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Torres Strait Hand Collectables, 2009 survey: Trochus

Wealth from Oceans Flagship

FINAL REPORT
March 2010

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Australian Government

Torres Strait Regional Authority

Australian Government
Australian Fisheries Management Authority

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Contents

List of Figures

List of Tables

PROJECT SUMMARY

The Torres Strait trochus fishery (TSTF) is a small but important source of income for local Islander communities, especially for east Torres Strait communities where the Tropical Rock Lobster Fishery is less active. The TSTF has been characterised by boom and bust cycles, as the result of resource depletion and/or price fluctuations. The small gross value of this fishery means regular stock assessments are hard to justify, and the Torres Strait Islander open access rights and artisanal nature of fishing makes regulatory control difficult.

Trochus were surveyed at 113 sites over a 10 day period from the 19-28 March, 2009 during a joint bêche-de-mer and trochus survey. Trochus were observed at only 12 of 113 sites surveyed, including 5 previously surveyed "sea cucumber" sites. This reflects the cryptic and patchy nature of trochus distribution. The resulting average density estimate was 24.9/Ha, and the stock estimate for the four logbook zones sampled (Cumberland, Darnley, Don Cay and Great North East Channel) was 634 t (shell weight). However, this estimate had a wide variance with the lower 90th and 80th percentile of the bootstrapped probability distribution for the population estimate being 137.6 and 213.7 t respectively.

The trochus population in Torres Strait appears to be at least stable compared to historical data. Densities were similar to the 1995 survey data and healthy populations elsewhere. This trend data however, has a low precision and therefore low reliability to detect even large changes in trochus density.

The reported annual catch of trochus over the last 10 years (4-82 tonnes) is nowhere near the current TAC of 150 tonne. As the original TAC was not scientifically based, we recommend a reference trigger point at a lower catch level that would prompt closer monitoring of the fishery. A trigger catch level for the TSTF of 75 t (shell weight) and 100 t (whole weight) is recommended based on historical information, anecdotal harvest patterns, and a 20% exploitation rate of potential carrying capacity from trochus specific habitat in east Torres Strait. Catches above the trigger level should not occur without additional stock assessments that demonstrate the sustainability or otherwise of higher catch levels. The only time this trigger may have been exceeded in recent years was in 2005, when 82 t was recorded, though it is not known if this is whole or shell weight.

The current TAC is based on trochus whole weight (animal in shell). As trochus fishers may sell product on a day fishing (whole weight) or stockpiled (shell only) basis, present catch data is more than likely a mixture of both. The difference between whole animal and shell weight equates to around 25% (Nash *et al*., 1995). If future catches approach the TAC, this difference becomes significant in regard to managing the fishery sustainably. We recommended that fisher log books also record trochus as whole animal or shell only, in order to alleviate this uncertainty.

Trochus weight was determined using the regression formula developed by Long *et al*. (1993). A conversion factor for whole animal weight to basal shell width, and updating of Long *et al*., (1993) shell weight to shell basal width are needed. This will allow for a more accurate account of trochus catch from the fishery.

Localised depletion of trochus in Torres Strait is an area of potential concern due to the nature of trochus fishing, and proximity of islander communities to trochus habitat (AFMA, 2008). Recent localised overharvesting in Torres Strait has been observed by fishers' from Darnley, who have noted that trochus stocks are less than they were 10 years ago (Tawake pers. comm.). Management strategies that spread effort from heavily fished areas (such as rotational closures), and the development of co-management harvest frameworks that devolves responsibility to the community level (Community Based Management), may ameliorate this problem.

Suggested harvest strategies for trochus in Torres Strait

<u>TAC/catch trigger management strategies:</u>

- Catch below 75 t in a year: current management arrangements (minimum and maximum size limits), stock assessment every 3-5 years.
- Catch exceeds 75 t in year: trigger TAC re-assessment and robust stock assessment.
- TAC above 150 t in a year: prohibitions (increase in minimum size restriction), yearly stock assessment, reduction in fishing effort, shortening of harvest season, closing depleted reefs, restocking.
- or TAC above 150 t in a year: closure of fishery until following year.

<u>Other potential management strategies (for localised depletion in particular)</u>

- Closing depleted reefs: overharvested reefs closed to fishing, not opened for 3-5 years to allow recruitment of trochus and growth to maturity.
- Increase in minimum size limit where over harvesting has occurred e.g. Solomon Islands, increase minimum size from 80 mm to 90 mm, improvement in egg production and yields (Foale & Day, 1997).
- Closed seasons: fishing banned during summer months (Dec-Feb) when trochus spawn. The trochus harvest could also be restricted to a short period eg. 2-3 months of the year.
- Marine sanctuaries: source reefs closed to fishing; sink reefs (down current of source reefs) open to fishing. This protects mature trochus on source reefs. Source reefs need to be close enough together to allow for larval recruitment to sink reefs. Trochus larvae remain planktonic for 3-4 days and can drift up to 10 km during this time (Foale, 1998).
- Translocation of brood stock: introduction of mature trochus to depleted areas.
- Restocking: development of aquaculture and re-seeding initiatives, as undertaken in other regions of the Indo Pacific.

1. INTRODUCTION

Torres Strait has two major Hand Collectable Fisheries; trochus and bêche-de-mer (sea cucumber). They have a small combined GVP ($321,000 in 2005) but are an important source of income for local Islander communities, especially for east Torres Strait communities where the Tropical Rock Lobster Fishery is less active. Both trochus and bêche-de-mer fisheries have been characterised by boom and bust cycles, as the result of resource depletion or price fluctuations. The small gross value of these fisheries means regular stock assessments are hard to justify, and the Torres Strait Islander open access rights[1] and artisanal nature of fishing makes regulatory control very difficult.

The Torres Strait Trochus Fishery (TSTF) is a single species (*Trochus niloticus*) fishery, having both commercial and subsistence aspects (AFMA, 2008). Subsistence fishing of the TSTF has been undertaken for centuries by the traditional owners of Torres Strait. Islanders have one of the highest recorded per capita seafood consumption rates in the world (Harris *et al.*, 1994; Skewes *et al*., 2004). Trochus meat provides a valuable source of protein for Islanders and the nacreous shell is used in arts and crafts (Crowe *et al*., 2002; AFMA, 2008).

The commercial fishery is the larger of the two sectors, beginning in 1912 when the mother-of-pearl layer of the trochus shell became popular for making buttons (AFMA, 2008; GBRMPA, 1995). In addition to buttons, the shell is used for jewellery, with the ground shell also used in floor tiles, metallic paints and shampoo (AFMA, 2008). The main importers of commercial products from the modern day trochus fishery are the countries of Asia and Europe (Crowe *et al*., 2002; AFMA, 2008).

Around 500 tonnes per year of trochus were reportedly fished from Torres Strait up to 1917, although the definition of catch area from the old Queensland records is ill-defined, and may include product from PNG and the Solomon Islands. Reports of overfishing of trochus stocks in Torres Strait occurred within four years of the commencement of the commercial fishery in 1912 (Wright & Hall, 1993). When catches began to decline in Torres Strait, fishers spread down the coast of Queensland as far south as Mackay. By 1927, the entire Queensland coast was being searched for trochus (D'Silva, 2001) with 1,027 t being exported (Fao, 1992; GBRMPA, 1995). During the 1940's the market for trochus shell declined, as did fishing pressure and only 6 t was taken by 1944 (Fao, 1992; GBRMPA, 1995). In the 1950's the fishery experienced a resurgence with exports amounting to 1,400 tonne in 1952 (GBRMPA, 1985). Since 1952, the fishery has operated sporadically closely linked to international demand; for example the catch in 2006 was less than half that caught in 2005, equating to an income loss of $200K from one year to the next (Raudzens, 2007).

In 2007 and 2008, there was reasonable demand for trochus shell and meat, however prices paid for landed product were close to or below the cost of production and operators reduced their efforts in response (QPIF, 2008). While this allows the fishery to recover from potential over harvesting, local income is affected and continuity of supply decreased. Conversely, if prices remain high for an extended period, there is a risk that stocks may be overexploited and unable to recover (AFMA, 2008).

[1] There is currently no cap on TIB licenses.

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Fishing in the TSTF is limited to traditional inhabitants only (AFMA, 2008). Management is focused around implementing measures that provide effective protection for a proportion of the breeding stock (AFMA, 2008). Arrangements currently in place include: collecting trochus by hand (though the underwater breathing apparatus is permitted); and a minimum size limit of 80 mm basal standard width (BSW) and maximum size limit of 125 mm BSW applies (except for traditional harvest). A competitive Total Allowable Catch (TAC) (measured in tonnes with animal in shell) of 150 t per year applies to the fishery (AFMA, 2008).

The impact of trochus fisheries on bycatch species is considered minimal, due to the highly selective method of harvest. This limits bycatch from the fishery to epifaunal and epifloral organisms living on or within trochus, such as bivalves, boring sponges and snails (Young & Challen, 2004; DEH, 2005).

Hand collection of trochus also limits the impact on endangered, threatened or protected species, and benthic flora or fauna (Young & Challen, 2004). Protected species occurring in the TSTF area include cetaceans, marine turtles, syngnathids, dugongs, sea snakes and seabirds (DEH, 2005). The taking of turtles and dugong is only allowed in the course of traditional fishing, which is separate to the commercial fishery for trochus. Turtles are known to eat trochus, but it is not known in what quantities or how heavily turtles rely on trochus as a food source (DEH, 2005). No other endangered, threatened or protected species are known to interact with trochus in the TSTF (DEH, 2005).

Other potential impacts from trochus fishing arise from small vessel operations, including boat strikes on endangered, threatened or protected species or damage to the seafloor from anchoring. Beyond the removal of trochus from the ecosystem, there is little evidence suggesting any impact on the benthic or pelagic communities in the area that the fisheries operate (Young & Challen, 2004). While it is recognised that some damage to the benthos may occur when trochus are collected by fishers walking across reefs, their level of contact and impact is negligible (DEH, 2005). The impact of vessel discharge on the ecosystem is considered to be low and there have been no issues with vessel discharge reported by the fishery (DEH, 2005).

It is unlikely that trochus would be poached by foreign fishing boats in Torres Strait, as they are of low value compared to other currently poached species in the region e.g. sandfish, lobster (PNG Nationals) and sharkfin (Indonesian fishers). However, illegal fishing for trochus has occurred within the Australian EEZ. In 2005, an Indonesian vessel was apprehended by Customs in the Australian Fishing Zone off the Western Australian coast; upon interview the crew indicated they were targeting trochus (DEH, 2005).

Trochus stocks in Torres Strait have never been properly assessed at the regional level (D'Silva, 2001; Wilson *et al*., 2009). Only one, localised, small scale study has been undertaken, where satellite image analysis and limited surveys were used to estimate the standing stock of trochus on Bourke Isles (Long *et al*., 1993). There is also no mandatory reporting of catches or mechanism to assess the suitability of the current TAC of 150 t, or the sustainability of historical catches. It is uncertain whether the current TAC of 150 t would be sustainable to harvest on a yearly basis. Localised depletion of trochus in Torres Strait is also an area of potential concern due to the nature of fisher behaviour and recognised reef tenure among Islanders (AFMA, 2008).

To try and gather information on the stocks that could be used to formulate informed management decisions, trochus were surveyed over a 10 day period from the 19-28 March, 2009 during a joint bêche-de-mer and trochus survey. The outcomes of that survey are reported here. The outputs from this project will aid in the management of Torres Strait Trochus Fishery and facilitate the move to adaptive co-management in line with aspirations for Torres Strait Traditional communities.

2. METHODS

2.1 Study area

The east Torres Strait fishery is a 16,844 km^2 area of Torres Strait situated at its eastern extent, which includes the Australian side of the Torres Strait Protected Zone east of Warrior Reef. It contains about 700 km^2 of shallow reef top habitat, 504 km^2 of shallow reef top buffer habitat, and 185 km^2 of reef edge (<20 m deep) habitat, accounting for approximately 64 % of all reefs in Torres Strait (Table 2-1).

Given the large extent of shallow reefs distributed over the region, the study area was divided into 7 zones (Table 2-1, Figure 2-1). Zones are derived from species distribution data and the physiographic characteristics of fishery habitats, and have been used to denote logbook areas for the collection of fishery catch data. These zones are very similar to those used in previous reef resource surveys (Skewes *et al.*, 2006), and have been used for the sample design and stratified analysis.

A marine habitat map delineating shallow reefs was used as the basis for the survey. The map was imported into GIS, with zones superimposed onto the map (Figure 2-1). Each zone was further divided into three habitat strata; the reef edge, the reef top and a reef top buffer stratum, being a 200 m wide buffer around the inside of the reef margin.

Table 2-1. Area (km^2) of shallow reef top, reef top buffer and reef edge habitat in the East Torres Strait study area for each zone.

Zone (km^2)	Top	Buffer	Edge	Non-reef	Total
Barrier	26.00	93.41	42.63	3,629.00	3,791.04
Cumberland Passage	309.39	133.68	46.79	1,471.85	1,961.71
Darnley	161.69	107.03	39.68	2,921.24	3,229.64
Don Cay	52.14	69.37	24.52	1,710.92	1,856.95
Great North East Channel	77.00	50.57	17.16	4,304.71	4,449.44
Seven Reefs	73.84	49.85	13.74	1,418.26	1,555.69
Total	700.05	503.91	184.53	15,455.99	16,844.48

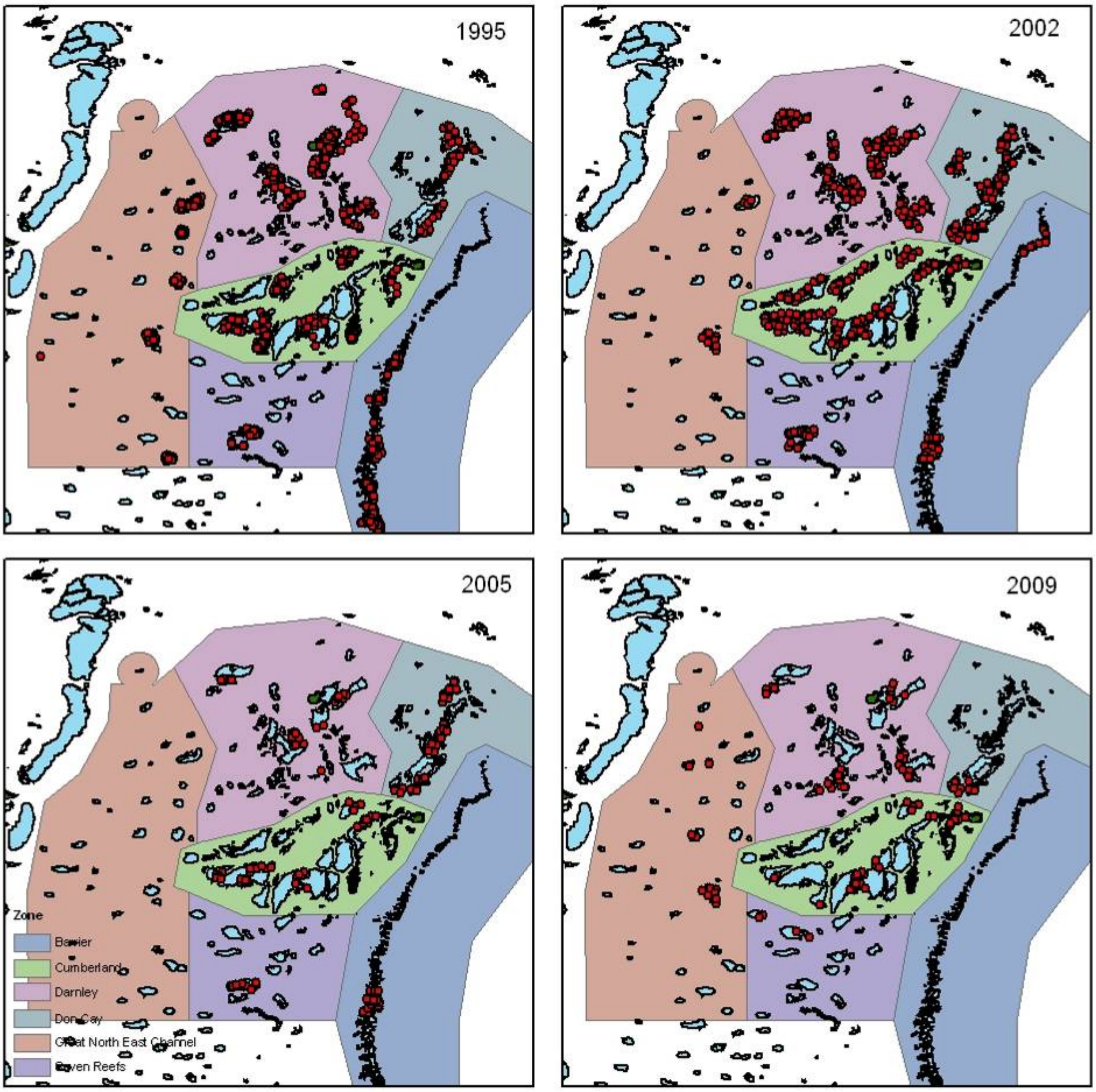

Figure 2-1. Sample sites sampled in 1995/96, 2002, 2005 and March 2009 with fishery zones and shallow reefs delineated.

2.1.1 Trochus habitat definition

A habitat definition for trochus was developed from literature reviews of research to date. The categorisation of trochus habitat was used to identify matching habitat type in satellite images of Torres Strait. To do this, a new technique of L shading the front edges of reefs was developed using GIS analysis. The location of trochus habitat and area estimates for Torres Strait was determined from these analyses (Appendix A).

Commercial sized trochus (80-125 mm) inhabit narrow zones of coral rubble and pavement on the windward edges of reefs (Ahmad & Hill, 1994). This substrate is typically dominated by stony corals and turf algae. Trochus avoid areas covered with sand or mud and do not usually reside on sandstone reefs, which lack the three dimensional structure typical of coral reefs (Ahmad & Hill, 1994; Foale & Day, 1997; DOFWA, 2009). Trochus require substantial water circulation, preferring sections of reefs where wave action deposits rubble, retards coral growth and scours fine sediments (Ahmad & Hill, 1994).

Juvenile trochus (<60 mm BSW) live on the intertidal reef flat that borders adult habitat. The stony coral and rubble substrate provides refuge from predators and exposure at low tides (Foale & Day, 1997; Castell, 1997; DOFWA, 2009). As juveniles grow a shift in microhabitat occurs, from small rubble (<10 mm) to larger rocks and coral bench; and from shallow pools (<10 mm deep) to deeper water (Castell, 1997). Juveniles are largely cryptic due to their size, similar shell colour to habitat and tendency to bury, up to 8 cm has been recorded (Crowe *et al*., 2001).

Maturing trochus are believed to migrate towards the wave-exposed, sub-tidal fore-reef areas where they reach adult size, most located around shallower than 10 m depth, with some found as deep as 24 m (AFMA, 2008; DOFWA, 2009).

2.2 Sample design

The selection of sample sites for the survey was based on three considerations: 1) logistic constraints on the amount of sampling that could be done in one day from the support vessel; 2) exclusion of sites with unsuitable habitat; >80% sand were not included as they were unlikely to contain high value species and 3) optimal allocation of sampling effort to the habitat strata; based on the density of species closed to fishing and other high value species such as trochus, White Teatfish and Prickly Redfish.

As a result of the sample design criteria and logistical constraints, 113 sites including 44 reef edge and 69 reef top were surveyed. Of these sites, 102 have been visited in previous surveys, allowing for repeated measures that give power to statistical analyses of abundance and size.

In addition, 11 new sites were sampled specifically for trochus, mostly in the Great North East Channel zone. These sites were identified by habitat criteria identified during the survey from direct observation and discussion with Torres Strait Islanders about their sea country.

2.3 Survey

The survey was carried out over a 10 day period from the 19 to 28 March 2009, following the trochus and bêche-de-mer survey training workshop (17-18 March) (Murphy *et al.*, 2009). Some participants of the workshop (Mer and Erub Islands) also assisted CSIRO researchers during the subsequent survey.

Rapid marine assessment techniques developed, improved and applied by CSIRO for reef resource and habitat surveys in several areas of Australia, Papua New Guinea and the Seychelles were used. As during previous surveys, the reefs of the study area were divided into two habitat strata; the reef edge and the reef top and sampled accordingly.

Field work was undertaken by a small team of divers operating from a dinghy and locating sample sites using hand-held GPS. On the reef-top, divers swam along a 40m-100m transect, and recorded resource and habitat information 1-2m either side of the transect line. Sea cucumbers, trochus and other benthic fauna of commercial or ecological interest were counted and where possible, returned to the dinghy and measured as total length and then returned to the water. For the dedicated trochus sites, divers swam along transects in likely trochus habitat adjacent to the reef front (SE side) edge.

At each site, substrate was described in terms of the percentage of sand, rubble, consolidated rubble, pavement and live coral. The growth forms and dominant taxa of the live coral component and the percentage cover of all other conspicuous biota, such as seagrass and algae were also recorded. On the reef-edge, a diver swam along a measured length transect between 1m and 15m water depth and recorded resource and habitat variables similar to those recorded on the reef-top.

2.4 Data analysis

Transect and sample data collected during the field survey was entered into an Access database on board the vessel to reduce transcription errors and clarify uncertainties. Once back at the laboratory in Cleveland, the database was imported into a centralised Oracle database for analysis and long term storage. We also took the opportunity to import all previous survey data into the same database, including data from the original 1995/96 reef resource inventory (Long *et al.*, 1996), much of which had to be imported from excel tables and entered from original datasheets. The data obtained from the field work were then input into statistical and GIS software for analysis.

Area estimates of the reef top strata for each zone were output from the GIS based on a spatial join of the satellite derived habitat map and zone map. The area of the reef edge habitat for each zone was derived from an edge length statistic of the shallow reef habitat output from the GIS, and the average edge width (to 20 m depth) from the field survey data. Edge lengths for each zone were calculated by densifying the outline of the shallow reef habitats with nodal distance set to 150 m. Topology was then used to limit the selected nodes to those not adjacent to land, or other reef polygons. The number of selected nodes were then counted for each strata and zone, and multiplied by 150 m to produce total edge length.

Observed counts were calculated between sampling years from site counts using a stratified analysis based on zones and reef strata, taking into account the heterogeneity of variance and the total area of the different habitats in the study area.

Estimates of mean density (count per hectare) were derived using a stratified analysis of transect counts based on logbook areas and reef strata. This takes into account the heterogeneity in the variance of observed counts and is representative of the physical size differences of the varying habitats in the surveys. The combination of small within stratum sample sizes, zero-inflation of counts and the skew and nonconformity of the distribution of observed densities, renders many standard parametric analyses inappropriate. To obtain comparable measures of uncertainty in density estimates across surveys, bootstrap confidence intervals were derived via the mirror-match bootstrapping technique developed by Sitter (1992). Mirror-match bootstrapping extends standard resampling methods to stratified, multistage sample designs by emulating the original within stratum sampling procedure. This was used to produce bootstrapped distributions for the estimates of mean density, with confidence intervals set as the quantile corresponding to the desired percentile of the distribution. Smith (1997) suggests that these percentile limits out perform bias corrected and accelerated confidence limits in trawl survey data, similar in nature to that of the current study.

We produced several outputs from the data analysis:

1. Stratified mean densities and population estimates for each year for the areas surveyed and the bottom 90^{th} percentile of the bootstrapped mean estimate distribution (assumes that the real estimate would be 95% certain of being greater than this value). This data is suitable for calculating standing stock estimates for the surveyed areas, but not for direct comparison between years.
2. Comparative average density data for between year comparisons using three zones that have data for 1995, 2002, 2005 and 2009, these include the Cumberland, Darnley and Don Cay zones.
3. Comparative average density data for between year comparisons using four zones that have data for 1995, 2002 and 2005, these include the Cumberland, Darnley, Don Cay and Great North East Channel.

For outputs 2 and 3, mirror-match bootstrapping was also used to construct sampling distributions for the difference in stratified means between pairwise combinations of years. By examining confidence intervals (1-α) derived from these bootstrapped distributions, particularly their zero coverage, we assessed whether significant changes in density had occurred between years (with test size α). This type of test is preferable to standard parametric tests due to the zero-inflation of counts and the skew and nonconformity of the distribution of observed densities.

Shell weight (g) for trochus was estimated using the size weight relationship previously established for Torres Strait trochus:

Shell Weight = $(7.4945 \times 10^{-5}) \times \text{Basal Shell Width}^{3.2898}$ ($r^2 = 0.97$) (Long *et al.*, 1993).

3. RESULTS

3.1 Survey data

3.1.1 Trochus density

Trochus niloticus were found at 12 sites from a total of 113 surveyed. Trochus were found at 5 previously sampled bêche-de-mer sites, and 7 of the 11 'trochus habitat' sites surveyed (Appendix B). Trochus were found throughout east Torres Strait during the four surveys (Figure 3-1). Previous full scale surveys have also found trochus on Warrior Reef and other central reefs, with few observed in west Torres Strait (Long et al. 1996).

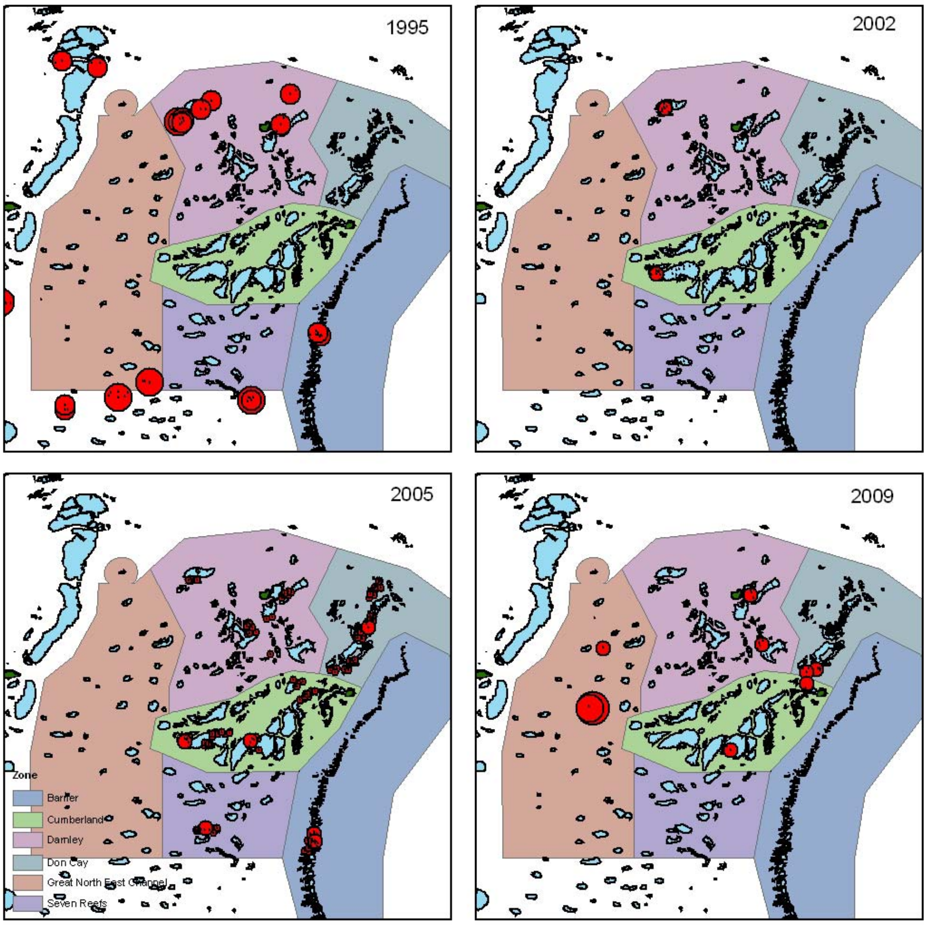

Figure 3-1. Plot of observed counts of *Trochus niloticus* from 1995, 2002, 2005 and 2009 at sampling locations in Torres Strait.

Few trochus were seen on the bêche-de-mer sampling sites visited in previous surveys. This was probably due to trochus having quite specific habitat requirements to that of bêche-de-mer. These two habitat types only on occasion overlap in Torres Strait due to the structure of the reefs in this region. When suitable trochus habitat was identified and specifically targeted, animals were commonly found.

Average density measurement for the survey area resulted in a population estimate of 2.7 M trochus, with a shell weight of 634 t (Table 3-1) using the average size of trochus collected during the survey (Table 3-2). The lower 90th and 80th percentile of the bootstrapped probability distribution for the population estimate is 137.6 and 213.7 t respectively (Table 3-1).

Table 3-1. The average density, and the lower 90th and 80th percentile of the bootstrapped confidence intervals of the mean distribution; and corresponding stock estimate for 2009 in four logbook areas (Cumberland, Don Cay, Darnley and GNEC, total area = 108,902 Ha).

Density (n/Ha)	Density L90	Density L80	Stock (n)	Stock L90 (t)	Stock L80 (t)	Stock (t)	Stock L90 (t)	Stock L80(t)
24.91	5.40	8.39	2,712,519	588,376	914,160	634.1	137.6	213.7

Table 3-2. Average size; basal width (mm) and shell weight (g) for *Trochus niloticus* collected during the 2009 survey for: all and legal sized trochus (80mm – 125 mm basal width).

	n	Basal width (mm)	Shell weight (g)
All trochus	73	88.38	233.78
Legal size (80mm – 125 mm)	44	100.27	299.40

Stratified trochus density estimates for three logbook areas (Cumberland, Darnley, Don Cay) in 1995, 2002, 2005 and 2009, show that trochus densities in 2009 were at similar levels to 1995 (Figure 3-2). The apparent decline in density in 2002 may be biased by observer error, where trochus were not a specifically targeted survey species. Even so, this data indicates a stable trend in trochus density when compared to 1995, and an increasing trend compared to 2002 and 2005.

When data from the Great North East Channel (mostly dedicated trochus sites) is also included in stratified analysis (with comparisons only available for 1995, 2002 and 2009), an increase in density is seen in 2009 (Figure 3-3). Higher densities of trochus in 2009, may however be related to sampling trochus specific habitat sites.

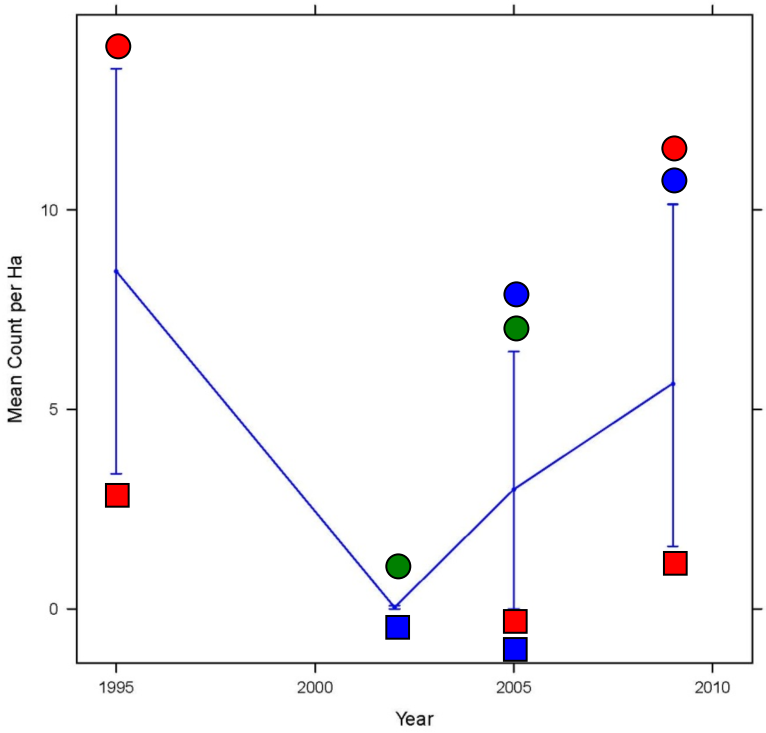

Figure 3-2. Stratified density of *Trochus niloticus* from Cumberland, Darnley and Don Cay Zones for 1995, 2002, 2005 and 2009. Error bars are bootstrapped 90% CI. Colours denote statistical groupings; circles (*P*<0.10), squares (*P*<0.05).

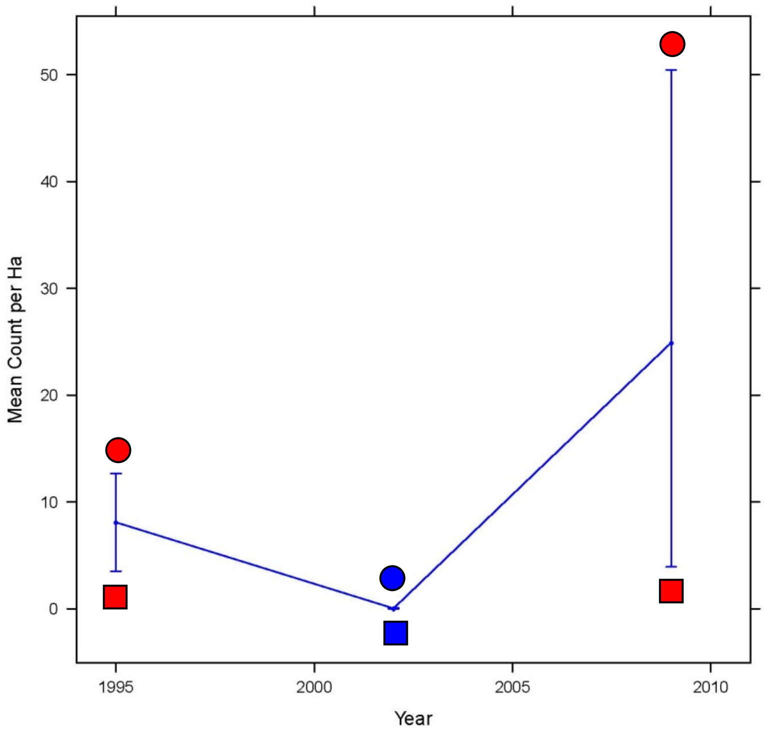

Figure 3-3. Stratified density of *Trochus niloticus* from Cumberland, Darnley, Don Cay and Great North East Channel zones for 1995, 2002 and 2009. Error bars are bootstrapped 90% CI. Colours denote statistical groupings; circles (*P*<0.10), squares (*P*<0.05).

Among the dedicated trochus survey sites, the average density was 203.2 per Ha, though with large variance levels (Table 3-3). The average density for sites in the Great North east Channel (GNEC) was 341.3 per Ha. These results are similar to previous density estimates from the Bourke Isles in Torres Strait; 445 trochus/Ha in 1991 (Long *et al*., 1993).

The average density of trochus in two primary trochus habitats was: rubble habitat (> 50% rubble and consolidated rubble), 665.9 trochus/Ha, and for intermediate habitat (> 50% hard substrate and coral pavement) the density was 34.0 trochus/Ha (Table 3-3).

Table 3-3. Density estimates for dedicated trochus survey sites. (See Appendix B)

	N	Average density (No./Ha)	s.e.
All trochus sites	11	203.2	476.6
GNEC	6	341.3	603.2
Rubble	3	665.9	769.8
Intermediate	7	34.0	28.0

3.1.2 Trochus size frequency

At two of the sites surveyed, the mean trochus size (BSW) was under the minimum allowable harvest size of 80 mm, with another two sites having a mean size just under 90 mm (Appendix B). Adult trochus are typically found between 2-10 m depth, with juveniles migrating to deeper water from the intertidal reef flat as they grow. The average depth for trochus from the sites surveyed was between 2-3 m (Appendix B). The size and depths of trochus found on the survey suggest that the sub-adult to adult population was being sampled. Future sampling needs to incorporate deeper depths to target adults and extend into the intertidal zone to also target juvenile trochus.

Size at first maturity of trochus from the Great Barrier Reef has been found to be around 55-65 mm (BSW) (D'Silva, 2001). This size would be the same for trochus from Torres Strait given the proximity of the two areas. The mean size for trochus sampled during the survey ranged from 75.7 to 170.5 mm (BSW) (Appendix B). The trochus population of Torres Strait are of spawning size and successful recruitment is believed to be occurring from the sizes of the sub-adult trochus sampled (Figure 3-4; Figure 3-5).

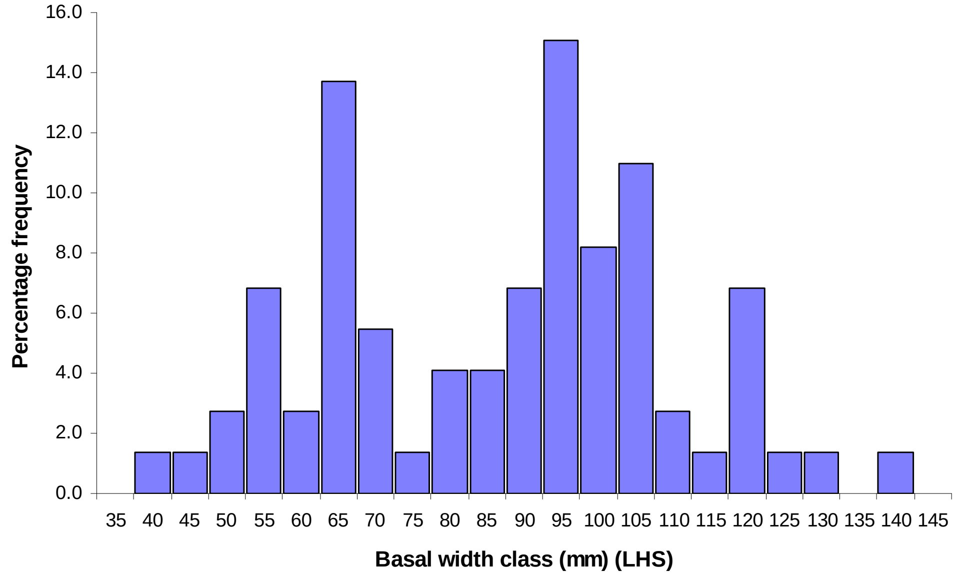

Figure 3-4. Size (basal diameter, mm) frequency for *Trochus niloticus* collected during the survey in east Torres Strait in 2009.

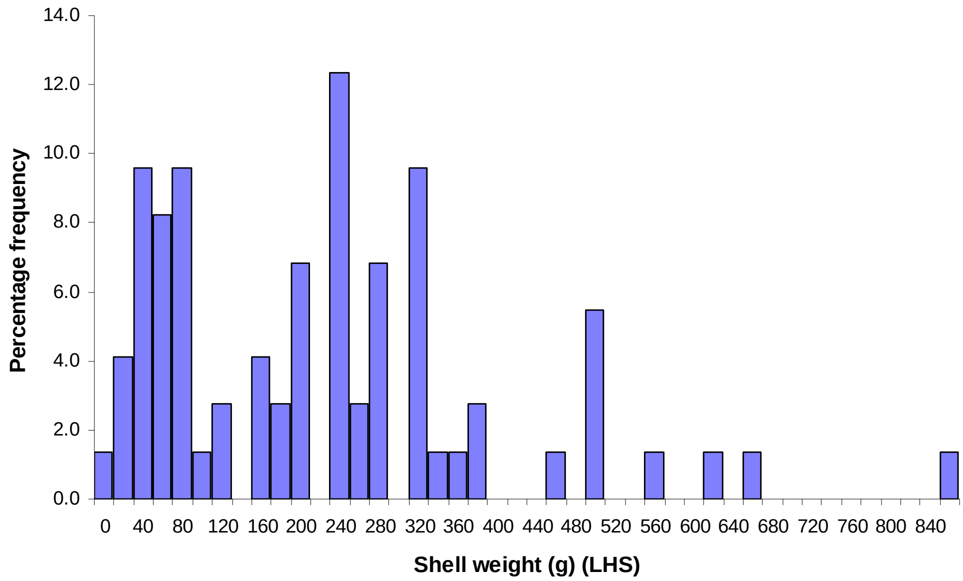

Figure 3-5. Size (shell weight, g) frequency for *Trochus niloticus* collected during the survey in east Torres Strait in 2009.

3.2 Status of trochus stock in Torres Strait

The survey data has some uncertainties and caveats, however, most outputs indicate a stable or increasing trend in trochus density in east Torres Strait compared to 1995 survey data (Figure 3-2, Table 3-3).

Also, the dedicated trochus sites on preferred rubble habitat, had a higher density to previous estimates from the Bourke Isles in Torres Strait for the same habitat of 445 trochus/Ha in 1991 (Long *et al*., 1993) (Figure 3-6), though the 2009 data has a low reliability and difference is not statistically significant.

The densities of trochus in Torres Strait are also comparable to the ECTF, where 500 trochus/Ha were recorded in 1991 (Larcombe, 1993) (Figure 3-6). Trochus densities in Torres Strait are typically higher than fished stocks and comparable to unfished stocks, from various locations in the South Pacific, such as the Cook Islands, Micronesia and Vanuatu (except for areas in Vanuatu that are seeded) (Figure 3-6).

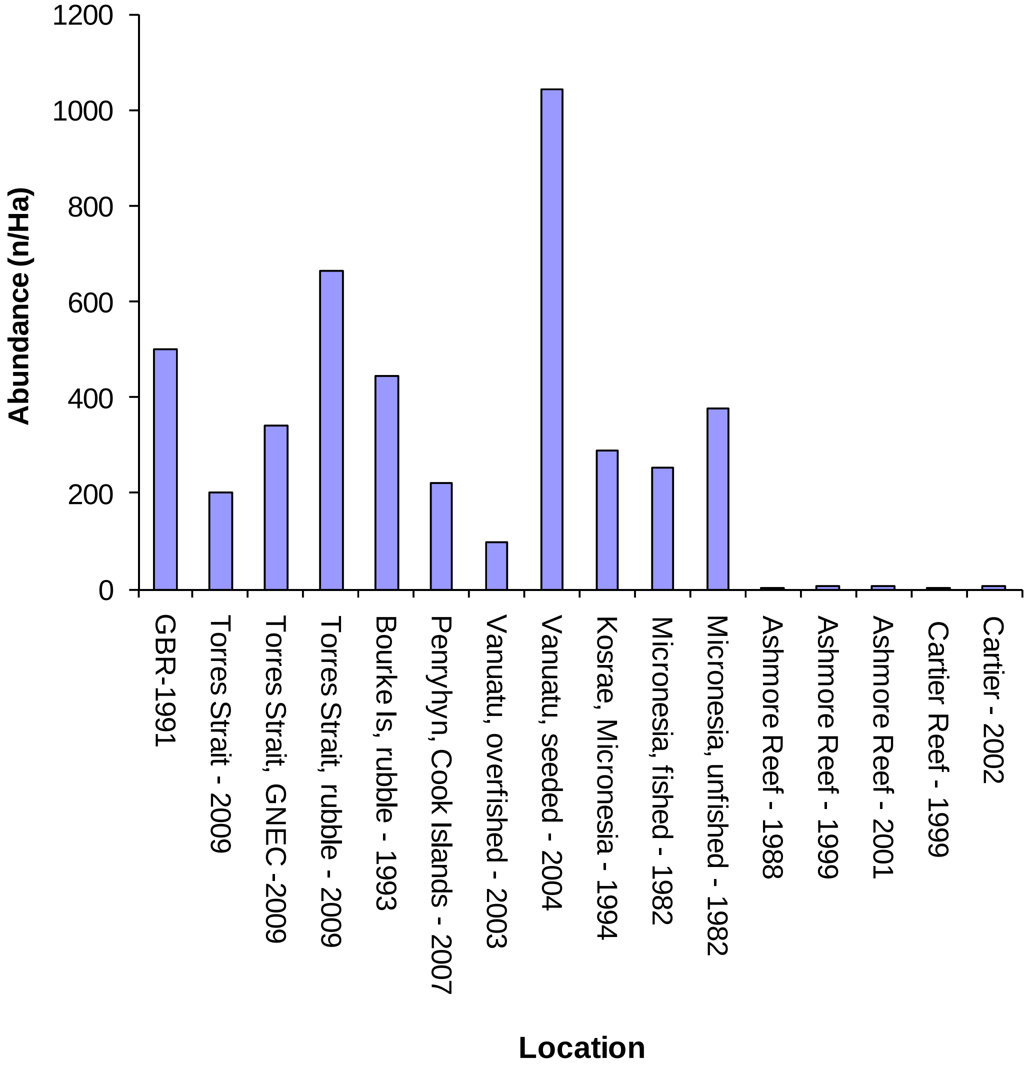

Figure 3-6. Trochus abundance (n/Ha) in the Indo Pacific region.

The population estimates and densities observed do indicate a substantial population of trochus in Torres Strait, with density estimates comparable to previous survey estimates and “healthy” populations elsewhere.

3.3 Carrying capacity for trochus in Torres Strait

To illustrate the potential trochus stock in all trochus habitat in east Torres Strait (as defined in section 2.1.1) we calculated the area of habitat in south east facing reef edge shallower than 10 m that was made up of two trochus habitat types, rubble (> 50% rubble and consolidated rubble), intermediate (> 50% all hard substrate) and then applied the observed density from the dedicated trochus sites. This is not meant to be a robust stock estimate, but an indication of the potential sustainability of the current TAC of 150 t.

For the 2009 survey, the average density of trochus from the intermediate zone was 34.0/Ha and for the rubble zone, 665.9/Ha (Table 3-3). The potential carrying capacity for *Trochus niloticus* in Torres Strait was calculated using the area estimates of intermediate and rubble habitat shallower than 10 m for all east Torres Strait logbook zones, and above density results (Table 3-4). Stock weight was calculated using average weight of harvestable stock (Table 3-2) using conversion factors in Long *et al*. (1993).

In Torres Strait, 57% of the population surveyed was in the harvestable size range between 80-125 mm (BSW) (Figure 3-4). Estimates of 30%, 20% and 10% of the potential harvestable population for trochus are also shown (Table 3-4). These calculations are based on shell weight of *Trochus niloticus* and do not include animal weight (Table 3-4).

Table 3-4. Potential carrying capacity and theoretical Total Allowable Catch (TAC) based on 30%, 20% and 10% of the harvestable *Trochus niloticus* population, for east and central Torres Strait logbook areas.

Location	Population (n)	Population (t)	30% TAC (t)	20% TAC (t)	10% TAC (t)
Barrier	115106	34.5	10.3	6.9	3.4
Cumberland	189764	56.8	17.0	11.4	5.7
Darnley	174688	52.3	15.7	10.5	5.2
Don Cay	107735	32.3	9.7	6.5	3.2
GBR	190414	57.0	17.1	11.4	5.7
Great North East Channel	121669	36.4	10.9	7.3	3.6
Seven Reefs	60128	18.0	5.4	3.6	1.8
South east	69605	20.8	6.3	4.2	2.1
Warraber	97030	29.1	8.7	5.8	2.9
Warrior	25763	7.7	2.3	1.5	0.8
Total	1151902	344.9	103.5	69.0	34.5

3.4 Torres Strait Trochus Fishery

3.4.1 Catch

Catch data has been collated from the Torres Strait seafood buyers and processors docket book returns since 2004 (Fao, 1992; AFMA, 2008). Data recorded before 2004 is based on anecdotal evidence and is considered unreliable (D'Silva, 2001). Data is not available for 1991-1995, 1998, 2000- 2003. (Table 3-5).

Table 3-5. Estimates of total catch for the commercial Torres Strait Trochus Fishery. (*includes East Coast Trochus Fishery data).

Year	Catch (t)
1987	*92
1988	~40
1989	~55
1990	*611
1996	~10
1997	~20
1999	~25
2004	4
2005	82
2006	~35
2007	~10

3.4.2 Effort

Catch and effort data for the Torres Strait trochus fishery is available for 2005 and 2006 (Raudzens, 2007). Mean catch per seller was higher in 2005 (1639 kg) than in 2006 (834 kg) (Table 3-6). The number of sellers declined from 50 in 2005 to 42 in 2006, with mean catch per diver day declining from 47 kg to 35 kg over the same period (Table 3-6) (mean catch per diver day was calculated by multiplying the number of divers, by the number of days fished and divided by the catch). During 2005, 62% of docket books returned had completed information, with 91% completed in 2006 (Table 3-6).

Table 3-6. Torres Strait trochus fishery catch and effort data for 2005 and 2006 (Raudzens, 2007).

Year	2005	2006
Trochus catch (kg)	81,946	35,043
Number of sellers	50	42
Number of diver days (% completed in dockets)	872 (62%)	909 (91%)
Mean catch per seller (kg)	1639	834
Mean catch per diver day (kg)	47	35

Mean catch per seller and catch per diver day was greatest for trochus obtained from Cumberland during 2005 (3825 kg and 210 kg respectively) and Darnley during 2006 (1090 kg and 39 kg respectively) (Table 3-7; Table 3-8) (Raudzens, 2007).

Of the areas fished in 2005 with the most sellers (Warraber, Great North East Channel and Darnley), the highest average catch per seller was obtained from Darnley (1816 kg), with the Great North East Channel recording the highest catch per diver day (61 kg) (Table 3-7). In 2006, the highest average catch per seller and the highest catch per diver day were obtained from the Darnley region (1090 kg and 39 kg respectively) (Table 3-8). All regions fished, with exception of Darnley, experienced a reduction in the amount of trochus caught per diver day from 2005 to 2006 (Table 3-8) (Raudzens, 2007).

Table 3-7. Torres Strait trochus fishery catch and effort by docket book region for 2005.

Area fished	Catch (kg)	Number of sellers	Mean catch (kg)	Diver days	Catch per diver day (kg)
Badu	500	1	500	-	-
Warraber	15640	22	711	244	45
Great NE channel	20650	22	939	150	61
Darnley	34506	19	1816	413	36
Cumberland	7650	2	3825	20	210
Barrier	3000	1	3000	45	44

Table 3-8. Torres Strait trochus fishery catch and effort by docket book region for 2006.

Area fished	Catch (kg)	Number of sellers	Mean catch (kg)	Diver days	Catch per diver day (kg)
Badu	720	2	360	16	45
Warraber	11724	17	690	349	31
Great NE channel	7740	13	595	184	36
Darnley	10903	10	1090	257	39
Cumberland	0	0	0	0	0
Barrier	3920	1	3920	102	36

The total catch, mean catch per fisher, total fishery value and mean fisher value for the Torres Strait trochus fishery were all higher in 2005, than 2006 (Table 3-9) (Raudzens, 2007).

Table 3-9. Torres Strait trochus fishery total catch and estimated financial values for 2005 and 2006.

Year	Total catch (kg)	Mean catch per fisher (kg)	Total fishery value	Mean fisher value
2005	81,946	1639	$311,395	$6,228
2006	35,043	834	$133,163	$3,171

4. DISCUSSION

Trochus were observed at only 12 of 113 sites surveyed, including 5 previously surveyed “sea cucumber” sites. This reflects the cryptic and patchy nature of trochus distribution. The resulting average density estimate was 24.9/Ha, and the stock estimate for the four logbook zones sampled was 634 t. This estimate had a wide variance, with the lower 90th and 80th percentile of the bootstrapped probability distribution for the population estimate being 137.6 and 213.7 t respectively.

The survey data most likely underestimates actual density, due to the cryptic nature of trochus and inadequacy of the survey technique for detecting trochus – dedicated searching is required for trochus census. Also, the estimates do not include some high density logbook zones, such as the ribbon reefs in the eastern approaches to Torres Strait which were not sampled in the current survey.

The trochus population in Torres Strait appears to be at least stable compared to historical data, with densities similar to the 1995 survey data and healthy populations elsewhere. This trend data however, has a low precision and therefore low reliability to detect even large changes in trochus density.

The reported total catch of trochus for the last 10 years (4-82 tonnes) is nowhere near the current TAC of 150 tonne. As the original TAC was not scientifically based, we recommend a reference trigger point at a lower catch level that would prompt closer monitoring of the fishery. A trigger catch level for the TSTF of 75 t (shell weight) and 100 t (whole weight) is recommended based on historical information, anecdotal harvest patterns, and a 20% exploitation rate of potential carrying capacity from trochus specific habitat in east Torres Strait. Catches above the trigger level should not occur without additional stock assessments that demonstrate the sustainability or otherwise of higher catch levels. The only time this trigger may have been exceeded in recent years was in 2005, when 82 t was recorded, though it is not known if this is whole or shell weight.

The current TAC is based on trochus whole weight (animal in shell). As trochus fishers may sell product on a day fishing (whole weight) or stockpiled (shell only) basis, present catch data is more than likely a mixture of both. The difference between whole animal and shell weight equates to around 25% (Nash *et al*., 1995). If future catches approach the TAC, this difference becomes significant in regard to managing the fishery sustainably. We recommended that fisher log books also record trochus as whole animal or shell only, in order to alleviate this uncertainty.

Trochus weight was determined using the regression formula developed by Long *et al*. (1993). A conversion factor for whole animal weight to basal shell width, and updating of Long *et al*., (1993) shell weight to shell basal width are needed. This will allow for a more accurate account of trochus catch from the fishery.

Localised depletion of trochus in Torres Strait is an area of potential concern due to the nature of trochus fishing, and proximity of islander communities to trochus habitat (AFMA, 2008). Recent localised overharvesting in Torres Strait has been observed by fishers’ from Darnley, who have noted that trochus stocks are less than they were 10 years ago (Tawake pers. comm.). Management strategies that spread effort from heavily fished areas (such as rotational closures), and the development of co-management harvest frameworks that devolves responsibility to the community level (Community Based Management), may ameliorate this problem.

Suggested harvest strategies for trochus in Torres Strait

TAC/catch trigger management strategies:

- Catch below 75 t in a year: current management arrangements (minimum and maximum size limits), stock assessment every 3-5 years.
- Catch exceeds 75 t in year: trigger TAC re-assessment and robust stock assessment.
- TAC above 150 t in a year: prohibitions (increase in minimum size restriction), yearly stock assessment, reduction in fishing effort, shortening of harvest season, closing depleted reefs, restocking.
- or TAC above 150 t in a year: closure of fishery until following year.

Other potential management strategies (for localised depletion in particular)

- Closing depleted reefs: overharvested reefs closed to fishing, not opened for 3-5 years to allow recruitment of trochus and growth to maturity.
- Increase in minimum size limit where over harvesting has occurred e.g. Solomon Islands, increase minimum size from 80 mm to 90 mm, improvement in egg production and yields (Foale & Day, 1997).
- Closed seasons: fishing banned during summer months (Dec-Feb) when trochus spawn. The trochus harvest could also be restricted to a short period eg. 2-3 months of the year.
- Marine sanctuaries: source reefs closed to fishing; sink reefs (down current of source reefs) open to fishing. This protects mature trochus on source reefs. Source reefs need to be close enough together to allow for larval recruitment to sink reefs. Trochus larvae remain planktonic for 3-4 days and can drift up to 10 km during this time (Foale, 1998).
- Translocation of brood stock: introduction of mature trochus to depleted areas.
- Restocking: development of aquaculture and re-seeding initiatives, as undertaken in other regions of the Indo Pacific.

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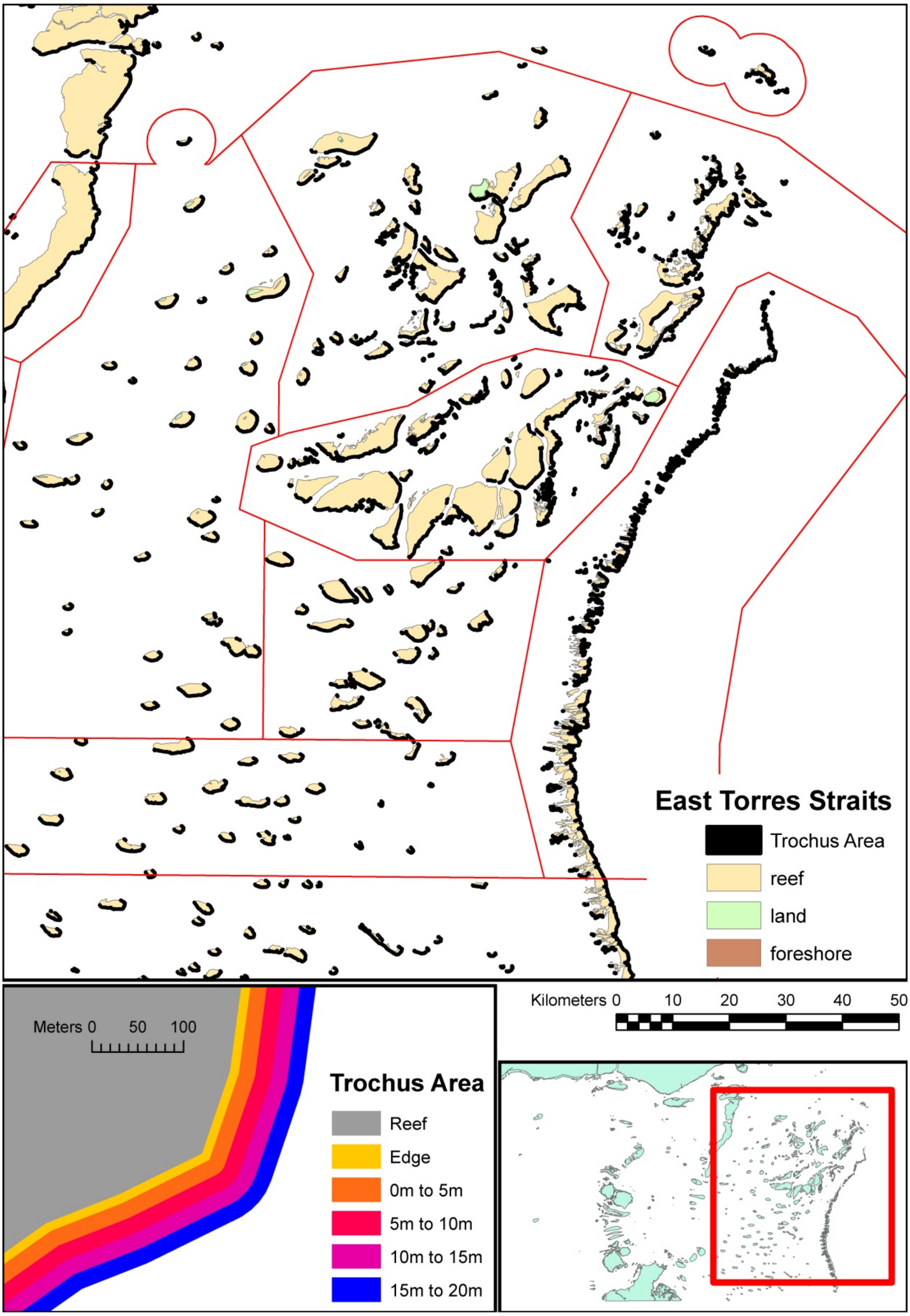
APPENDIX A: *TROCHUS NILOTICUS* HABITAT MAP FOR TORRES STRAIT



APPENDIX B TROCHUS SURVEY DATA

Abundance, size, transect area, density and depth of trochus observed at 5 “sea cucumber”, and 11 dedicated trochus sites during the 2009 survey.

Site	Trochus (n)	Transect area (m^2)	Depth (m)	Density/Ha	Region	Habitat
215	2	80	2	250.0	Don Cay	Intermediate
2269-N	4	80	1	500.0	Don Cay	Intermediate
2311	1	80	2	125.0	Darnley	Intermediate
219	1	160	2.6	62.5	Don Cay	Intermediate
423	4	260	2	153.8	Cumberland	Intermediate
TROCH0	4	1000	1	40.0	Murray	Intermediate
TROCH1	4	600	3	66.7	Darnley	Intermediate
TROCH2	3	1600	2.5	18.8	Darnley	Intermediate
TROCH3	0	2000	1	0.0	Darnley	Low
TROCH4	1	160	1.6	62.5	Darnley	Intermediate
TROCH5	9	1400	3	64.3	GNEC	Rubble
TROCH6	0	600	3	0.0	GNEC	Intermediate
TROCH7	1	200	3	50.0	GNEC	Intermediate
TROCH8	12	300	2	400.0	GNEC	Rubble
TROCH9	23	150	2.5	1533.3	GNEC	Rubble
TROCH10	0	10	1.5	0.0	GNEC	Intermediate

APPENDIX C. LITERATURE REVIEW OF TROCHUS NILOTICUS

Habitat, biology and ecology

General description of animal

The topshell, *Trochus niloticus* Linnaeus 1767 (Trochidae) is a large, conical shaped marine gastropod. Its external shell has mottled red, green and white bands, with an internal layer of mother-of-pearl (nacre) (Castel, 1997; Crowe *et al*., 2002; DOFWA, 2009). Two phenotypic variants exist for *T. niloticus*, previously believed to be two species (*T. niloticus* and *T. maximus*). The two growth forms differ depending on reef aspect. On more exposed reef, the form *T. niloticus* lives (wide basal flange), with '*T. maximus*' (conical shape) found on less exposed reefs (Wright & Hall, 1993).

Distribution

The distribution of trochus includes many areas of the eastern Indian and western Pacific Oceans (Castel, 1997; Crowe *et al*., 2002). In Australia, trochus are found in two tropical locations. The first location includes the Great Barrier Reef and the Torres Strait Islands off the east coast of north Queensland (ACWA, 2009). The second location is Western Australia; on the Buccaneer and Bonaparte Archipelagos in the Kimberley, offshore at Rowley Shoals, Browse Island, Scott Reef, Seringapatam Reef, Ashmore Reef and Cartier Island (ACWA, 2009).

*Life sp*an

Trochus are known to live for up to 12-15 years (Foale, 1998; Foale, 2008; DOFWA, 2009).

Growth

Adult trochus grow to ~160 mm BSW (Basal Shell Width), after one year they reach 25-30 mm (BSW) and when 2-3 years old, around 55-70 mm in size (Purcell & Lee, 2001; Foale, 1998; Foale, 2008; DOFWA, 2009). In Western Australia, adults attain 100 (BSW) in around five years, their growth rate slowing to below 1 mm per month after this (DOFWA, 2009). In Queensland, growth rates of trochus average between 2.3-2.6mm (BSW) per month, they reach marketable size in 2-3 years (DEH, 2005). Growth rates have been found to vary geographically, with studies showing differences between trochus from Japan, New Caledonia, Australia and Vanuatu (Table 1) (Figure 1) (Lemouellic & Chauvet, 2008). Growth rate after settlement may be temperature dependent, with survival rates of cohorts spawned in early summer found to be higher than those spawned toward the end of the summer (Wright & Hall, 1993).

Table 1. Estimated shell diameter of *Trochus niloticus* with age in different locations throughout the Indo Pacific region (Lemouellic & Chauvet, 2008). *sexual maturity

	Shell diameter (mm)				
Age (yrs)	Japan	New Caledonia	Australia	Vanuatu	Wallis
1	400	230	363	276	440
2	680	420	638*	502	736
3	876	578	847	687	934
4	1012	708	1005	839	1066
5	1107	816	1125	963	1215
6	1174	905	1260	1064	1255
7	1220	978	1285	1147	1281
8	1253	1039	1338	1216	
9	1275	1089	1378	1271	
10	1291	1131	1408	1317	
11	1302	1165	1430	1354	
12	1310	1194	1448	1385	
13	1315	1218	1461	1410	
14	1319	1237	1471	1430	

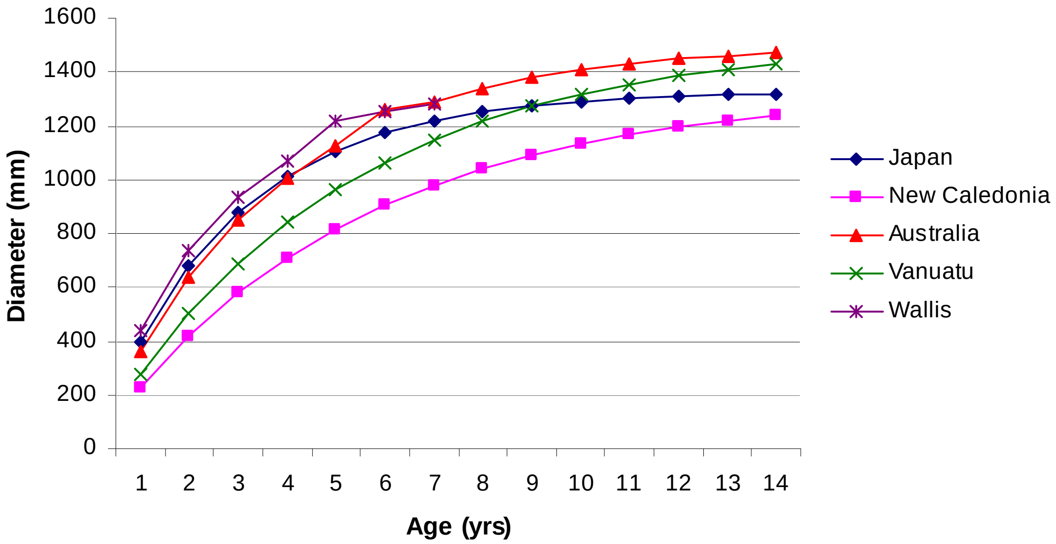


Figure 1. *Trochus niloticus* growth curves in different locations throughout the Indo Pacific region (Von Bertalanffy curves) (Lemouellic & Chauvet, 2008).

Mortality rates

- Predation

Juvenile and adult trochus are susceptible to a wide range of predators including crabs, stomatopods, predatory gastropods, flatworms, fish, octopus, turtles, sharks, rays and gymnodontid fishes, with predation rates believed to be inversely related to shell size (Amos & Purcell, 2003; DOFWA, 2009). On The Great Barrier Reef, trochus divers have reported active predation of *T. niloticus* by hermit crabs; an observation also noted in Japan, where hermit crabs are believed to be the major source of trochus mortality (Wright & Hall, 1993).

- Disease

Trochus shells are damaged by a variety of invertebrate animals that bore into the shell, lowering the quality for sale. These parasitic and commensal organisms include copepods, vermetid gastropods, limpets, boring sponges and bivalves (Nash, 1993). The prevalence of shell damage by these boring animals increases with the age of the animal, differing among reefs and regions. (DOFWA, 2009).

Nutrition

Trochus are nocturnal, active grazing herbivores which feed on a range of epilithic algae and detritus. They hide in holes and crevices during the day (Foale & Day, 1997; Amos & Purcell, 2003).

Reproduction

- Size at first maturity

Trochus have separate sexes, with ratios in the wild found to be close to 1:1, males and females cannot be distinguished from external shell characteristics (Foale, 1998; DOFWA, 2009). Trochus grow quickly, both sexes becoming mature at around 55-70 mm BSW, when they are around 2-3 years old (Foale, 1998; Foale, 2008; DOFWA, 2009). Size at first maturity for trochus in the Great Barrier Reef Region has been found to be 55-65 mm (BSW) (D'Silva, 2001), around two years of age (DEH, 2005). Reproductive maturity is reached at around 12 months for trochus reared in aquaculture facilities (Young & Challen, 2004).

- Breeding seasonality

Spawning occurs throughout the year at low latitudes, but only during the summer months at the southern limit of the species range (Wright & Hall, 1993). In Australia, trochus are believed to spawn once or twice a year, most actively during the summer months (DOFWA, 2009). A paper from 1936 which studied trochus from the Andaman Islands, has recorded spawning in Australia to occur all year round (Lemouellic & Chauvet, 2008).

Recruitment

Trochus larvae are lecithotrophic, typically remaining in the plankton for around three days before settling (Foale & Day, 1997). Larvae selectively settle within crevices or holes on reefs with suitable algae and may also use chemical cues from resident trochus (DOFWA, 2009). Once settlement occurs, larvae metamorphose into juvenile trochus in three to four days (DOFWA, 2009). A high number of larvae are lost during this phase due to failure to settle and/or metamorphose (DOFWA, 2009).

Larval ecology

Trochus are asynchronous broadcast spawners (Foale, 1998; DOFWA, 2009). Larger adults spawn less frequently, but can produce more than one million eggs (DOFWA, 2009). Animals may form spawning aggregates, typically moving to high points on the reef (Wright & Hill, 1991). Spawning usually occurs in the evenings around the new moon or full moon phase, with the lunar periodicity of spawning believed to be related to tidal movement (DOFWA, 2009). Spawning is initiated by males, which release sperm into the water column during the incoming tide, this is followed by the release of eggs by nearby females in response (Foale, 1998; DOFWA, 2009).

Habitat requirements

- Density

Trochus inhabit narrow zones of coral rubble and pavement on the windward edges of reefs (Ahmad & Hill, 1994). This substrate is typically dominated by stony corals and turf algae. Trochus avoid areas covered with sand or mud and do not usually reside on sandstone reefs, which lack the three dimensional structure typical of coral reefs (Ahmad & Hill, 1994; Foale & Day, 1997; DOFWA, 2009) (DOFWA, 2009). Trochus require substantial water circulation, preferring sections of reefs where wave action deposits rubble, retards coral growth and scours fine sediments (Ahmad & Hill, 1994).

Juvenile trochus (<60 mm BSW) live on the intertidal reef flat that neighbours adult habitat. The stony coral and rubble substrate provides refuge from predators and exposure at low tides (Foale & Day, 1997; Castell, 1997; DOFWA, 2009). As juveniles grow a shift in microhabitat occurs, from small rubble (<10 mm) to larger rocks and coral bench; and from shallow pools (<10 mm deep) to deeper water (Castell, 1997). Juveniles are largely cryptic due to their size, similar shell colour to habitat and tendency to bury, up to 8 cm has been recorded (Crowe *et al*., 2001). When juveniles reach 25-30 mm (BSW), around one year of age, they move onto the upper surfaces of reefs (Purcell & Lee, 2001). In WA, no trochus has ever been found less than 22 mm (BSW) in size (Bellanger, 2004).

Movement

Maturing trochus are believed to migrate towards the wave-exposed, sub-tidal fore-reef areas where they reach adult size, most are located around 8-10 m depth, with some found as deep as 24 m (AFMA, 2008; DOFWA, 2009).

Impacts/Threats

Fishing (on other species)

- Australia

Trochus are collected by hand. This highly selective method of harvest limits bycatch from the fishery to epifaunal and epifloral organisms living on or within trochus, such as bivalves, boring sponges and snails (DEH, 2005). The impact of trochus fisheries on bycatch species is considered minimal, due to the small scale of harvests and management measures in place (Young & Challen, 2004; DEH, 2005).

Hand collection of trochus also limits the impact on endangered, threatened or protected species, and benthic flora or fauna (Young & Challen, 2004). Protected species occurring in the Torres Strait Trochus Fishery area include cetaceans, marine turtles, syngnathids, dugongs, sea snakes and seabirds (DEH, 2005). The taking of turtles and dugong is only allowed in the course of traditional fishing, which is separate to the commercial fishery for trochus. Turtles are known to eat trochus, but it is not known in what quantities or how heavily turtles rely on trochus as a food source (DEH, 2005). No other endangered, threatened or protected species are known to interact with trochus (DEH, 2005).

Potential impacts from trochus fishing arise from small vessel operations, including boat strikes on endangered, threatened or protected species or damage to the seafloor from anchoring. Beyond the removal of trochus from the ecosystem, there is little evidence suggesting any impact on the benthic or pelagic communities in the area that the fisheries operate (Young & Challen, 2004). While it is recognised that some damage to the benthos may occur when trochus are collected by fishers walking across reefs, their level of contact and impact is negligible (DEH, 2005). The impact of vessel discharge on the ecosystem is considered to be low and there have been no issues with vessel discharge reported by the fishery (DEH, 2005).

Coastal processes

Grazing plays an important process in structuring of the marine environment, particularly in the tropics where macroalgae is maintained at low levels by intense herbivory (Elfwing & Tedendren, 2002). A study looking at the effect of salinity and copper concentrations on *Trochus maculates*, found a reduction in grazing activity, without a corresponding decrease in macroalgae at low salinity and high copper levels (Elfwing & Tedendren, 2002). The study was performed in the inner Gulf of Thailand, an area that frequently experiences salinity drops from freshwater runoff and pollution in the form of heavy metal contamination (Elfwing & Tedendren, 2002).

Trochus have also been suggested as bio-indicator species, with heavy metal accumulation in their tissues used to monitor trace metal pollution in the environment (Hutchings & Haynes, 2000). Management strategies for subsistence fishing of trochus in polluted areas need to take these levels into account.

Greenhouse changes, changes in coral reef ecology

Ocean acidification results in a decrease in pH and carbonate ion concentration in seawater (Orr *et al*., 2009). Early life stages have been found to be particularly sensitive to acidification, as the chemical nature of the seawater into which gametes are released, plays a critical role in fertilization and larval development (Havenhand *et al*., 2008). Sea urchin reproduction has been found to be negatively affected by acidification, reducing sperm motility and swimming ability, which lowers fertilization success and impedes embryo and larval development (Havenhand *et al*., 2008). As trochus are broadcast spawners like urchins, this impact is also a possibility for trochus species. Acidification could also affect the survival of trochus by weakening their shells and increasing their exposure to predators during the vulnerable juvenile stages (Bell, 2009).

The inner shelf of the Great Barrier Reef is believed to have suffered impacts from enhanced sediment and nutrient runoff, caused by cattle grazing and sugar production (AIMS, 2009). Acid sulphate soils from farming also result in the production of acidic waters, which has severely affected local biota along the Queensland coast (AIMS, 2009). On the whole, the GBR is considered to be in good condition, with the majority remote enough from land influences, at the moment this includes the trochus areas of Torres Strait. Reefs off Western Australia are also believed to be in good health and are generally not impacted by land influences, petroleum exploration or fishing (AIMS, 2009).

Trochus Fisheries

Trochus fisheries are most productive on reefs comprised of both adult and adjacent juvenile habitat (Foale & Day, 1997).

In addition to Australia, trochus is harvested in Japan, throughout South East Asia and the Pacific (Crowe *et al*., 2002). Australia, Indonesia and some Pacific Island nations supply around 90 per cent of the world's trochus shell (ACIAR, 2009). The current global demand for trochus shell is estimated at 7,000 tonnes annually, which is worth about $AUS 50-60 million (ACWA, 2009).

A pattern of rapid declines shortly after commencement of commercial fishing suggests that *Trochus niloticus* is highly susceptible to overfishing (Castell, 1997; Wright & Hall, 1993). Populations experiencing declining densities from overfishing can suddenly collapse due to fertilization failure (Foale & Day, 1997; Foale, 1998). Once numbers drop below a certain threshold, the increasing average distance between spawning individuals and consequent dilution of gametes results in few or no larvae, this is known as the allee effect (Foale, 1998).

The short planktonic duration of trochus larvae before settlement, limits the dispersal range of this species (Foale & Day, 1997). Populations like trochus are prone to recruitment overfishing on the scale of individual reefs, especially if neighbouring reefs are also overfished (Foale & Day, 1997). Recruitment is further affected on reefs with relatively little suitable habitat for juveniles (Foale & Day, 1997).

Evidence of stock collapse due to recruitment overfishing of trochus, has been reported for several reefs on the Great Barrier Reef and in New Caledonia (Foale & Day, 1997). In recent decades, harvests from the reefs north of King Sound, Western Australia, dropped from over 135 tonnes per annum in 1980 to 30-50 tonnes per annum in the 1990s; in 1998, the harvest was only ~12 tonnes (Crowe *et al*., 2002). *Trochus niloticus* has also been declared protected in Indonesia (Crowe *et al*., 2002).

<u>Torres Strait</u>

*Area description, cove*rage

The Torres Strait Trochus Fishery (TSTF) encompasses tidal waters within the Torres Strait Protected Zone (TSPZ) and the area declared under the TSF Act to be 'outside but near' the TSPZ for commercial fishing for trochus (AFMA, 2008). The 'outside but near' area extends to waters just south of Prince of Wales Island to the west and due east of Cape York Peninsula (AFMA, 2008). The majority of trochus harvested in 2005 was taken from the central eastern Torres Strait regions comprising the Great North East Channel, Darnley and Warraber regions (AFMA, 2008).

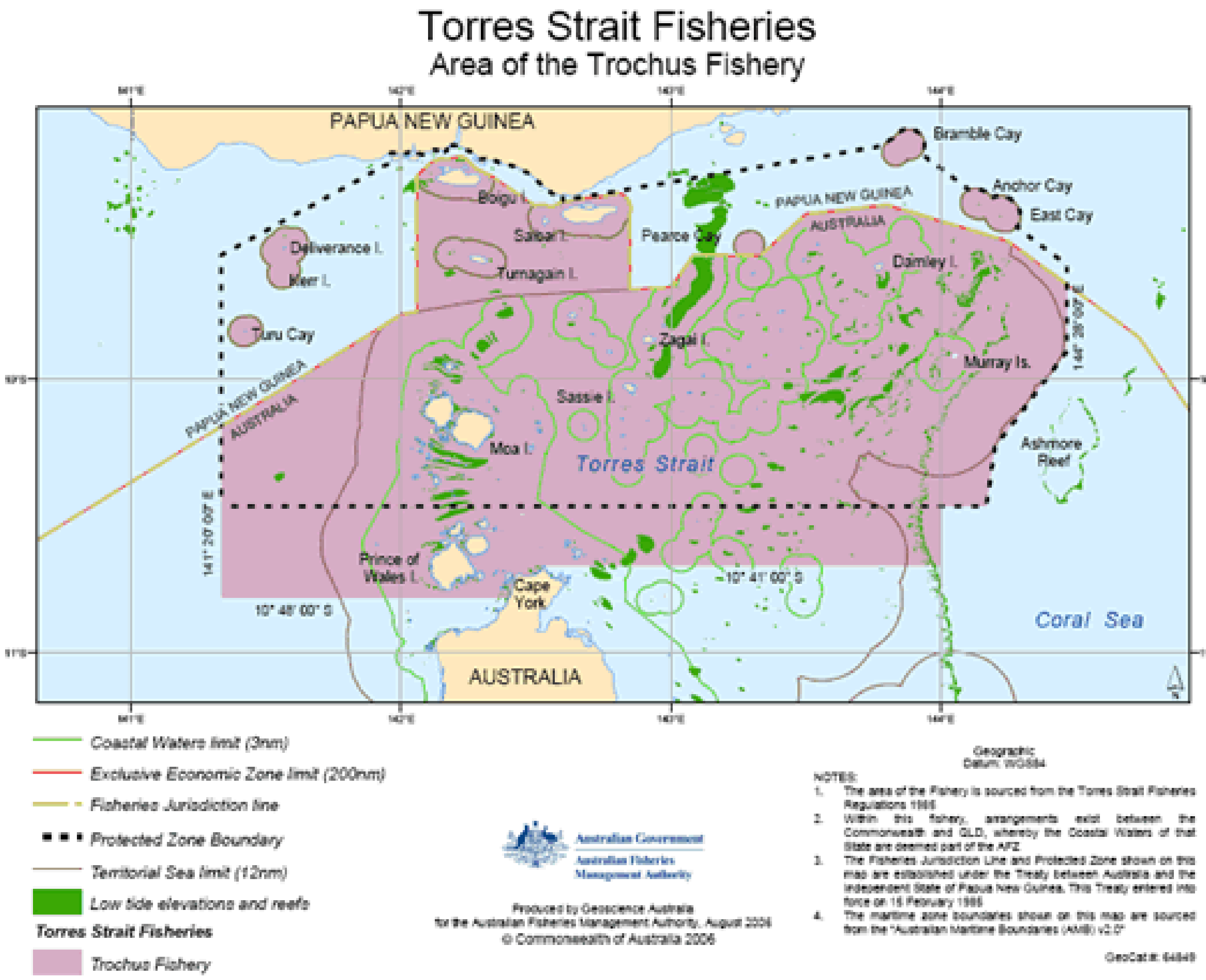


Figure 2. Map showing the area of the Torres Strait Trochus Fishery (AFMA, 2006).

Stakeholders

The TSTF is a small, single species (*Trochus niloticus*) harvest fishery, having both commercial and subsistence aspects (AFMA, 2008). The commercial fishery is the larger of the two industries, beginning in 1912 when the mother-of-pearl layer of the trochus shell became popular for making buttons (AFMA, 2008; GBRMPA, 1995). Around 500 tonnes of trochus where fished up to 1917, after which fishermen moved out of the Torres Strait and spread along the coast of Cape York. By 1927, the entire Queensland coast was being searched for trochus as far south as Mackay (GBRMPA, 1995; D'Silva, 2001). During the 1950's, plastics became more popular for buttons than the pearl shell from trochus and the industry declined until the 1970's, when trochus became fashionable again (GBRMPA, 1995). In addition to buttons, the pearl shell is used for jewellery and the ground shell also used in floor tiles, metallic paints and shampoo (AFMA, 2008). The main importers of commercial products from the modern day trochus fishery are the countries of Asia and Europe (Crowe *et al*., 2002; AFMA, 2008).

Subsistence fishing of the TSTF has been undertaken for centuries by the traditional owners of Torres Strait. Trochus meat provides a valuable source of protein for Islanders and the pearl shell is used in arts and crafts (Crowe *et al*., 2002; AFMA, 2008).

Catch

Estimate of catches (AFMA, 2008). Data not available for 1991, 1992, 1993, 1994, 1995, 1998, 2000, 2001, 2002, 2003. Catch information derived from Torres Strait seafood buyers and processors docket book docket book returns since 2004 and anecdotal evidence (Fao, 1992; AFMA, 2008). Data recorded before 2004 is based on anecdotal evidence and is considered to be unreliable (D'Silva, 2001).

Table 2. Catch data (tonne) for the Torres Strait Trochus Fishery (AFMA, 2008; Fao, 1992).

Year	Catch (tonne)
1987	*92
1988	~40
1989	~55
1990	*611
1996	~10
1997	~20
1999	~25
2004	4
2005	82
2006	~35
2007	~10

*data includes East Coast Trochus Fishery

Management

Management objectives for the TSTF were developed in accordance with the Torres Strait Treaty and Torres Strait Fisheries Act (TSF Act) 1984 (AFMA, 2008), these include:

1. to manage the resource so as to achieve optimum utilisation;
2. to maximise opportunities for traditional inhabitants of Australia; and
3. to encourage traditional inhabitants of the Torres Strait to participate in the trochus fishery.

Fishing is limited to traditional inhabitants only in the commercial trochus fishery (AFMA, 2008). Torres Strait Islanders are able to enter the fishery by obtaining a Traditional Inhabitant Boat (TIB) fishing licence with trochus (TR) endorsement. In June 2008, 110 TIB-TR licences were issued by the Queensland Department of Primary Industries and Fisheries (QDPI&F), on behalf of the Protected Zone Joint Authority (PZJA) (AFMA, 2008).

Management arrangements currently in place for the Australian area of the TSTF include:

1. Fisheries Management Notice No. 52: Prohibition on taking trochus (gear size restrictions) (AFMA, 2008) includes:

- limiting the method of taking trochus shell to either hand or hand held non-mechanical implements;
- the use of underwater breathing apparatus is permitted; and
- a minimum size limit of 80 mm BSW and maximum size limit of 125 mm BSW (when measured in their original form as fished, at the widest part of the base of the shell) applies to all fishing, except traditional fishing.

2. Licence condition: Implemented by way of licence conditions, a competitive Total Allowable Catch (TAC) (measured in tonnes with animal in shell) of 150 tonnes exists in the fishery (AFMA, 2008).

3. Licensing arrangements: The issue of additional licences is restricted to boats wholly owned and operated by traditional inhabitants (AFMA, 2008).

The TSTF is managed by the PZJA considering advice from its consultative bodies (AFMA, 2008). These include the Australian Government (represented by the Minister for Agriculture Fisheries and Forestry), the Queensland Government (represented by the Minister for Primary Industries and Fisheries) and the Torres Strait Regional Authority (represented by the Chair) (AFMA, 2008). The Australian Fisheries Management Authority (AFMA) coordinates and delivers fisheries management and surveillance/enforcement programs in the Torres Strait, in conjunction with Fisheries Queensland on behalf of the PZJA and in accordance with the TSF Act (AFMA, 2008).

Localised depletion of trochus in Torres Strait is an area of potential concern due to the nature of fisher behaviour in the region. Management of the TSTF involves implementing measures that provide effective protection for a proportion of the breeding stock (AFMA, 2008).

The potential for illegal fishing was highlighted in 2005 when an Indonesian foreign fishing vessel carrying 25 men, was apprehended by Customs in the Australian Fishing Zone off the Western Australian northern coast (DEH, 2005). Reports indicate the apprehended fishermen were looking to poach trochus (DEH, 2005). Trochus are of comparably low value compared to other products taken by illegal fishers and unless market prices increase substantially, it is unlikely that trochus would be poached by foreign fishing boats in the Torres Strait (DEH, 2005).

Activity in the TSTF is closely linked to the international demand and price for trochus, with the fishery operating in a boom and bust fashion (AFMA, 2008). During 2007-2008, reasonable demand for trochus shell and meat existed, however prices paid for landed product were close to or below the cost of production, with operators reducing their efforts in response (QPIF, 2008). While this allows the fishery to recover from potential over harvesting, there is a risk if prices remain high for an extended period, overfishing may occur if the 150 t TAC is not sufficient (AFMA, 2008).

Research

Trochus stocks in Torres Strait have never been properly assessed at the regional level (D'Silva, 2001). Only one, localised, small scale study has been undertaken, where satellite image analysis and limited surveys were used to estimate the standing stock of trochus on the Bourke Isles (Long *et al*., 1993). The current total allowable catch of 150 tonne is not scientifically based and it is uncertain whether it would be sustainable to harvest this amount on a yearly basis.

Fishery Effort

Data available from 2005 and 2006 (Raudzens, 2007). Mean catch per seller was higher in 2005 (1639 kg) than 2006 (834 kg). The number of sellers declined from 50 in 2005 to 42 in 2006, with mean catch per diver day declining from 47 kg to 35 kg over the same period (Table 3-5) (mean catch per diver day was calculated by multiplying the number of divers, by the number of days fished and divided by the catch). During 2005, 62% of docket books returned had completed information, with 91% completed in 2006 (Table 3-5).

Table 3-5 Torres Strait trochus fishery catch and effort for 2005 and 2006 (Raudzens, 2007).

Year	2005	2006
Trochus catch (kg)	81,946	35,043
Number of sellers	50	42
Number of diver days (% completed in dockets)	872 (62%)	909 (91%)
Mean catch per seller (kg)	1639	834
Mean catch per diver day (kg)	47	35

Mean catch per seller and catch per diver day was greatest for trochus obtained from Cumberland during 2005 (3825 kg and 210 kg respectively) and Darnley for 2006 (1090 kg and 39 kg respectively) (Table 3-6; Table 3-7) (Raudzens, 2007).

Of the areas fished in 2005 with the most sellers (Warraber, Great North East Channel and Darnley), the highest average catch per seller was obtained from Darnley (1816 kg), with the Great North East Channel recording the highest catch per diver day (61 kg) (Table 3-6). In 2006, the highest average catch per seller and the highest catch per diver day were obtained from the Darnley region (1816 kg and 39 kg respectively) (Table 3-7). All regions fished, with exception of Darnley, experienced a reduction in the amount of trochus caught per diver day from 2005 to 2006 (Table 3-7) (Raudzens, 2007).

Table 3-6 Torres Strait trochus fishery catch and effort by docket book region for 2005.

Area fished	Catch (kg)	Number of sellers	Mean catch (kg)	Diver days	Catch per diver day (kg)
Badu	500	1	500	-	-
Warraber	15640	22	711	244	45
Great NE channel	20650	22	939	150	61
Darnley	34506	19	1816	413	36
Cumberland	7650	2	3825	20	210
Barrier	3000	1	3000	45	44

Table 3-7 Torres Strait trochus fishery catch and effort by docket book region for 2006.

Area fished	Catch (kg)	Number of sellers	Mean catch (kg)	Diver days	Catch per diver day (kg)
Badu	720	2	360	16	45
Warraber	11724	17	690	349	31
Great NE channel	7740	13	595	184	36
Darnley	10903	10	1090	257	39
Cumberland	0	0	0	0	0
Barrier	3920	1	3920	102	36

The total catch, mean catch per fisher, total fishery value and mean fisher value for the Torres Strait trochus fishery were all higher in 2005, then 2006 (Table 3-8) (Raudzens, 2007).

Table 3-8 Torres Strait trochus fishery total catch and estimated financial values for 2005 and 2006.

Year	Total catch (kg)	Mean catch per fisher (kg)	Total fishery value	Mean fisher value
2005	81946	1639	$311,395	$6,228
2006	35043	834	$133,163	$3,171

East Coast Queensland

Area description, coverage

The area of the East Coast Trochus Fishery (ETCF) is comprised all tidal waters south of latitude 10°41'south and east of longitude 142°31'49" with harvest and effort spread from reefs east of Ingham to the southern reefs of the Swains reef complex (QPIF, 2009).

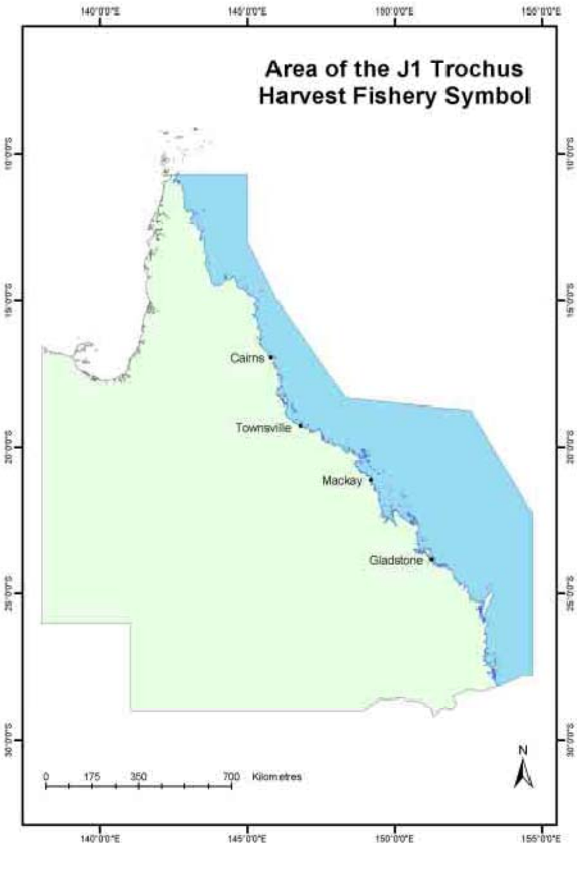


Figure 3. Map showing the area of the East Coast Trochus Fishery (QPIF, 2009).

Stakeholders

The East Cost Trochus Fishery (ECTF) is a single species (*Trochus niloticus*) commercial, subsistence and recreational fishery. The focus of the commercial fishery is mainly offshore from Mackay, with subsistence fishing reported in waters north of

Palm Island, near Townsville (QPIF, 2009). The recreational harvest is considered negligible. The ECTF is predominately a commercial fishery (QPIF, 2009).

Catch

Trochus are unevenly distributed across a wide area, with fishers selecting sites based on prior knowledge of reefs known to have high abundance. The majority of harvest comes from a single logbook grid east of Mackay (QPIF, 2009). This grid has consistently produced high levels of harvest at an average 690 kg/day since 1997/98 (QPIF, 2009). Over the last ten years, the annual harvest of trochus from the ECTF has remained below the allocated commercial TAC of 250 tonne.

Catch has varied for the East Coast Trochus Fishery from 230 tonne in 1997/98 to 115 tonne in 2007/08. Like the TSTF it is highly variable due to rapid fluctuations in market conditions. Commercial logbook data show the annual harvest of trochus has remained below the allocated TAC of 250 tonne for the last ten years. Harvest in the ECTF is considered sustainable at current levels (QPIF, 2009).

Table 3. Catch data (tonne) for the East Coast Trochus Fishery from 1997 to 2008 (QPIF, 2009).

Financial Year	Catch (Tonne)
1997/1998	223
1998/1999	148
1999/2000	191
2000/2001	117
2001/2002	127
2002/2003	61
2003/2004	45
2004/2005	110
2005/2006	178
2006/2007	181
2007/2008	115

Management

The East Coast Trochus Fishery (ECTF) is managed under the Queensland Fisheries Act 1994 and in accordance with the Queensland Fisheries Regulation 2008 (QPIF, 2009). Sections for the fishery operate within the Great Barrier Reef Marine Park and as such the ECTF is also managed under the Great Barrier Reef Marine Park Act 1975 and its regulation and zoning plan, the Queensland Marine Parks Act 2004 and Marine Parks Regulation 2006, and relevant gazetted notices and permit conditions (QPIF, 2009).

The East Coast Trochus Fishery (ECTF) is managed through a series of input and output controls, which vary between commercial and recreational fisheries (QPIF, 2009). The TAC is set at 250 tonnes, with a minimum size limit of 80 mm and maximum limit of 125 mm (QPIF, 2009). The ECTF was granted a five-year exemption from export requirements of Part 13A of the Environment and Protection Biodiversity Conservation Act 1999 on 7 June 2005 (QPIF, 2009). The exemption acknowledges that the fishery is being managed in an ecologically sustainable manner and allows the continued export of trochus caught in Queensland waters (QPIF, 2009). Fishing in the

ECTF is considered sustainable at current levels. The fishery is regarded as being managed in a precautionary and sustainable manner (QPIF, 2009).

Research

Initial management of the ECTF was based on results of a study on the distribution and abundance of trochus on the Great Barrier Reef (Nash, 1985). In 1991, a more rigorous stock assessment of trochus on the GBR was commissioned by QDPI, over concerns relating to the setting and allocation of quotas and size limits (Young & Challen, 2004). An accurate estimate of the size of the trochus standing stock on the GBR was determined and a model developed for trochus production, in order to estimate a sustainable yield from the fishery (Larcombe, 1993). The study also investigated size distribution, size and fecundity relationships, growth rates and mortality of trochus (Larcombe, 1993). The current management strategies for the ECTF are based on these results (Young & Challen, 2004).

Western Australia

Area description, coverage

In Western Australia, trochus are fished from remote offshore reefs and the inshore reefs extending from One Arm Point to the eastern side of King Sound, and north-east up to the Bathurst, Irvine and Cockatoo Islands (Bellanger, 2009).

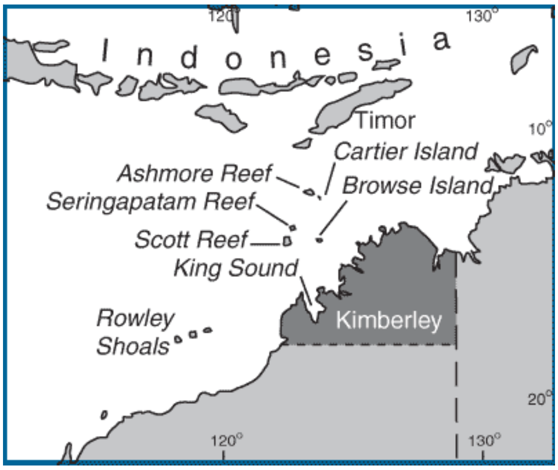


Figure 4. Map of the trochus fishing area of Western Australia (ACWA, 2009).

Stakeholders

On the remote offshore reefs of Western Australia, trochus are fished by Indonesian fishers. On inshore reefs, trochus are fished by the Bardi, Jawi and Myala indigenous communities from One Arm Point (ACWA, 2009).

Catch

In recent decades, harvests from the reefs north of King Sound, Western Australia, dropped from over 135 tonnes per annum in 1980 to 30-50 tonnes per annum in the 1990's. In 1998, the harvest was only ~12 tonnes (Crowe *et al*., 2002). Anecdotal accounts from fishermen suggest these reefs are becoming depleted (Magro, 1993).

Management

The collection of trochus is assessed against the Commonwealth Guidelines for the Ecologically Sustainable Management of Fisheries as required under Parts 13 and 13A of the Environment Protection and Biodiversity Conservation Act 1999 (DOFWA, 2008). Since 1995, trochus have been hand collected under the authority of an Instrument of Exemption granted under Section 7 of the Fish Resources Management Act 1994 (FRMA) (DOFWA, 2008).

On the remote offshore reefs of Western Australia, trochus are fished by Indonesian fishers under a Memorandum of Understanding (MOU) signed between the Republic of Indonesia and the Commonwealth of Australia in 1974 (ACWA, 2009). Under the MOU, only sailing vessels are allowed into the offshore zone.

A number of policy guidelines have been developed for implementation of re-seeding initiatives in the Kimberley region, these include (DOFWA, 2009):

1. Relocation of brood stock to areas with few trochus (fishing for these brood stock must be discouraged).
2. Releasing large numbers of small hatchery-produced juveniles (losses to predators are a major risk).
3. Release of large juveniles after an extended nursery phase in cages on reefs (major risks are high costs, insufficient food supply and storm damage to cages).

Methods used depend on what is appropriate for local conditions, success can be variable due to the differences in biological and physical characteristics of individual reefs (DOFWA, 2009). These methods all require a long-term change in fishing strategy involving sustainable management, so that enhanced reefs are not overfished (DOFWA, 2009).

Research

Increasing scarcity of trochus in King Sound, Western Australia, where aboriginal communities have fished for centuries, raised concerns of over harvesting (ACIAR, 2009).The Northern Territory University worked with the Bardi Aboriginal community from One Arm Point and other communities in the Kimberley, to develop hatchery techniques for trochus and undertake re-seeding trials on depleted reefs (ACIAR, 2009). Significant potential for increasing and sustaining the annual harvest of wild trochus was demonstrated through stock enhancement using cultured juveniles (Purcell & Lee, 2001).

The Department of Fisheries Western Australia (DOFWA) conducted research through joint funding with the Australian Centre for International Agricultural Research (ACIAR), on the benefits of mass release of juveniles (1-4 mm) on reefs along the Kimberley coast (Purcell & Lee, 2001). It was found that the release of unprotected juveniles onto coral reefs worked well for this region (ACIAR, 2009).

<u>Indo Pacific Region</u>

Trochus niloticus is native to countries of the Western Pacific and has been introduced to many additional locations throughout the Pacific Islands (Preston, 1992). The Pacific Islands region is the most important trochus producing area in the world (Preston, 1992). Proper resource management, marketing strategies and evaluation of processing capacity, are all dependent on the knowledge of the amount of trochus harvested (ICECON, 1997). Despite their importance, the trochus statistics for most Pacific Island countries remain poor and need to be derived from a variety of sources, including fisheries statistics, export permit records, customs export data, and specialised surveys (ICECON, 1997).

Trochus production from the 22 Pacific Island countries and territories during 1985 to 1994, were estimated using the best available documentation (ICECON, 1997). The Pacific Island countries harvested an average of 2,300 tonne of trochus annually. This total also includes unreported trochus, estimated to be 25 per cent (ICECON, 1997).

Table 2. Pacific Islands trochus harvests (tonnes) from 1985 to 1994 (ICECON, 1997).

Country	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Average 1985/94
American Samoa	~	~	~	~	~	~	~	~	~	~	0
Cook Islands	27	45	18	0	26	0	0	26	0	0	14
Micronesia	132	332	132	339	132	227	199	172	132	266	206
Fiji	294	250	250	400	250	200	n/a	n/a	n/a	243	271
French Polynesia	43	0	0	0	0	380	36	82	87	27	66
Guam	1	1	1	1	1	1	1	n/a	n/a	0	1
Kiribati	~	~	~	~	~	~	~	~	~	~	0
Marshall Islands	n/a	n/a	100	150	145	100	0	0	0	0	62
Nauru	~	~	~	~	~	~	~	~	~	~	0
New Caledonia	518	305	270	110	213	103	127	190	107	274	222
Niue	~	~	~	~	~	~	~	x	x	x	0
Northern Marianas	n/a	n/a	n/a	n/a	15?	n/a	n/a	n/a	n/a	n/a	n/a
Palau	104	32	87	163	257	0	0	229	29	0	90
Papua New Guinea	437	535	441	437	275	346	164	282	392	n/a	368
Pitcairn	~	~	~	~	~	~	~	~	~	~	0
Solomon Islands	500	662	445	460	371	376	287	320	394	306	412
Tokelau	~	x	x	x	x	x	x	x	x	x	0
Tonga	~	~	~	~	~	~	~	x	x	x	0
Tuvalu	x	x	x	x	x	x	x	x	x	x	0
Vanuatu	75	75	67	86	100	170	130	150	160	107	112
Wallis & Futuna	n/a	n/a	15	15	18	17	34	17	16	34	21
Western Samoa	~	~	~	~	~	~	~	x	x	x	0
Total											1845

n/a: Harvest data not available
~: *Trochus niloticus* does not occur
x: Trochus transplanted but not yet harvested

- Case study: Solomon Islands

At West Nggela, in the Solomon Islands, several approaches were taken to assess the artisanal trochus fishery. These included calculating stock density, which demonstrated many of the reefs were overfished, as well as understanding the social and economic factors influencing the performance of the fishery (Foale, 1998). The importance of fishers' ecological knowledge was found to be extremely valuable with respect to stock assessment. In turn, fishers' understanding of the biology and ecology behind stock assessment and management decisions, led to better implementation of harvest strategies (Foale, 1998).

A lack of knowledge about the planktonic larval phase of many reef fauna, including trochus and the implications this has for recruitment failure was realised. This knowledge gap directly contributes to poor management practices and overharvesting of these fisheries. Collaboration and/or consultation with scientists and training of community representatives from fisher groups proved to be highly valuable (Foale, 1998). It was found new information needed to be presented in similar cognitive frameworks to existing local knowledge, allowing it be identified with and incorporated into local custom. The synergistic combination of specialised expertise of both scientists and rural fishers led to significant improvements in community-based management strategies (Foale, 1998).

Multiple reservations were established, spaced more closely than the average trochus larval dispersal distance of about 10 km (Foale, 1998). Reefs downstream (‘sink reefs) of others, are likely to receive larvae from the latter (source reefs), and are thought to be capable of sustaining much higher levels of fishing pressure (Foale, 1998). This protects against the collapse of fisheries both locally and on neighbouring reefs (Foale & Day, 1997).

Other suggested management measures for West Ngglea included a reduction in fishing effort, re-seeding of reefs with cultured juveniles and the enforcement of a higher minimum size limit at the market end (Foale & Day, 1997). An increase in the minimum size limit from 8 cm to 9 cm, improves egg production and yields (Foale & Day, 1997). Although an increase in minimum size is unlikely to result in rapid increases in stock densities on heavily fished reefs, it is considered to be a strategy that will lead to more robust fisheries in the long term (Foale & Day, 1997).

- Case study: Cook Islands

The Aitutaki fishery in the Pacific (Cook Islands) is believed to among the best managed in the region (Foale, 2008). It is run on a simple quota system and is subject to regular stock assessments involving members of the local community (Foale, 2008). The management scheme at Aitutaki was developed over several years of collaboration between the Cook Island Fishery Department and the Aitutaki community (Foale, 2008).Harvest presently takes place over a period of only one or two days, with each animal being landed live for size verification before shucking (Preston, 1992).

Sustainable fishing

A number of trochus fisheries in the Indo-Pacific region have suffered from over-harvesting, with these fisheries no longer yielding their full potential (Foale & Day, 1997; Clarke *et al*., 2003; AFMA, 2008). Evidence of stock collapse due to recruitment overfishing of trochus, has been reported for several reefs on the Great Barrier Reef and in New Caledonia (Foale & Day, 1997). In recent decades, harvests from the reefs north of King Sound, Western Australia, dropped from over 135 tonnes per annum in 1980 to 30-50 tonnes per annum in the 1990’s. In 1998, the harvest was only ~12 tonnes (Crowe *et al*., 2002).

Trochus are highly vulnerable to any form of intensive exploitation (David, 2006). Seven ways of managing trochus have been suggested, these include a) catch size limits (minimum and maximum), b) limiting access to fishing areas, c) catch quotas (total allowable catch), d) fishing seasons, e) re-seeding of reefs with aquaculture reared juveniles and/or translocation of wild brood stock, f) fishing catch effort log books and g) analysis of fishery data (David, 2006). Combinations of these management options are implemented depending on results of stock structure analyses (David, 2006). Analyses also allow the effectiveness of management strategies to be assessed (David, 2006). Detailed socio-cultural studies have also been shown to benefit management of these small-scale subsistence and artisanal fisheries (Foale, 1998).

Data that needs to be collected for fisheries to enable sustainable management includes trochus abundance, density and if possible growth rates. At West Nggela in the Solomon Islands, the Peterson mark recapture technique is used to estimate trochus numbers on reefs. Trochus are marked with a pencil on the nacre of the shell just inside the aperture (Foale, 2000). Marking is typically timed to proceed harvest by two or three weeks, allowing marked animals time to mix with the rest of the trochus population (Foale, 2000). Densities of trochus can be calculated using abundance data and the area of trochus habitat (Foale, 2000).

Growth rates have been found to vary geographically, with studies showing differences between trochus from Japan, New Caledonia, Australia and Vanuatu (Lemouellic & Chauvet, 2008). Management strategies need to incorporate these growth variations within fisheries, and adjust size restrictions to suit (Lemouellic & Chauvet, 2008). In the Cook Islands, size restrictions of trochus are set at 80-120 mm (BSW) at Aitutaki and 75-110 mm (BSW) at Penryhn, where trochus grow more slowly (Ponia *et al*., 1997).

<u>Methods for enhancing trochus fisheries</u>

Aquaculture

Spawning and tank culture of *Trochus niloticus* was first carried out by Heslinga & Hillmann (1981) (DOFWA, 2009), with standardised induced spawning and mass production of juveniles achieved by Lee (1997).

Brood stock are kept in holding tanks in seawater at ambient temperature (28-30°C), with strong aeration (DOFWA, 2009). Between 30 and 100 animals are needed for a successful spawning, only a small percentage of adults are ready to spawn at any one time. Trochus are induced to spawn using a 'temperature shock' method. At sunset, the water temperature in the holding tank is raised and maintained by 2-3°C above ambient, adults usually spawn within the hour (Lee, 1997). The neutrally buoyant, fertilised eggs are removed from the holding tank using a fine (100 µm) mesh net. Several hundred thousand eggs are typically transferred to a 1000-3000 L culture tank containing aerated seawater. Seawater is filtered to 5 µm, to exclude larvae of animals which may eat or compete with juvenile trochus (Lee, 1997).

The bottom of each tank is lined with a thin layer of coral rubble, this acts as a substrate for benthic diatoms upon which trochus juveniles feed (Lee, 1997). Cultures of benthic diatoms (eg. *Navicula* spp. and *Nitzchia closterium*) are introduced into the tanks a week prior to spawning and fertilised with 20-50 ppm Aquasol (a commercial fertiliser used in horticulture) (Lee, 1997). Culture tanks are kept under shade-cloth, which reduces UV light and allows partial sunlight, providing good growing conditions for diatoms (Fulks & Main, 1991). Trochus larvae do not feed until after settlement. For optimum larval survival and juvenile growth, the salinity in culture tanks should be maintained at 35 ppt and the temperature kept at 30-33°C (Lee, 1997). More than 50,0000 juveniles can be grown to 3 mm size in each tank, this typically takes 6-8 weeks (Lee, 1997; DOFWA, 2009). Juveniles can be cultured in tanks to adult size, however this is considered to be uneconomic as densities need to be continually lowered to avoid overcrowding (Lee, 1997; DOFWA, 2009).

Determining the sex of *Trochus niloticus* for induced spawning is extremely difficult, as males and females cannot be distinguished from each other by external shell characteristics (Dobson & Lee, 1996; Foale, 1998). A method was developed by Dobson & Lee (1996), where a simple 'window' is cut through the shell to reveal the nacre layer, which the gonad can be seen through underneath. The sex of the animal can be determined by the colour of the gonad, dark green for females and creamy white for males (Dobson & Lee, 1996). Successful spawning inductions were achieved using this method, with no obvious stress or mortality observed to brood stock animals (Dobson & Lee, 1996). Other ways found to sex trochus include pushing the animal back into the shell, collecting the water produced inside the shell and looking at under the microscope, where sperm or eggs can be seen (Wright & Hall, 1993). Removing trochus from the water, letting them sit and looking at the colour of the water under the animal also works , the water has a white tinge for males and green tinge for females (pers. comm. S. Naawi).

Stock enhancement is not always economically viable and should be assessed as part of a package of management techniques such as habitat protection, fishery regulation or stricter enforcement of size limits (Crowe *et al*., 2002). In cases where existing stocks are critically low or locally extinct, a program of stock enhancement may be the only option (Crowe *et al*. 2002).

Re-seeding Initiatives

High rates of mortality attributed to predation have been reported for studies trialling the release of small (<30 mm basal shell width) juvenile trochus, from aquaculture hatcheries directly onto reefs (Crowe *et al*., 2002). Release of larger juveniles has also had shortcomings as aquaculture produced trochus can differ in shell architecture from wild juveniles, leading to potential behavioural deficiencies (Amos & Purcell, 2003). Evidence from other gastropods also suggests that cultured juveniles can be behaviourally naïve, resulting in abnormally high rates of predation upon release compared to wild juveniles (Amos & Purcell, 2003).

Intermediate culture of trochus in reef-based cages has proven an effective approach for providing sub-adults for restocking, while protected from predators (Amos & Purcell, 2003). Trochus feed on a range of epilithic algae and detritus and can be cultured in cages without feed supplements if cage substrates have established algae (Amos & Purcell, 2003). Advantages of sea cages over land-based systems include lower cost, simplicity of construction, manageability, ease of relocation and the benefits of using existing water bodies (Amos & Purcell, 2003). While cage culture requires the construction and maintenance of cages, it is considered more cost-effective for restocking than the free release of juveniles (Amos & Purcell, 2003). The grown-out trochus can then be released onto reefs with much higher rates of survival to replenish adult stocks (Amos & Purcell, 2003). Research in Vanuatu, Indonesia and King Sound (Western Australia), showed that intermediate culture of juveniles in cages on the reef to a size of 30-40 mm, was highly successful (DOFWA, 2009). At 40 mm juveniles were less vulnerable to predation after cage release (DOFWA, 2009).

Western Australia

In 2001, a 3.2 million multi-species hatchery was built in Broome, managed by the Kimberley Aquaculture Aboriginal Corporations (KAAC) (ACIAR, 2009). The KAAC hatchery supplies juvenile trochus to aboriginal communities that hold aquaculture licences, for re-seeding onto reefs in the Kimberley region (ACIAR, 2009).

The majority of trochus shells collected from the Kimberley are currently sold through Perth at a wholesale price around $9.50 per kg (DOFWA, 2009). Some aboriginal communities value add to this product by polishing trochus shells for ornaments that sell for $20 to $50 apiece (DOFWA, 2009). Recent interest has also been expressed on the processing and export of trochus meat, known to fetch a high price in Japan (DOFWA, 2009).

Solomon Islands

In the Solomon Islands, Clarke *et al*. (2003) found higher growth rates and survival of hatchery size trochus (30 mm), when grown to 46 mm in cages (with juvenile giant clams) before release. Growth was also found to be significantly higher at densities of 14 trochus juveniles m^{-2} than at 28 juveniles m^{-2} (Clarke *et al*., 2003). Trochus were found to not be detrimental to clam culture (Clarke *et al*. 2003).

Vanuatu

Trochus have been heavily exploited in Vanuatu for decades. To prevent stock collapse, the Vanuatu Fisheries Department (VFD) instigated aquaculture initiatives to replenish overfished stocks and substitute the export of wild-caught trochus with hatchery raised animals (Teitelbaum & Rena, 2008). The VFD hatchery has been producing trochus since the early 1980's, the annual production from the hatchery is around 20,0000 juveniles, most of which are supplied to communities for restocking purposes (Teitelbaum & Rena, 2008). In 2006, 36 tonnes of processed trochus shell was exported to China and Hong Kong, with shells sold to button factories for 3.3-4.7 US$/kg; in 2007, 55.2 tonnes was harvested (Teitelbaum & Rena, 2008).

Studies into cage stocking of reefs found that high numbers of juvenile trochus can be cultured in cages to 40-50 mm BSW in 9 months, than released onto reefs with corresponding high levels of survival to brood stock size (Amos & Purcell, 2003). The average growth rate was found to be >2.3 mm per month (Purcell *et al*., 2004). Consistently high proportions of released sub-adults were recaptured alive after 6 months, averaging a shell size of 50-60 mm believed to be within the range for size at sexual maturity (Purcell *et al*., 2004). Under community based management, release of sub-adult trochus was a successful, final step in promoting hatchery-produced juveniles to maturity, allowing natural restocking of types of depleted reefs in Vanuatu (Purcell *et al*., 2004).

Policy framework for enhancing reefs (Western Australia) (DOFWA, 2009)

The licensing pathway that allows groups to enhance and harvest specific reefs is governed by the Department of Fisheries, in formal interaction with other state departments (DOFWA, 2009). These departments share a duty of care for maintaining the biodiversity and quality of these reefs (DOFWA, 2009). A series of principles were developed relating to re-seeding of molluscs on reefs specifically for enhancing trochus fisheries (DOFWA, 2009), these include:

1. Impact on genetic diversity
2. Risk of the introduction of disease and pests to wild populations
3. Physical disturbance to the reef during re-seeding operations
4. Impact on the ecology of the reef system

In addition, natural predators are not allowed to be controlled around reefs where trochus are released and the use of artificial feeds is banned in the production or restocking of trochus in the Kimberley region (DOFWA, 2009).

Translocation and introduction of trochus

Translocation of trochus brood stock has been used extensively throughout the Pacific as a way of establishing breeding populations on reefs (Purcell & Lee, 2001). Trochus were introduced to Penrhyn, Cook Islands from Aitutaki in the mid 1980's, the abundance of trochus 10 years later was estimated at 27, 300 (Ponia *et al*., 1997). In accordance with the sustainable limits for trochus harvesting set on Aitutaki, which allows 30% of the population in the legal size range to be removed (Ponia *et al*., 1997). A harvest of 30% of trochus in the 75-110 mm size range was fished at Penryn, equating to a catch of 5, 000 animals (Ponia *et al*., 1997).

The Aitutaki population itself originated from just 280 shells translocated from Fiji in 1957 (Ponia *et al*., 1997). They were left to breed undisturbed for more then 20 years before being fished in 1981, when 200 tonne was harvested. Since then, trochus have been harvested at irregular intervals over several years. The last harvest at Aitutaki in 1995 amounted to about 25 tonne of dry shell (Ponia *et al*., 1997).

In addition to Penryn and Aitutaki, trochus have been successfully introduced to numerous Pacific Islands and French Polynesia from 1927 to 1998 (Gillet, 2002). Trochus were also transplanted to many parts of Micronesia by the Japanese between the two World Wars (Gillet & Gaudechoux, 2001). Introduced populations usually reach commercially exploitable levels within 20-25 years (Chambers, 2007).

On the Great Barrier Reef, Trochus fishermen are reported to have transplanted trochus to previously productive reefs, that had been depleted from fishing (Wright & Hall, 1993).

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