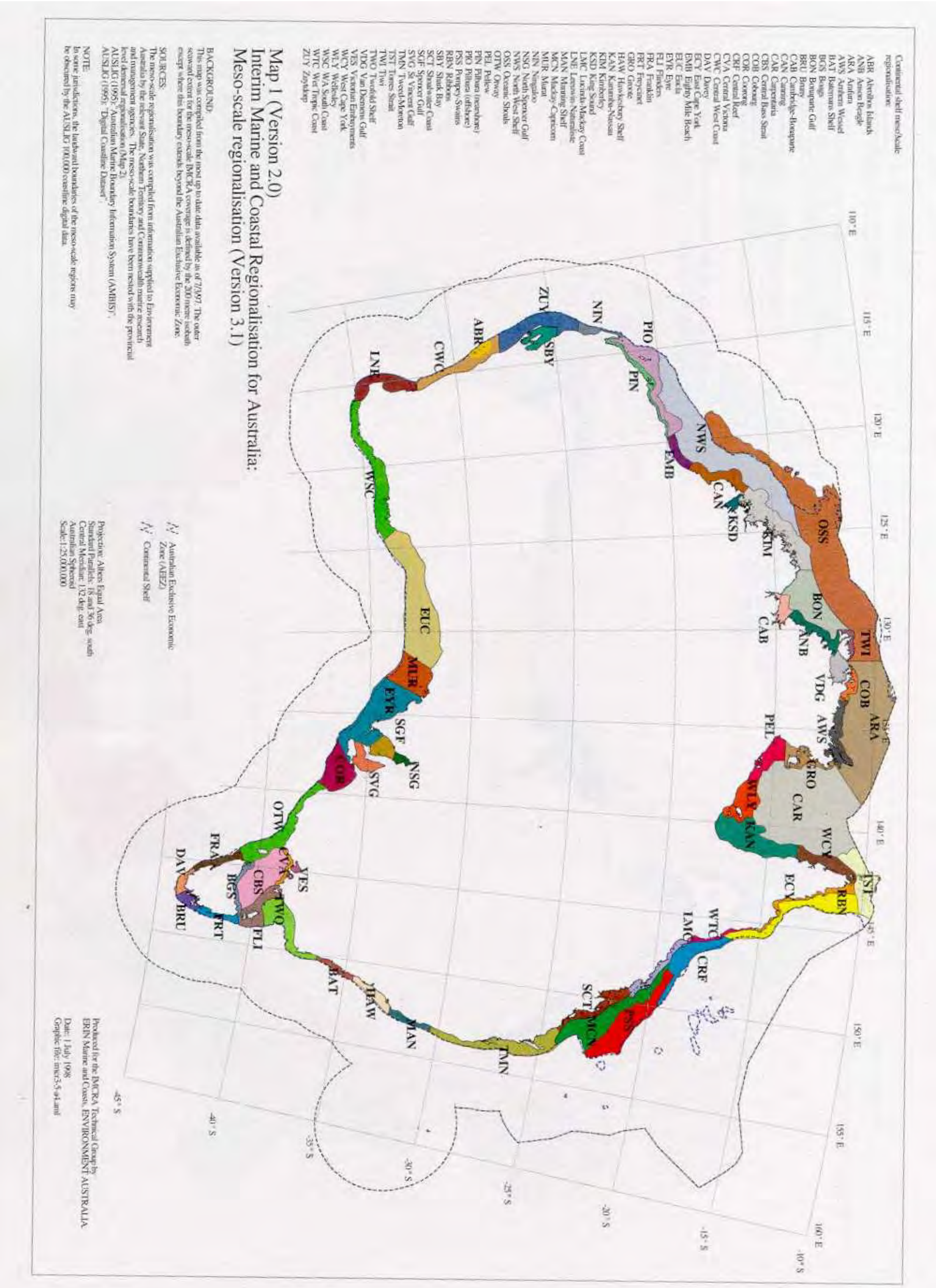
Documentation	Reference	de Vries, C., Danaher, K. and Dunning, M.C. (2002) Methods for monitoring the abundance and habitat of northern Australian mud crab, Scylla serrata. Milestone report. Objective 1: Habitat mapping. Report to the NT DBIRD and FRDC. Department of Primary Industries, Brisbane.

Appendix 3. Northern Territory Reference Fishing Grid

NORTHERN TERRITORY OF AUSTRALIA – FISHING GRIDS REFERENCE



Appendix 4. IMCRA (1998) Meso-scale Regionalisation of Northern Australia



Appendix 5. Northern Territory and Queensland Mud Crab Fishery Bycatch

Northern Australia Mud Crab Fishery Bycatch Summaries

Northern Territory

In the NT the crab pot design used by commercial and most recreational crabbers is highly selective towards legal size mud crabs (Figure 21). This is primarily due to the large mesh size used in the pots construction (75 x 25 mm wire mesh). NT Fisheries has constructed research crab pots (Figure 29) using a much finer mesh size (25 x 25 mm) so that information on undersize mud crab population may also be collected. In the NT study described in this document both pot types were used and we hereby present our results on catch other than mud crabs during this study.

Over the course of the two-year study a total of 10416 potlifts were observed using the two pot types. No observations of interactions between the fishing gear and protected species were made during this study.

Commercial pots caught a total of 14 species. A total of 277 individual fish and crustacean species were captured in commercial pots over the 21 fishery independent sampling trips during 2002-2003.

Estuary cod *Epinephelus coioides* were the dominant species at 30% of the total commercial pot bycatch, with sandcrab *Portunus pelagicus* 25%, catfish *Arius* sp 13% and silver bream *Acanthopagrus berda* 13% contributing to the rest of the by-catch.

As would be expected, the finer mesh research pot was more selective than the commercial pots, providing little opportunity for escape. A total of 25 species were collected from the research pots with 12 species recording less than 10 individuals. Research pots recorded around 10 times the bycatch caught from commercial pots. In all 2801 individual fish and crustacean species were captured in research pots over the 21 fishery independent sampling trips during 2002-2003.

Puffer fish *Marilyna darwinii* were the dominant species, accounting for 33% of the total bycatch for research pots. The remainder of the bycatch was made up of catfish *Arius* sp. 19%, sandcrabs *Portunus pelagicus* 17%, hermit crabs *Paguristes* sp. 15% and cod *Epinephelus* sp. 6%.

The total number of fish and crustaceans captured by pot type during the study is presented in Table 44. CPUE data for both regions confirms the effectiveness of the commercial pots in permitting bycatch to escape. Comparison of each gear types CPUE shows the Adelaide River study site has a greater abundance of bycatch species.

Table 44. Observed bycatch from research and commercial crab pots reported in numbers caught at study sites near the Adelaide and Wearyan Rivers in 2002 and 2003

		Research pot					Commercial pot				
Adelaide		potlifts	Total N	live	dead	CPUE N/potlift	potlifts	Total N	live	dead	CPUE N/potlift
fish	2002	2520	1176	1040	136	0.47	840	65	53	12	0.08
	2003	1590	598	444	154	0.38	460	32	23	9	0.02
crustacean	2002	2520	407	400	7	0.16	840	525	522	3	0.21
	2003	1590	48	48	0	0.02	460	34	34	0	0.01
GOC											
fish	2002	790	195	187	8	0.25	2370	99	95	4	0.1
	2003	610	146	142	4	0.18	1620	11	8	3	0.0
crustacean	2002	790	4	4	0	0.01	2370	0	0	0	0.0
	2003	610	6	6	0	0.01	1620	0	0	0	0.0

Queensland Bycatch Summary

Sand crabs, *P. pelagicus* were by far the most dominant single bycatch species during the 2002 surveys. However, the high numbers were only apparent in significant numbers on the two foreshore sites in Trinity Inlet. Due to such large numbers of sand crabs being found only on the two foreshore sites, they have been omitted so as not to skew the results. Despite the large bycatch of sand crabs, the mortality rate was extremely low. Mortality rates showed only 27 of the 752 individuals caught during 2002 died due to agonistic interactions and only 25 died of the 463 caught during 2003.

Excluding the sand crabs, the 2002 bycatch was dominated by fish species including toadfish, catfish, cod and bream, and a limited number of crustacean species, primarily hermit crabs (Table 45).

On two occasions during initial pilot studies at the Bizant River, Princess Charlotte Bay, interactions with what were suspected to be large turtles (species unknown) were observed It is assumed that they were preying on both the bait and the captured mud crabs in the pots. .Pots were bent out of shape and the entrances and bait bags in most cases were torn open with no bait or crabs remaining. In all over 30 crab pots were destroyed and this study site was abandoned.

Table 45. Bycatch from research mud crab surveys 2002 (excluding sand crabs)

Location	**Site**	**Total pot lifts**	**Fish Species**		**Crustacean Species**	
			Total caught (dead)	CPUE catch/pot lift	Total caught (dead)	CPUE catch/pot lift
Karumba	Six Mile Ck	900	323 (11)	0.36		
	The Oaks	400	73 (8)	0.18	1 (0)	0.003
Princess Charlotte Bay	Bizant River	300	64 (1)	0.21	1 (0)	0.003
Trinity Inlet	Crowleys Ck	600	17 (0)	0.03	5 (0)	0.008
	Rolling Bay	440	62 (4)	0.14	122 (0)	0.28
	Wah Day Ck	300	48 (3)	0.16	2 (0)	0.007
	Esplanade	200	5 (1)	0.03		
Total For all Sites		3140	592 (28)	0.19	131 (0)	0.04

Bycatch during the 2003 surveys, apart from sand crabs, was again dominated by fish species with catfish being the most predominant followed by toadfish, cod and bream. The total number of crustacean species caught during the 2003 surveys was slightly higher than 2002 with stone crabs being the most prominent in the estuaries and hermit crabs being the most common on foreshore sites (Table 46).

Table 46 - Bycatch from research mud crab surveys 2003 (excluding sandcrabs)

Location	**Site**	**Total pot lifts**	**Fish Species**		**Crustacean Species**	
			Total caught (dead)	CPUE catch/pot lift	Total caught (dead)	CPUE catch/pot lift
Karumba	Six Mile Ck	900	246 (25)	0.27	6 (1)	0.007
	The Oaks	600	38 (9)	0.06	2 (0)	0.003
Trinity Inlet	Wah Day Ck	600	56 (0)	0.09	49 (0)	0.08
	Redbank2 Ck	300	25 (0)	0.08	53 (0)	0.18
	Rolling Bay	400	36 (7)	0.09	43 (0)	0.011
	Esplanade	200	3 (0)	0.02	7 (0)	0.04
Total For all Sites		3000	404 (41)	0.14	160 (1)	0.05

Figures 45 and 46. A 126 cm barramundi (*Lates calcarifer*), which was released alive after becoming caught in the exterior framework of the crab pot, Karumba, and a large Pike eel, which was released alive after being caught in a crab pot on the Rolling Bay foreshore - Trinity Inlet, Cairns

Appendix 6. Northern Territory Mud Crab Fishery Training Manual

Sampling Procedures

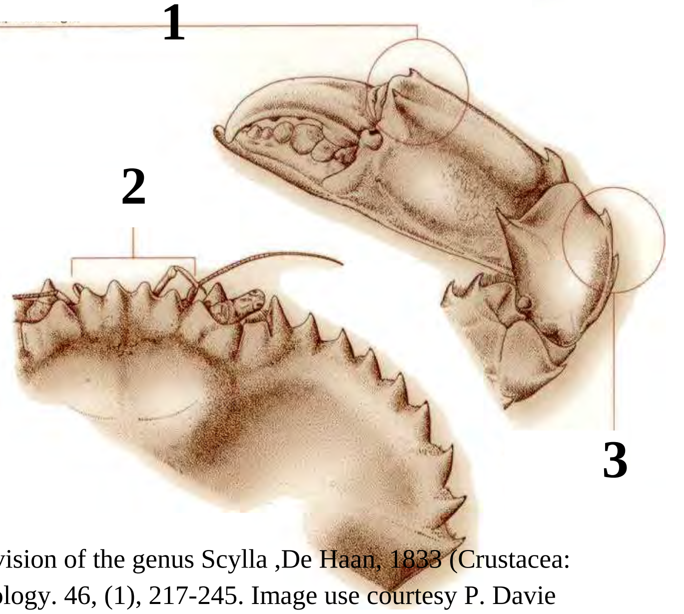
Mud Crab Research Unit
NT Fisheries Group

Northern Territory Government
Department of Business, Industry and Resource Development

MUD CRAB

The mud crabs of the genus *Syclla* occur throughout northern Australia. Commonly known as 'mud crabs' they are the largest crab species found in mangrove forests and adjacent habitats. There are now four recognised species in the genus *Scylla*: at least two of which are known to inhabit NT and Qld waters. *S. serrata* is the most abundant species, while *S. olivacea* is less frequently encountered. When sampling mud crabs the presence of species other than *S. serrata* is always noted in the comments section of the datasheet.

INDENTIFICATION



Scylla serrata

Distinguishing features

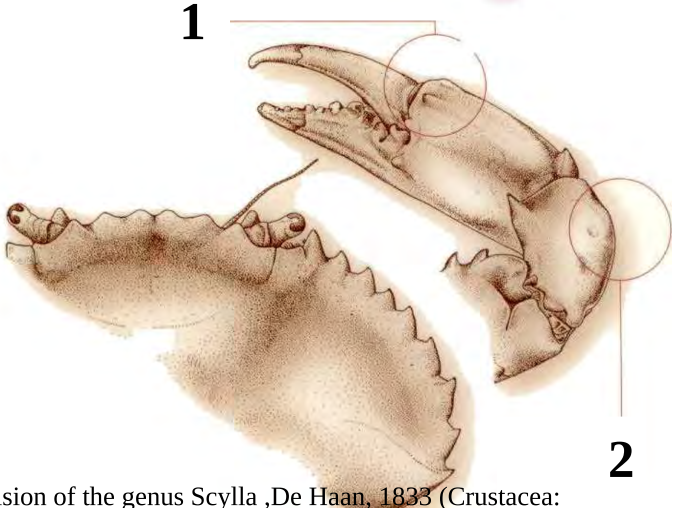
1. Spines distinct

2. High, rounded lobes

3. Spines prominent

Ref:. Keenan, C. P., Davie, P., and Mann, D. (1998). A revision of the genus Scylla ,De Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). Raffles Bulletin of Zoology. 46, (1), 217-245. Image use courtesy P. Davie Qld Museum

Scylla olivacea



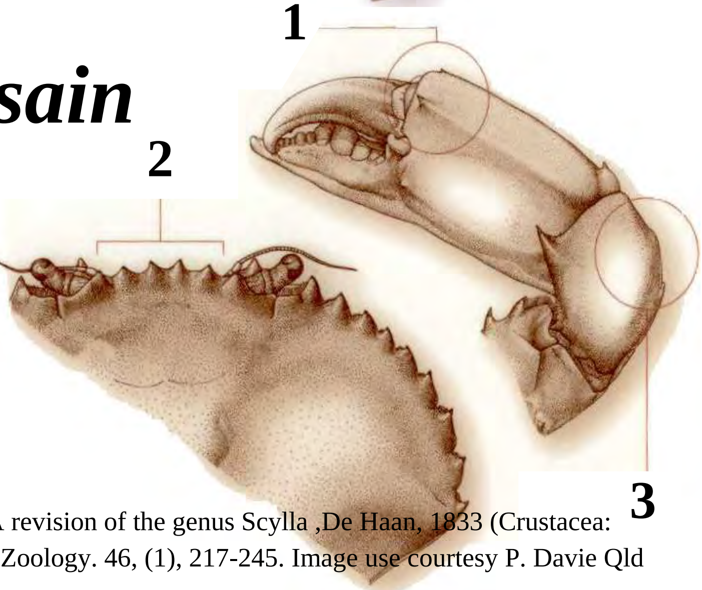
Distinguishing features

1. Spines reduced and blunt

2. Both spines absent

Ref:. Keenan, C. P., Davie, P., and Mann, D. (1998). A revision of the genus Scylla ,De Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). Raffles Bulletin of Zoology. 46, (1), 217-245. Image use courtesy P. Davie Qld Museum

Scylla paramamosain



Identifying features

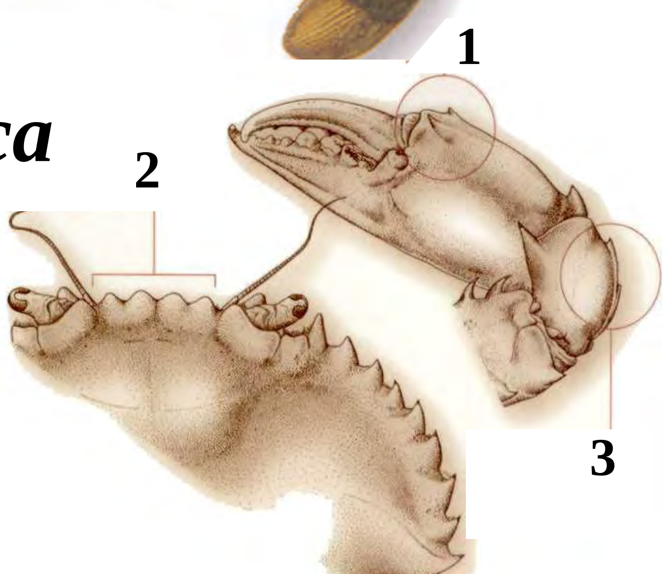
1. Moderate, sharp spines

2. High, pointed lobes

3. Spines absent or very reduced

Ref:. Keenan, C. P., Davie, P., and Mann, D. (1998). A revision of the genus Scylla ,De Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). Raffles Bulletin of Zoology. 46, (1), 217-245. Image use courtesy P. Davie Qld Museum

Scylla tranquebarica



Distinguishing features

1. Spines large and distinct

2. High, broad, blunt lobes

3. Both spines prominent

Ref:. Keenan, C. P., Davie, P., and Mann, D. (1998). A revision of the genus Scylla ,De Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). Raffles Bulletin of Zoology. 46, (1), 217-245. Image use courtesy P. Davie Qld Museum

SAMPLING

Mud crab tagging has been collected in the same format by the Northern Territory's Fisheries Division since 1996, and it is extremely important that the dataset maintains its integrity. The text below follows the format of the datasheets adopted in tagging programs and density estimation experiments (see Appendix 1). Please note that the monthly commercial catch monitoring program follows a different format.

While there can be no hard and fast rules when categorising animals, as there will always be exceptions, this guide is to be followed as far as possible for the purpose of achieving consistency. When in doubt – ask the most senior staff member.

MUD CRABS

Sex

Categories	M: Male
	F: Female
	U: Unknown

The sex of the mud crabs is determined principally by the dimorphism of the abdominal flap (see Figures 1 to 3); though secondary indicators are also useful.

The abdominal flap of the male is comparatively narrow and its colour is consistent with the surrounding sternum, whereas the abdominal flap of female crabs are broad and become increasingly pigmented as the size of the crab increases.

Figures 1 and 2: Ventral view of the abdominal flap and sternum plates of an adult male (above) and adult female (below) mud crab

Figure 3 : Ventral view of a juvenile female mud crab

The chelea (claws) of male crabs are also distinctly larger in proportion to their carapace width in morphologically mature males. Juvenile females also lack the feather-like edging of the abdominal flap that is present in female adults.

The sex of the mud crabs can be difficult to determine in small juveniles and in some specimens infected with *Loxothylacus ihlei*. This parasite may induce feminisation of males, which may be evidenced by a relatively broader abdominal flap.

Shell Index

Categories 1: Post moult

2: Early inter-moult

3: Late inter-moult

Shell index is evaluated by pressing set points on the carapace. The degree of flex primarily determines the category, though other indicators, i.e. wear of the carapace and the presence of adhering epizoites, are equally important.

Test points are located on both the dorsal and ventral sides of the crab and differ between male and females (see Figures 4 to 6). Be aware that the points on the sternum are easily reached by the claws of an unrestrained crab

Figure 4: The dorsal test point of a mud crab

Figure 5: Testing the upper sternum plates of a female mud crab

Figure 6: Testing the second sternum plate of a male mud crab

Upon moulting the exoskeleton of a mud crab is very soft and extremely flexible (see Figure 7). The exoskelton hardens rapidly though remains soft for some days. Post moult crabs (category 1) are relatively light, flex at the test points with little pressure applied and have carapaces that are typically unmarked and clean (see Figure 8).

Figure 7: A moulting female mud crab

Early intermoult crabs (category 2) retain some flex at the test points, may have anemones attached to the carapace but are generally free of sizeable bivalves and barnacles. The dactyls (tips of the walking legs) and chelea may display some slight marking and wear of the dentition between the claws.


Figures 8 and 9: Claws of category one (left) and category three (right) crabs

Late intermoult crabs (category 3) are generally rigid at the test points, though females may flex at the dorsal points. The carapace typically displays old marks and significant wear of the chela dentition between the claws (see Figure 9).

The presences of adhering epizoites may also help define late intermoult crabs. Anemones commonly encountered in NT waters can grow quickly on a carapace and may attain a diameter exceeding 1 cm in less than a week. Sizeable barnacles and bivalves are however indicative of a more distant settlement and therefore an older carapace.

Occasionally some late intermoult crabs may have some flex at the test points possibly resulting from fractures in the carapace. However, these crabs are easily distinguished by the weight of the crabs and the general wear of the carapace.

Growth phase

Categories

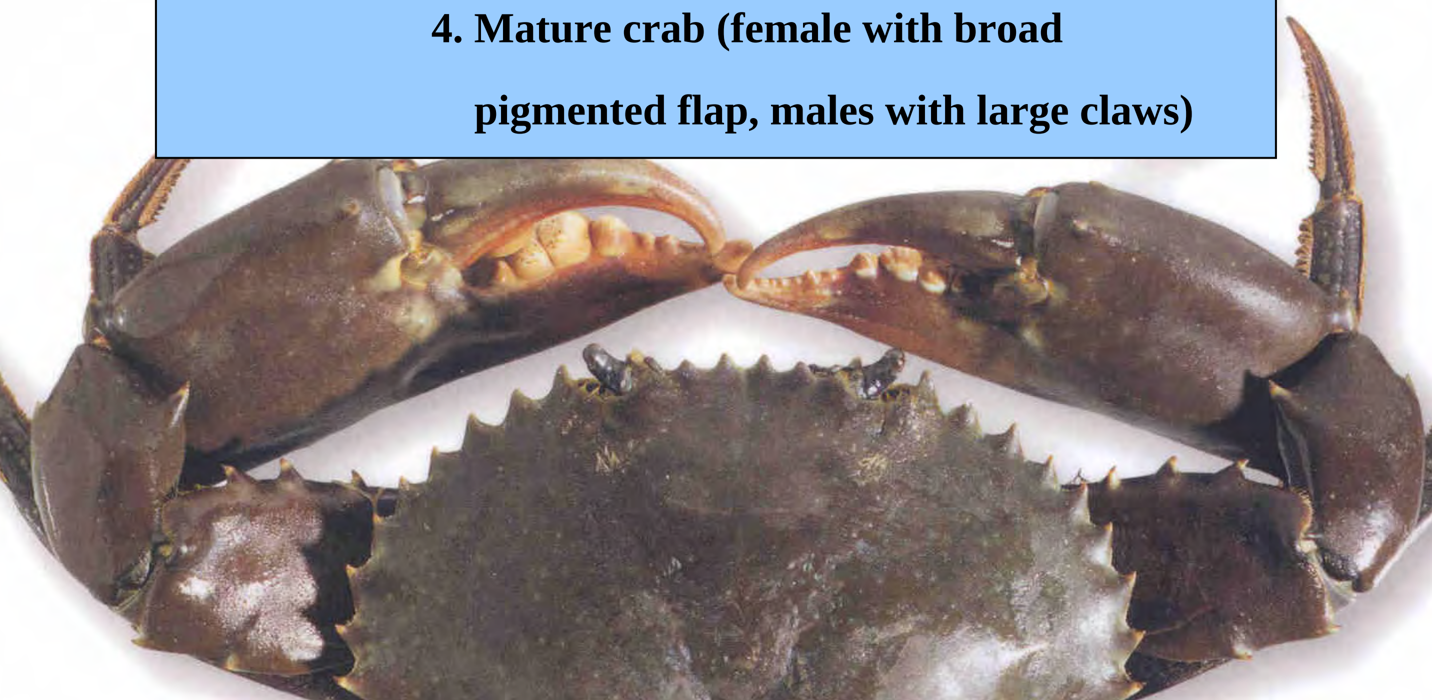
0. Cannot be determined due to parasite

1. Immature crab less than 50 mm CW

2. Immature crab less than 100 mm CW

3. Immature crab general equal to and greater than 100 mm CW

4. Mature crab (female with broad pigmented flap, males with large claws)



Parasitism by *Loxothylacus ihlei* may inhibit moulting and can stunt the growth of mud crabs; and all infected mud crabs are recorded as category 0. Category 1 to 3 are immature crabs sorted by their carapace width. Category 4 crabs are not determined by size but rather indicate that the crab is morphologically mature.

In mature male mud crabs the chelea are distinctly larger in proportion to their carapace width (see Figure 6), and the crab may possess mating scars (see Figure 14). In mature females the abdominal flap is broad and darkly pigmented in contrast to the to the sternum (see Figure 2).

Another indicator of maturity in females is the presence of feather-like edging along the periphery of the abdominal flap. This is not present in juvenile females, and their flap is 'locked' to the sternum and hence cannot be opened.

Carapace Width

Figure 10: Measurement of carapace width

Categories:

Measured in mm

Width across the widest part of the carapace to the last full mm (see Figure 10). This is taken from the set of 9th antero-lateral spines (counted from the eyestalks) along the edge of the serrated carapace. If the carapace is damaged an estimate is required. It must be noted in the comments section that an ‘estimate’ was taken.

Damage Index

Categories:	**+1. right claw missing**	**-1. left claw missing**
	+2. right first leg missing	**-2. left first leg missing**
	+3. right second leg missing	**-3. left second leg missing**
	+4. right third leg missing	**-4. left third leg missing**
	+5. right swimmer missing	**-5. left swimmer missing**

The damage index records only the absence of appendages (see Figure 10). Broken appendages, regeneration of the limbs, and damage outside of these categories should be recorded in the comments section of the datasheet.

Figure 11: A male mud crab with -1, +1, +2, and +5 damage.

Old damage is recorded as 'existing damage' whereas new damage is recorded as 'handling damage' in order to provide an indication of the state of the crabs upon capture. Mud crabs possess the instinctive habit known as autotomy - that is the automatic throwing off of the appendages. The chelae, especially are sacrificed by the crab for a safe escape.

Loxothylacus ihlei index

Ref: Knuckey, I. A., Davie, P. J. F., and Cannon, L. R. G. (1995). *Loxothylacus ihlei* Boschma (Rhizocephala) and its effects on the mud crab, *Scylla serrata*(Forskal), in northern Australia. *Journal of Fish Diseases*. **18**, 389-395.

Categories	**I: Crab infected - no externae or scar present**
	E: Crab infected – externae present
	S: Crab infected – no externae, scar present

Infected crabs with *Loxothylacus ihlei* are categorised through the close examination of the cavity enclosed by the abdominal flap. Unrestrained crabs vigilantly defend this area of their body so due caution is required. *Loxothylacus ihlei* may induce feminisation of males resulting in a relatively broader abdominal flap (see Figure 12). Parasitism may also inhibit moulting resulting in a stunted growth of males and females.

Figure 12: Feminisation of a male mud crab

The abdominal flap of a crab with externae present may be notably raised by varying degrees (see Figure 13) and the externae may be readily observed by raising the abdominal flap (See Figure 14). Other infected crabs require the careful examination for the presence or absence of a scar that results from the former presence of the externae. Their abdominal flap will not be locked.

Figures 13 and 14: Mud crab infected with *Loxothylacus ihlei*. Note the raised abdominal flap (above) indicating infection with the parasite (below)

Mating scars

Ref: Knuckey, I. A. (1996). Maturity in male mud crabs, *Scylla serrata*, and the use of mating scars as a functional indicator. *Journal of Crustacean Biology*. **16**, (3), 487-495.

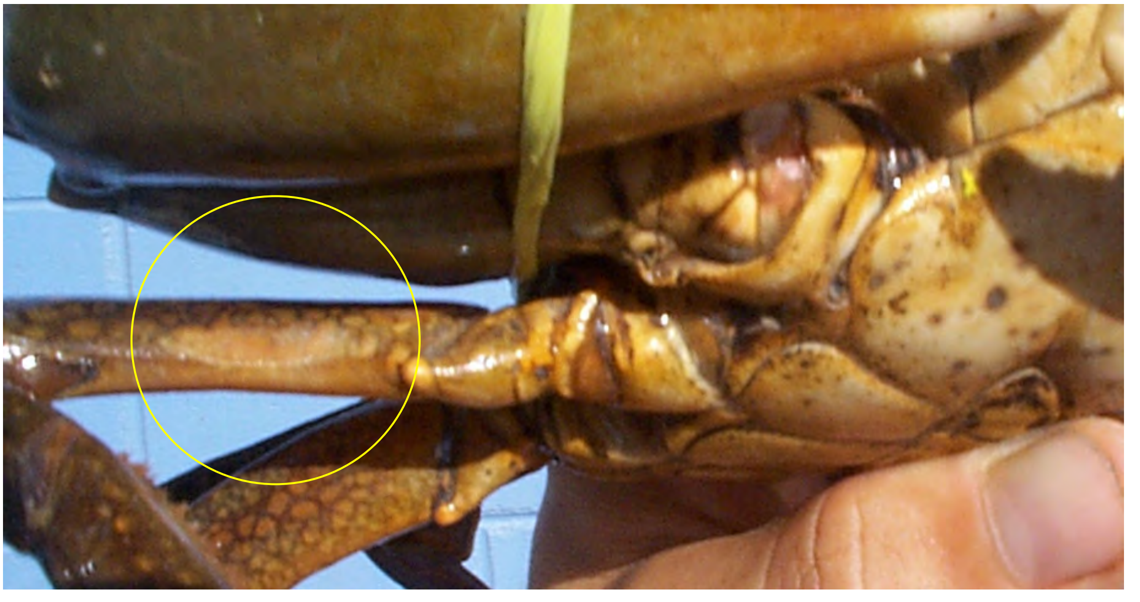
Categories:

1. **Marks on the chest and legs appear new and are transparent/ weeping**
2. **Marks on the chest appear very black**
3. **Marks appear yellowish brown , look very old and faint**

Male mud crabs may possess mating scars only on attainment of functional maturity, i.e. ability to mate successfully. Scars on the sternum or forward walking legs are produced by abrasion with the female during the pre and post-copulatory embrace (see Figures 15 and 16) This results in temporary scars on the two forward walking legs (see Figure 17) and the centre of the sternum (see Figure 18).

Figures 15 and 16: Mud crabs in a copulatory embrace leading to the presence of black spot

Category 1 crabs have 'raw' scars that are pale to almost clear in colour (see Figure 18). This is followed by a phase (category 2) in which the scars become very dark brown or black and obvious in appearance (see Figure 18). Following this the scars continually fade (category 3), turning brown and increasing lighting in colour (see Figure 20).



Figures 17 and 18: Mating scars on the forward walking leg (above) and category one scars on the sternum (below).

Figures 19 and 20: Category two black spot (above) and category three black spot (below).

Figure 21: Tagging

The tags are inserted at the posterior end of the crab between the dorsal carapace plate and the top of the abdominal flap. It is important that the tag gun needle is inserted only 1-1.5 cm, and that the tag is inserted off the centre line in order to avoid internal damage. When inserting the tag gun needle a slightly upward angle is to be adopted although the tip of the needle does not scrap along the inside of the carapace (which may damage the next carapace of the next moult). The lever on the handle of the tag gun should be squeezed and released in a smooth action. At all times the crab should be held steady and with due caution.