RESEARCH FOR SUSTAINABLE USE OF BECHE-DE-MER RESOURCES IN MILNE BAY PROVINCE, PAPUA NEW GUINEA

CSIRO DIVISION OF MARINE RESEARCH FINAL REPORT

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This report contains the results of a beche-de-mer stock survey carried out in Milne Bay Province in late 2001 by CSIRO, PNGNFA and Conservation International (CI). The project was funded by ACIAR, CI, CSIRO and PNGNFA. We would like to thank the Captain and crew of the MV James Kirby for their able assistance. We would also like to express our sincere appreciation to the people of Milne Bay for their warm welcome and friendliness during the survey.

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Summary

Milne Bay Province is a 256,000 km^2 area of Papua New Guinea (PNG) situated at its eastern extreme. It contains about 5,355 km^2 of reefs and shoals (<20m deep) which accounts for about one third of all the reefs of PNG.

The most important artisanal fishery in the province is beche-de-mer with catches peaking in 2001 at over 209 tonnes (dry wt) with an estimated value of over 8M Kina (US$2M). Milne Bay is the most important supplier of beche-de-mer for export in PNG .The beche-de-mer fishery operates at the community level.

In October and November 2001, we surveyed the shallow reefs and shoals (0 - 20 m deep) at 1126 locations throughout a large section of Milne Bay Province to estimate the distribution and abundance of commercial holothurians in the area, and to assess their fishery status.

The overall average density of commercial holothurians was 21.2 per ha, which equated to a total live wet weight of 15,347 tonnes (± 4,082 tonnes, 90 % CI), or approximately 920 t (± 245 t, 90 % CI) of dried beche-de-mer. The most abundant commercial species was *H. atra* (lollyfish) (49 % by weight) followed by *S. chloronotus* (greenfish) (17 %) and *T. anax* (amberfish) (8 %). Premium value beche-de-mer species (*H. nobilis, H. fuscogilva, H. scabra, T. ananas*; black teatfish, white teatfish, sandfish, prickly redfish) comprised only 9 % by weight of all commercial holothurians. Low survey densities and a comparison of historical catch data indicates the *H. scabra* (sandfish) and *H. nobilis* (black teatfish) populations are grossly overexploited.

Goodenough LLG had the highest estimated overall density of commercial holothurians (216.1 per ha) and Louisiade LLG had the lowest (4.9 per ha). Generally the central LLGs had very low densities compared with the western and northern LLGs. Premium value species were in low densities throughout the study area apart from Bwanabwana (2.36 per ha), Maramatana (4.12 per ha) and Yeleyamba (1.83 per ha) LLGs (Fig. 10).

Kiriwina LLG had the highest estimated standing stock of commercial holothurians in the study area, 4,253 tonnes (± 1,429 tonnes, 90% CI), followed closely by Murua and Yeleyamba LLGs. Dobu and Maramatama LLGs had the lowest standing stocks (<100 tonnes). Louisiade LLG also had a very low standing stock, 242 tonnes (± 101 tonnes, 90% CI) considering its large size.

While the overall population estimate is reasonably encouraging given historical catch rates, the overall density of commercial species in Milne Bay is very low when compared to similar fisheries in eastern Torres Strait and the northern GBR. Also, LLGs that have been traditionally fished heavily are the most depleted. There has also been a 58% reduction in the proportion of the catch made up of premium value species since 1990. The total number of species exported has also increased from 14 in 1993 to 18 in 2001. All additional species were low value species.

While there is still a significant population of commercial holothurians in Milne Bay Province, the resource is grossly overexploited for some species at least, and for some LLGs. Management measures should be implemented immediately to curb fishing effort in depleted LLGs such as the Loiusiade LLG, and on depleted species such as *Holothuria scabra* (sandfish) and *H. nobilis* (black teatfish). Measures will have to be considered that ensures

that fishing effort is not transferred from protected species/areas to more abundant species/areas in the province.

The current total allowable catch (140 t TAC) for the fishery is substantially greater than the lowest estimated maximum sustainable yield (108 t) and is probably too high to allow for a recovery of depleted areas and species, and for a subsequent increase in yield from the fishery. The current holothurian density is most likely substantially lower than virgin biomass levels therefore there is some risk of stock collapse. Given the recent history of the TACs being exceeded in the Province, catches should be monitored carefully and TACs strictly enforced.

Interim management recommendations

- Close the *H. scabra* (sandfish) and *H. nobilis* (black teatfish) fishery.
- Strictly enforce the current TAC (140 t) given it is substantially greater than the lowest estimated maximum sustainable yield (108 t) and the recent history of the TACs being exceeded in the Province. Consideration should be given to reducing the TAC in 2003, given the depleted state of some species and LLGs, and the possibility of stock collapse.
- Divide the total TAC into three categories, high, medium and low value (see conclusions for species composition), and restrict the catch of each category as follows: high value 7%, medium value 18%, low value 75%.
- Consider mechanisms for managing the Milne Bay fishery at the level of individual LLGs such as individual LLG catch limits. Heavily depleted LLGs such as the Louisiade LLG should see a drastic reduction in fishing effort.
- Ensure minimum sizes are larger than published size at maturity for each species in the fishery. Enforce minimum size limits, and educate fishers to return undersize animals alive.

INTRODUCTION

Milne Bay Province is a 256,000 km^2 area of Papua New Guinea (PNG) situated at its eastern extreme (Fig. 1). It contains about 15,000 km^2 of landmass and 5,355 km^2 of reefs and shoals (<20m deep) which accounts for about one third of all the reefs of PNG. It has approximately 205,000 people representing a diverse range of cultures who live mainly on the coast. With an estimated average annual household income of just US$130.00 (Kinch, 2002), they rely heavily on artisanal and subsistence fishing for their livelihood. The marine environment is also important to the culture of the area and supports a developing sea-based tourism industry. The pressure on the marine resources of the Province is likely to increase in the future due to the high rate of population growth (2.5 % per annum) and increasing desire for a cash income.

The most important artisanal fishery in the province is beche-de-mer with catches peaking in 2001 at over 209 tonnes (dry wt) with an estimated value of approximately 8M Kina (US$2M). The beche-de-mer fishery operates at the community level. Villagers collect and process beche-de-mer and the product is sold to exporters, mostly bound for markets in Hong Kong and Singapore. Milne Bay is the most important supplier of beche-de-mer for export in PNG with its total contribution rising from 10 - 15% in the early 1990s to over 30% in 2000 (Kinch, 2002), due to an increase in the Milne By catch and a decrease in other areas such as Western and Manus Provinces. The fishery of the Western Province in particular has become depleted several times since 1990 and is probably producing at well below its maximum sustainable yield (Lari, 2001).

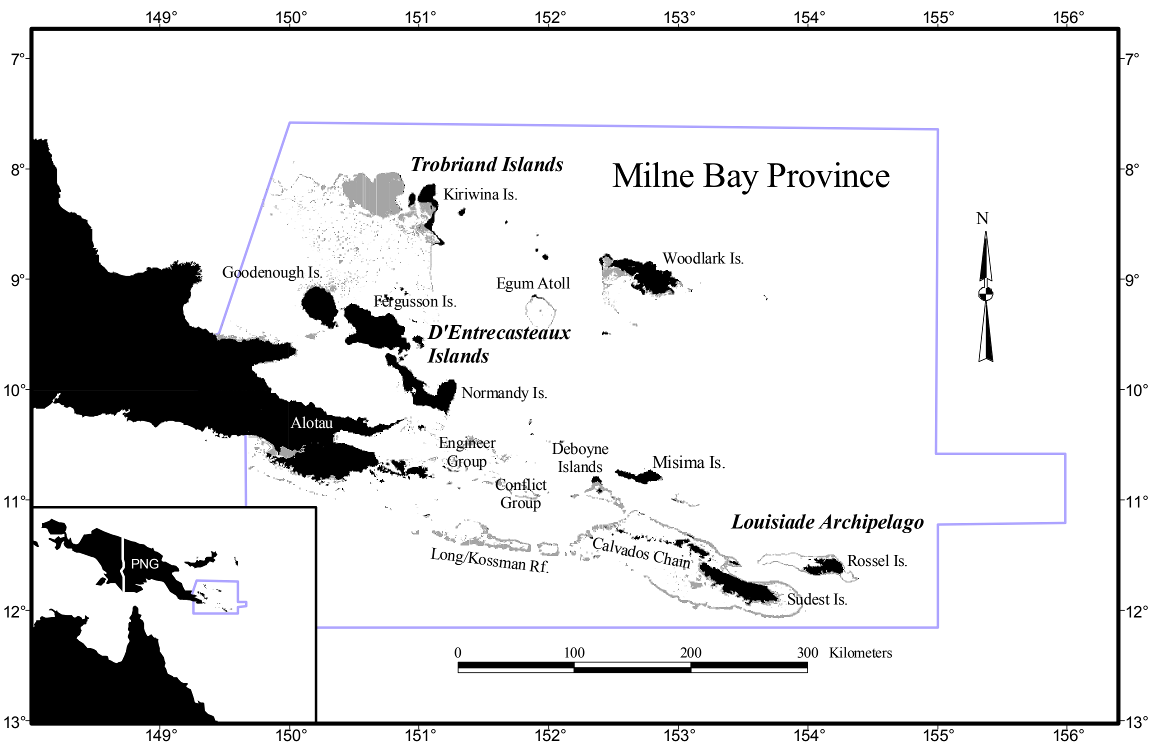

Figure 1. Map of Milne Bay Province showing the major island and reef groups.

The catch and total income derived from beche-de-mer fishing in Milne Bay increased dramatically throughout the 1990s, mainly due to the dramatic increase in the value of beche-de-mer over that period, and declining prices for traditional cash commodities such as copra (Preston, 1993; Kinch, 2002). Prices paid for beche-de-mer in Milne Bay Province have increased greatly during the past 10 years with increases of up to 3000 % for some species. The total value of the fishery in Milne Bay increased from 0.3M Kina in 1993 to over 8M Kina in 2000 (Kinch, 2002).

Bech-de-mer is the processed body wall of holothurians. Holothurians are highly diverse, abundant and exclusively marine invertebrates that play crucial roles in the recycling of nutrients and bioturbation processes in marine benthic communities. While over 1000 species have been described, only about two dozen are commercially important in the tropics and most of these occur in Milne Bay (Cannon and Silver, 1986; Preston, 1993; Allen *et al.*, 2000). They have been harvested for centuries in Asia and have become an important source of income for fishing communities worldwide.

The commercial value of a species is generally determined by its size and the thickness of the body wall. Species of high commercial value such as *Holothuria nobilis* (black teatfish) *H. fuscogilva* (white teatfish) and *H. scabra* (sandfish) tend to be fished preferentially. Medium value species include the genus Actinopyga (blackfish, redfish or red surf-fish), and *Thelenota annas* (prickly redfish). Other shallow water tropical species fall into the low- or no-value category (Conand, 1990).

The history of beche-de-mer fisheries goes back for thousands of years. Beche-de-mer is in demand principally in China and South-east Asia, where it is considered a delicacy. The main markets are Hong Kong and Singapore, with smaller markets in Korea, Taiwan and Malaysia. The current high demand for beche-de-mer now is likely to continue, and may strengthen, due in part to the high economic growth in China.

Papua New Guinea National Fisheries Authority (PNG NFA) is the agency responsible for overall management of beche-de-mer fisheries in PNG, including the Milne Bay Province beche-de-mer fishery. Management arrangements are formulated by a National Management Advisory Committee (NMAC) for presenting to the National Fisheries Board for ratification. Input from provincial stakeholders occurs through Provincial Management Advisory Committees (PMAC), one of which exists for Milne Bay Province, which has a broad representation of fishery stakeholders and provides at least one representative to the NMAC.

PNG NFA has developed a *National Beche-de-mer Management Plan* (Anon., 2001) for beche-de-mer fisheries in PNG. The primary objectives of the management plan are to maximize economic benefit from the fishery to both the nation and the local inhabitants, to ensure the use of the beche-de-mer resource is sustainable, and to minimize impacts on the marine and coastal environment. The principal management mechanisms used to protect the fishery from overexploitation are provincial level total allowable catches (TAC), including some individual quotas for higher value species, minimum legal sizes (live and dry), gear restrictions (no underwater breathing apparatus), and a minimum closure period (1st October to 15th December). However there is insufficient information with which to complete the development of, and have confidence in, these management plans. PNG NFA have identified research to support sustainable use of beche-de-mer resources as an urgent priority.

There was some evidence that the beche-de-mer resource in Milne Bay was coming under increasing, and perhaps unsustainable, fishing pressure. Some limited surveys of the area indicated low abundances in some areas of high fishing pressure, particularly of the higher value species. There have been attempts to carry out stock assessments of beche-de-mer in

Milne Bay in 1980 (Chesher, 1980) and 2000 (Allen *et al.*, 2000). While these surveys provide indicative abundance levels, species composition and limited distribution data, they were not able to produce population parameter estimates useful for designing robust management strategies. The most recent survey did however indicate some depletion of the commercial holothurians (beche-de-mer), especially the higher value species.

Experience elsewhere has demonstrated that beche-de-mer fisheries are extremely prone to overexploitation, and the recovery of depleted populations is slow and sporadic (Anon., 2001*b*), particularly for the shallow species such as *H. scabra* (sandfish). In Torres Strait, the *H. scabra* fishery has still not recovered from heavy depletion in 1996, even though the fishery has been closed since 1998 (Skewes *et al.*, 2000). *H. nobilis* (black teatfish) are also a particularly vulnerable species and are considered overexploited in the Great Barrier Reef (GBR) (Uthicke and Benzie, 2001) and Coral Sea fisheries (Hunter *et al.*, 2002).

Stock size and indications of stock status are two useful parameters on which to base robust management strategies. In the absence of detailed, reliable fisheries data, stock size can only be estimated by abundance surveys. Using a combination of outputs from the abundance survey and limited fishery dependant data (eg yearly catch), stock status can be estimated with some confidence. These parameters can then be used to indicate future catch levels that allow for sustainable development of the fishery, using rule of thumb surplus production models. Repeated measures sample strategies can also be formulated using the original survey data to allow for efficient fishery independent monitoring to assess the impact of future management strategies and monitor population trends. Certainly, the application of sustainable management strategies would increase the production of fisheries in the longer term, by maximising yields and reducing the risks of stock collapse.

Objective

The overall objective of the project is to provide stock size and stock status information for each species of commercially important beche-de-mer in Milne Bay and to formulate sustainable management strategies for the Milne Bay beche-de-mer fishery for implementation early in 2002.

METHODS

Milne Bay study area

Milne Bay is divided into 15 maritime Local Level Government (LLG) areas, 9 of which were sampled during the survey (Fig. 2). There is also a Provincial waters LLG that contains some reef areas, however, for the purposed of this study, these reefs were included in adjacent LLGs, for example, the Louisiade and Yeleyamba LLGs.

Given the large extent of shallow reefs distributed over the large area of the Province, we further divided the Province into 26 zones (Appendix C), based on available catch information, likely holothurian abundance and physiographic characteristics of the fishery habitats. The zones were formulated after consultation with various stakeholders and from analysis of existing information. These zones formed the basis for the sample design and stratified analysis.

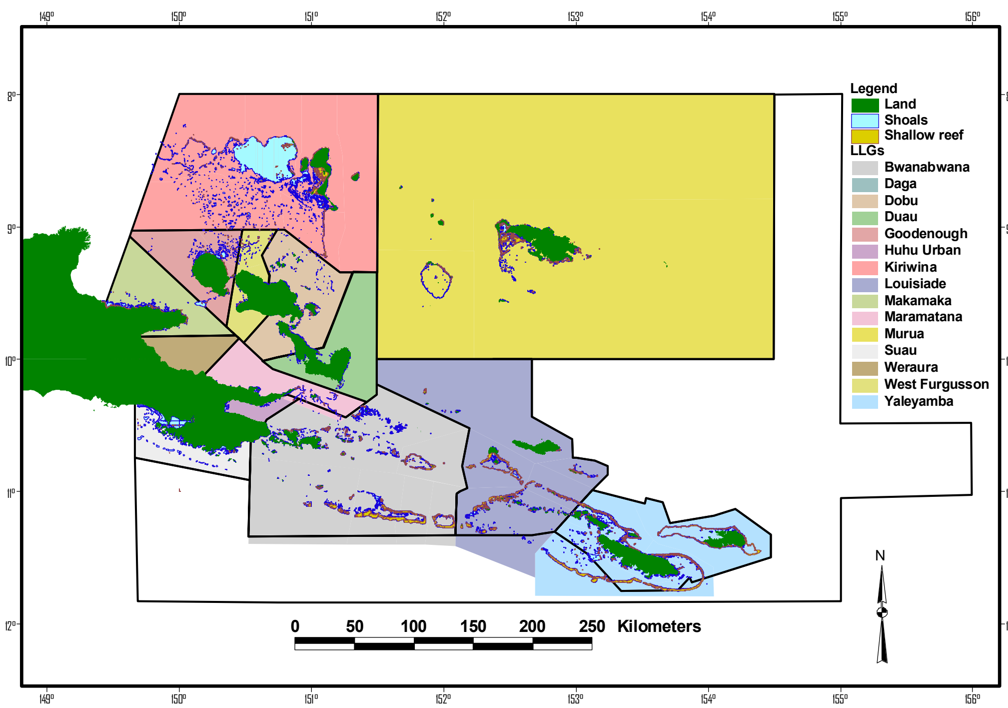

Figure 2. Map of Milne Bay showing the Local Level Government (LLG) boundaries. Dark lines represent the official LLG boundaries; colours represent LLG boundaries used for analysis. Land and marine habitat map constructed from classified satellite images and commercially available chart data.

A marine habitat map that delineated shallow reefs (0 m – 10 m deep) and shoals (10 m – 20 m deep) was constructed from various remote sensed and commercially available spatial data. Initially, satellite data (LandSat TM5) of the Milne Bay region was image processed to delineate and quantify the area of the reefs and shoals, and to produce provisional reef habitat types. Four satellite images covering the study area were rectified by using reef-edge location data from 1:100k and 1:250k AMG topographic maps as control points in the image analysis program ER Mapper. An isodata clustering algorithm was used to group pixels in bands 2-4 into 10 spectral classes. The pixel groups were then classified into several habitat types, including shallow reefs and shoals, using data from existing nautical and topographic charts of the area, and similar analysis of groundtruthed images from surveys in Torres Strait (Long *et al.*, 1997) and Timor MOU Box (Skewes *et al.*, 1999*b*), and from limited survey data from previous surveys in the area (PNG NFA and CI). The resulting habitat classes included shallow reefs and shoals. A small area in the north-west of the study area was not covered by a suitable cloud free satellite image, therefore we used commercially available nautical and topographic chart data to construct reef and shoal habitat maps (Fig. 2). The tops and edges of these two habitat areas made up the four habitat strata used in the sample design and analysis.

Table 1. Area (km^2) of shallow reefs (0–10 m deep) and shoals (10–20 m deep) in the Milne Bay study area for each Local Level Government (LLG) area.

	Area (km^2)		
LLG	Reef	Shoals	Total
Bwanabwana	321.61	405.17	726.78
Daga	0.00	0.29	0.29
Dobu	6.38	46.27	52.65
Duau	0.80	15.32	16.12
Goodenough	16.97	116.92	133.89
Huhu Urban	0.25	14.24	14.49
Kiriwina	163.04	1950.32	2113.36
Louisiade	230.46	219.21	449.68
Makamaka	24.45	112.46	136.92
Maramatana	4.58	31.39	35.97
Murua	130.91	206.25	337.16
Suau	4.49	305.47	309.96
Weraura	0.65	0.00	0.65
West Furgusson	4.35	20.42	24.77
Yeleyamba	530.13	472.05	1002.18
Total	**1439.07**	**3915.80**	**5354.87**

The resulting classified images were then imported into a GIS and area estimates produced for each habitat type by LLG (Table 1, Fig. 2) and zone (Appendix A). The Milne Bay study area contained 1,439 km^2 of shallow reef (1 - 10 m deep) and 3,916 km^2 of shoals (10 - 20 m deep) (Table 1). The southern and eastern LLGs had approximately equal quantities of reef and shoal habitats, with the proportion of shoal habitat increasing towards the northwest (Table 1, Fig. 3). Yeleyamba LLG had the highest area of shallow reef in the province (37 %) followed by Bwanabwana (22 %) and Louisiade (16 %). Kiriwina LLG had extensive areas of shoal habitat (50 % of all shoals) and the largest total habitat area of any LLG in the province (39 % of total) followed by Yeleyamba (19 %) and Bwanabwana (14 %) LLGs (Table 1, Fig. 3).

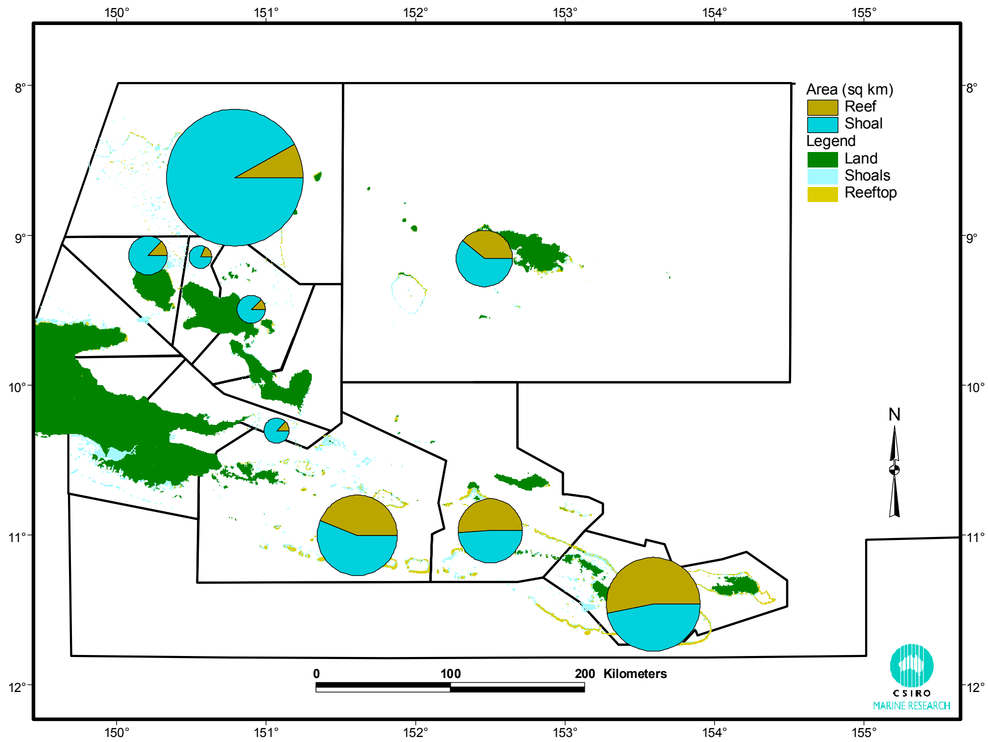

Figure 3. Milne Bay showing area of reef (0 - 10 m deep) and shoal (10 - 20 m deep) for each LLG sampled during the survey in November 2001. The area of the pie diagram is proportional to the total reef and shoals in each LLG. (Range 2113 km^2 (Kiriwina LLG) to 25 km^2 (West Furgusson LLG)).

Sample design

We sampled 9 out of the 14 LLGs, which accounted for 98 % of all shallow reefs in the province and 89 % of shoal areas, and contained the primary beche-de-mer producing areas (Kinch, 2002).

The sampling density was varied in each strata due to predicted abundance and variance estimates, logistics and time constraints. The density of sampling on the shallow reef top was 1 site per 2 km^2 and on the shoals 1 site per 8 km^2 (Fig. 3). With an equivalent effort spent on the reef edge, this meant a sampling density of one site every 4 km around the reef edge and every 10 km around the shoal edges (Fig. 2). This meant that sampling effort, in terms of the number of sites sampled, was roughly divided evenly between reef top and reef edge habitats. This allocation of sampling effort was based on the experiences of previous reef resource surveys in the Torres Strait and the Timor MOU Box, and has been shown to be the best compromise for efficient sampling of reef resources, while allowing for habitat mapping of reef top areas.

Survey sites were assigned by dividing each stratum on the reef top into 2 km^2 or 8 km^2 grids (depending on the strata type), and the reef and shoal edge into sections 4 km and 10 km long. Sample sites were then located within the grids/sections at random. For the reef top, this meant that the sample site was selected from 25 possible sites within a restricted area (75% of total) of the 2 km^2 or 8 km^2 primary sampling units. For the reef edge, the sample sites were selected at random from sites spaced 150 m along the edge within a restricted area (90% of total) of each of the primary sample units.

Generally, the sampling effort was randomly allocated to habitat strata within each zone in a representative way, except in cases where the sample areas were too spatially dispersed, such as the north west of the study area. In these areas, we allocated samples randomly within an area that could be sampled by the two teams of divers within a days sampling. This means that this area in particular is sampled in a clumped fashion. While this represents some limitations on the conclusions drawn from the data in these areas, we feel that the results are probably representative of the zone in which the sampling occurred. Generally, where areas were sampled at a different density, they were treated separately in the analysis, nullifying the potential bias that this could cause.

We sampled 1126 sites throughout the study area including 626 top and 500 edge sites (Table 2, Fig. 4). The shallow reefs were sampled at 964 sites and the shoals at 162 sites. The average depth of the shallow reefs was 2.13 m compared with the shoal sample sites at 7.69 m (Table 2).

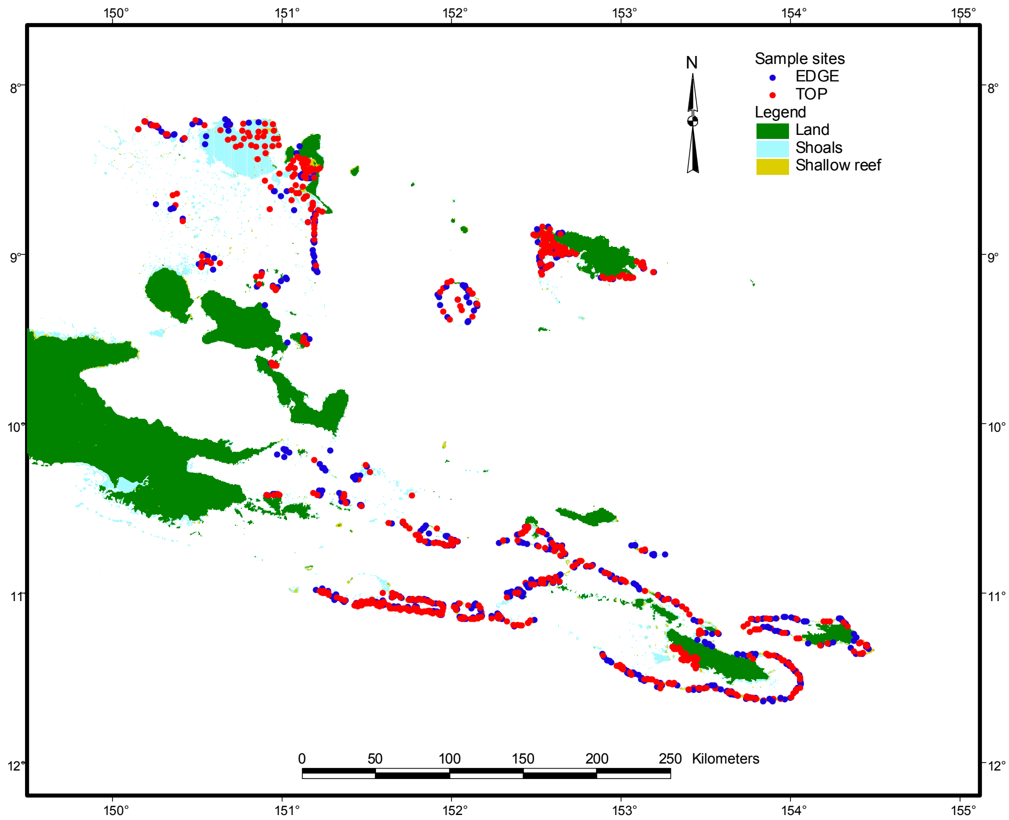

Figure 4. Map of Milne Bay showing the location of sites sampled during October/November 2001.

Table 2. Table showing strata sampled in the study area, the number of sample sites and average depth of the reef top and average strata depth of the edge strata.

Stata	*n*	Depth (m)
Reef top	529	2.13
Reef edge	435	3.82
Shoal top	97	7.69
Shoal edge	65	8.32

Field sampling

Sampling was carried out from 11 October to 19 November 2001. The survey employed rapid marine assessment techniques that have applied to beche-de-mer surveys in Torres Strait (Long *et al.*, 1996; Skewes *et al.*, 2000), Moreton Bay (Skewes *et al.*, 2002) and Timor MOU Box (Skewes *et al.*, 1999). Field work was undertaken two teams of divers operating from dinghies and locating sample sites using portable GPS. On the reef top, a diver swam along a 40 m transect and record resource and habitat information 2 m either side of the transect line. Holothurians and other benthic fauna of commercial or ecological interest were counted, and where possible, returned to the dinghy and measured (weight and length where possible). 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 was also recorded.

On the reef edge, at each site two divers swam adjacent transects perpendicular to the reef edge from the top of the reef edge to a depth of 20 m or a distance of 100 m whichever came first. One diver counted species of interest and recorded habitat information using the same protocol as the reef top, and the second diver counted species of interest and collected them for measuring back in the dinghy.

Data analysis

The data obtained from the field work were input into statistical and GIS software for analysis. Average density (number per hectare) estimates were calculated from site counts using a stratified analysis based on zones and reef strata that takes into account the heterogeneity of abundance and variance in different habitats in the study area (Appendix G).

Area estimates of the reef top and shoal strata for each zone were output from the GIS based on a spatial join of the satellite derived habitat map and zone map. Area of the reef and shoal edge habitat for each zone was derived from an edge length statistic of the shallow reef and shoal 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 and shoal 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 for reefs; and those not adjacent to land, reef and other shoal polygons for shoals. The number of selected nodes were then counted for each strata and zone, and multiplied by 150 m to produce total edge length.

Estimates of standing stock were calculated by combining estimates of density, reef area and average weight from size frequency data collected during the survey. To convert wet weight to dry weight for comparison to catch data, we used an average conversion rate for whole live to dry product of 6 % based on existing conversion rates (Conand, 1990; Preston, 1993; CSIRO, unpublished data).

Recommendations for management strategies will use the results of the stock size, population composition and stock status analyses to assess several different management strategies, using simple population dynamics principles and rule of thumb surplus production models. We used precautionary principles and assess risk where possible. Several management strategies were assessed including TACs, closed areas and seasons, and sizes limits. The emphasis was on maximising long term returns from the fishery for the inhabitants of Milne Bay Province.

Stock status

Determining stock status, generally expressed as the level of depletion compared to virgin levels, from a single abundance survey is difficult. However, we will be able to provide an indication of stock status of the main target species using the following analytical approaches.

i) A comparison of density (number per hectare) of each species with the population density of the same species on reefs in other fisheries with variable exploitation levels such as the Torres Strait and the Northern GBR (Long et *al.*, 1996; Skewes *et al.*, 1998; Skewes *et al.*, 1999), the Timor MOU74 Box (Skewes *et al.*, 1999), and the South Pacific (Conand, 1990; Preston, 1993). This analysis will take into account effort trends and the presence of similar habitats on the reefs between the different study areas.

ii) A comparison of standing stock estimates between reefs in Milne Bay study area including a comparison with effort trends that can be inferred from available information. This analysis will take into account the amount of suitable habitat for each resource species on each of the reefs.

iii) A comparison of standing stock estimates with estimates of the catch. This will give rough indications of the sustainability of the catch on a whole area basis.

iv) The selective depletion of high value species for multispecies fisheries such as beche-de-mer has been documented (e.g. Torres Strait, Long *et al.*, 1996; Skewes *et al.*, 1998: Timor Sea; Skewes *et al.*, 1999: South Pacific; Preston, 1993; Conand, 1990).

RESULTS

Note: In this section, unless stated otherwise, tonnages quoted are live wet weight.

We recorded 16 species of commercial holothurians during the survey (Fig. 5, Appendix E). We also observed several commercial species off transect, indicating their presence in low densities, including *Holothurian scabra* (sandfish, 3), *Bohadschia similis* (chalkfish, 2), *Thelenota rubralineata* (4), *Stichopus horrens* (1), *Stichopus sp.* (2), and *Thelenota sp.* (possibly a *T. ananus*/*T. anax* hybrid, 1).

Holothurians were found throughout the study area and were observed at 16.8 % of reeftop and 50.1 % of reef edge sample sites. The overall average density of commercial holothurians was 21.2 per ha and there was an estimated 10.2M (± 2.7M, 90 % CI) commercial holothurians on the shallow reefs and shoals of the study area, which equated to a total live wet weight of 15,347 t (± 4,082 t, 90 % CI) (Appendix E). This equates to approximately 920 t (± 245 t, 90 % CI) of dried beche-de-mer using an average conversion rate of 6 % (dry weight = 0.06 live wet weight).

The most abundant commercial species in the study area was *H. atra* (lollyfish) with an average density of 9.8 per ha and an estimated standing stock of 7,489 tonnes (± 2,411 tonnes, 90 % CI) (Fig. 5, Appendix E); being 46 % and 49 % of all commercial holothurians in the study area by numbers and weight respectively. Next most abundant species was *S. chloronotus* (greenfish), which was 18 % of total by number and 17 % of total by weight. Although *H. edulis* (pinkfish) was the third most abundant species by numbers (10 % of total), *T. anax* (amberfish) was third most abundant by weight (8 % of total) (Fig. 5, Appendix E).

Premium value beche-de-mer species (*H. nobilis, H. fuscogilva, H. scabra, T. ananas*; black teatfish, white teatfish, sandfish, prickly redfish) totaled only 1,366 tonnes (± 576 tonnes, 90 % CI) being 9 % of all commercial holothurians by weight, or approximately 82 tonnes of dried beche-de-mer. The medium and high-grade beche-de-mer species, as per the National Beche-de-mer Management Plan (Appendix E), totaled 4,385 tonnes (± 3,113 tonnes, 90 % CI) or 29 % of all commercial holothurians by weight (Appendix E).

The highest density of commercial holothurians was found on the reef top (Fig. 6, Appendix B), but they were almost all low value species. The highest density of medium and high grade holothurians, and by far the highest density of premium value holothurians was found on the reef edge followed closely by the shoal edge. The shoal top habitat had a low density of commercial holothurians but relatively high densities of medium and high grade holothurians.

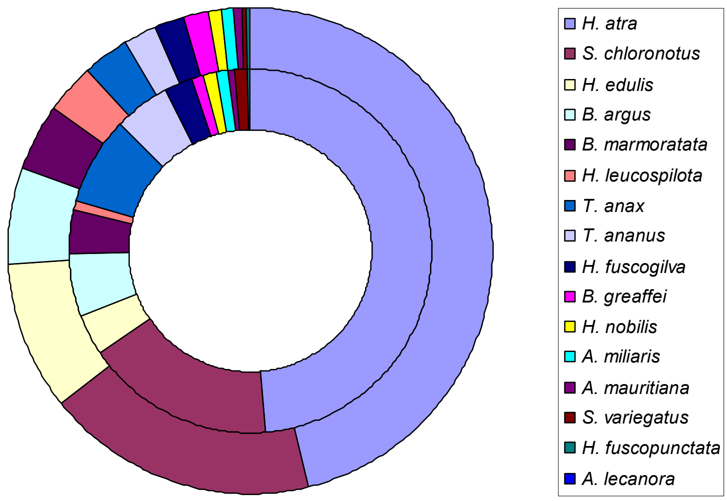

Figure 5. Multiple pie chart showing species composition of the commercial holothurian population sampled in the study area by density (no per ha, outer ring) and wet weight (inner ring).

The reef top had the highest standing stock, closely followed by the shoal top (Fig. 7, Appendix B). The shoal top also had the highest standing stock of medium and high grade holothurians but again, the reef edge had the highest standing stock of premium value species.

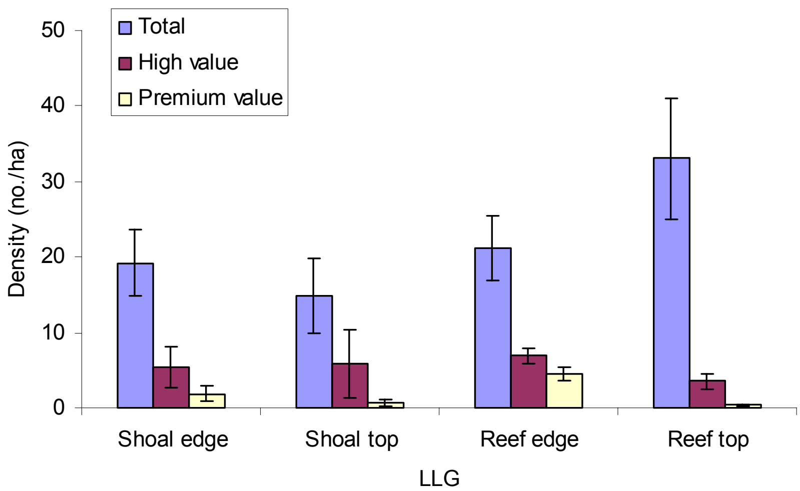

Figure 6. Density (number per ha) of all commercial holothurians (Total), medium and high grade holothurians (High value; as per PNG NFA National management plan) and premium value species (see Appendix E) for each strata type in the study area. (Error bars are one standard error).

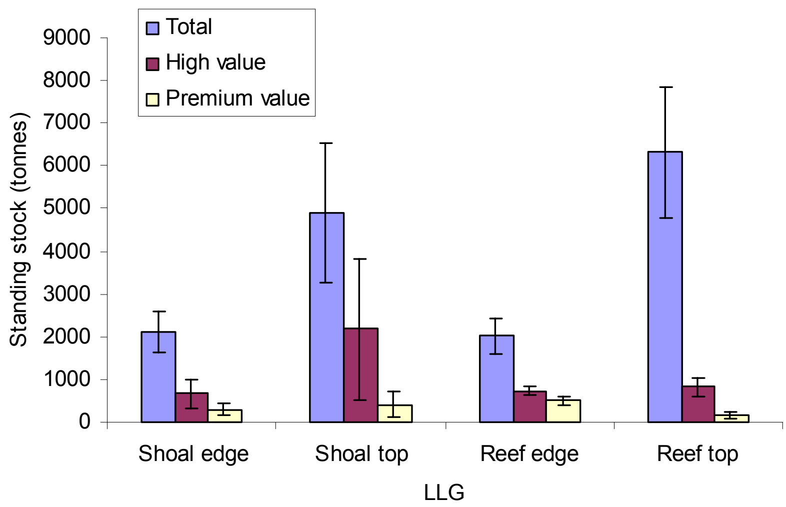

Figure 7. Standing stock estimates (tonnes) of all commercial holothurians (Total), medium and high grade holothurians (High value; as per PNG NFA National management plan) and premium value species (see Appendix E) for each strata type in the study area. (Error bars are one standard error).

The reef top strata holothurian population was dominated by *H. atra* (lollyfish) and *H. edulis* (pinkfish), with a fairly high proportion of *S. chloronotus* (greenfish). We observed 13 species of commercial holothurian on the reef top during the survey (Fig 8). The reef edge strata was more diverse with 15 species observed and, as well as *H. atra*, it also contained the highest densities of *H. fuscogilva* (white teatfish), *B. graeffei* (flowerfish), *T. ananas* (prickly redfish) and *T. anax* (amberfish). The shoal top strata had the lowest diversity with only 7 species observed, and apart from the ubiquitous *H. atra*, also contained high densities of *S. chloronotus* and *B. marmorata* (brown sandfish). The shoal edge had 13 species and was dominated by *H. atra*, *B. argus* (tigerfish), *S. chloronotus* and *T. anax* (Fig. 8).

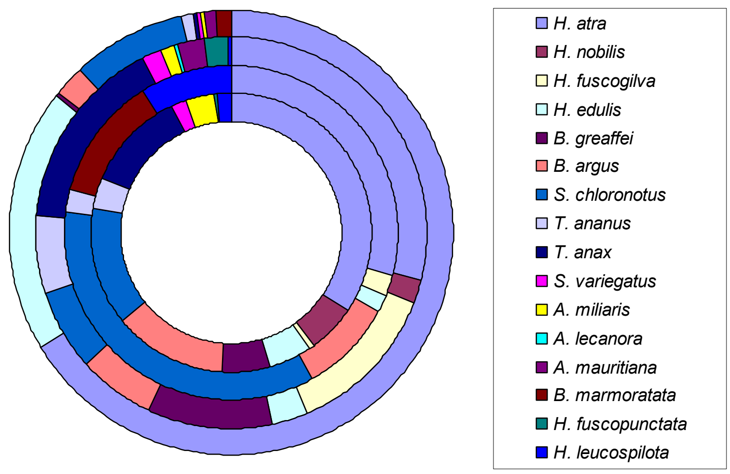

Figure 8. Multiple pie chart showing species composition of populations sampled by density (no per ha) in the four strata: (outer to inner ring) reef top, reef edge, shoal top and shoal edge.

There was a wide variation in the spatial distribution and abundance of holothurians in the study area. Goodenough LLG had the highest estimated overall density of commercial holothurians (216.1 per ha) and Louisiade LLG had the lowest (4.9 per ha) (Appendix E, Fig. 9.1 and 10). Generally the central LLGs had very low densities compared with the western and northern LLGs. The exception was Kiriwina LLG which had a low density of commercial holothurians, however, it also contained extensive areas of shallow sand areas on the large shoal strata (Fig. 3) that had a very low density of holothurians (Appendix A), probably due to low carrying capacity of that habitat. Premium value species were in low densities throughout the study area apart from Bwanabwana (2.36 per ha), Maramatana (4.12 per ha) and Yeleyamba (1.83 per ha) LLGs (Fig. 10).

Kiriwina LLG had the highest estimated standing stock of commercial holothurians in the study area, 4,253 tonnes (± 1,429 tonnes, 90% CI) due mainly to its large area of habitat (Table 2, Fig. 3), followed closely by Murua and Yeleyamba LLGs (Appendix D, Fig 9.3 and 11). Dobu and Maramatama LLGs had the lowest standing stocks (<100 tonnes). Louisiade LLG also had a very low standing stock, 242 tonnes (± 101 tonnes, 90% CI), considering its large size. Bwanabwana, (474 tonnes), Yeleyamba (363 tonnes) and, surprisingly because of its low abundance estimate, Kiriwina (385 tonnes) had the bulk of the standing stock for premium species (Appendix E, Fig 9.3).

The species composition of the holothurian populations in each of the LLGs differed markedly, reflecting changes in the constituent habitats of the LLGs (this study, in prep). While some ubiquitous species were throughout the study area, such as *H. atra*, others had a patchy distribution; for example, *H. edulis* had its highest densities in the Murua LLG, and was especially prevalent in the nearshore habitats adjacent to Woodlark Island (Fig. 9.1). *S. chloronotus* also had a relatively restricted distribution with its highest density in the Goodeneough LLG.

Kiriwina and Yeleyamba had the highest number of species observed during the survey and West Furgusson the lowest with 6 species, however, the relationship between number of species and area of the LLG habitat indicated that the number of species observed was more a factor of samples visited (number of sample sires was proportional to LLG area) than LLG diversity (Fig. 12). However, some deviations from this relationship are worth noting, such as; Murua LLG had a lower number of species than expected, and Louisiade LLG higher than expected. This may be related to the number if habitats contained within each LLG, or to the fact that Murua LLG is somewhat isolated from the other reef and shoal habitats in Milne Bay Province.

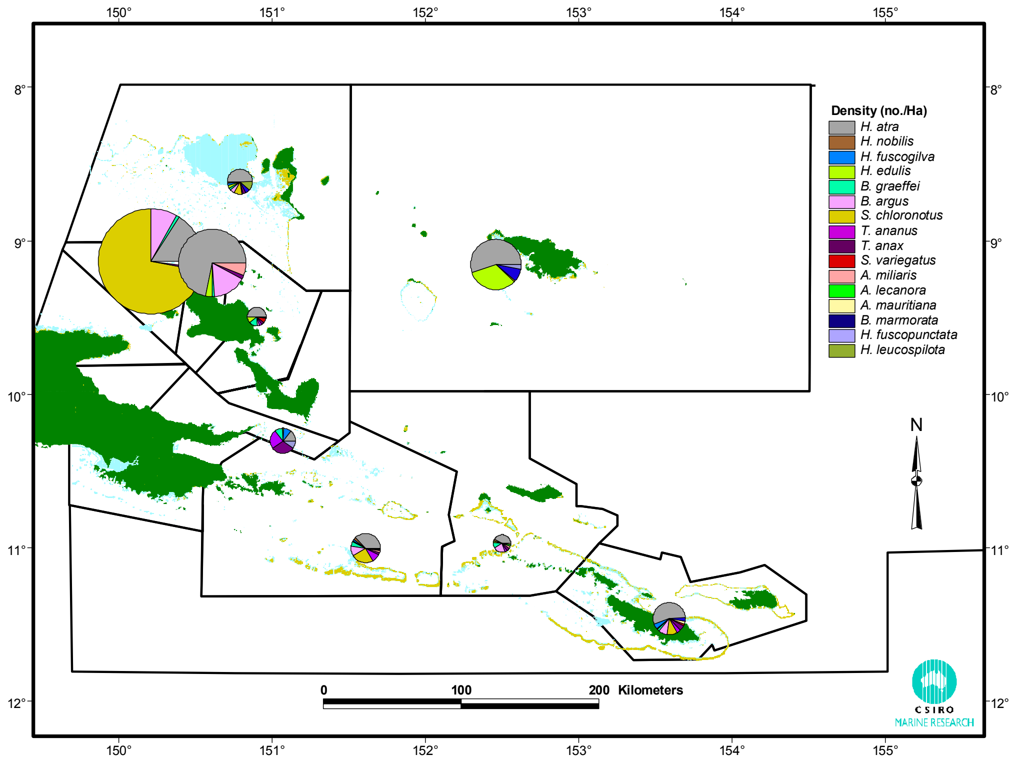

Figure 9.1. Milne Bay showing population density of commercial holothurians sampled during the survey in November 2001. The area of the pie diagram is proportional to the population density (no./ha) in each LLG. (Range 216.1 per ha (Goodenough LLG) to 4.9 per ha (Louisiade LLG)).

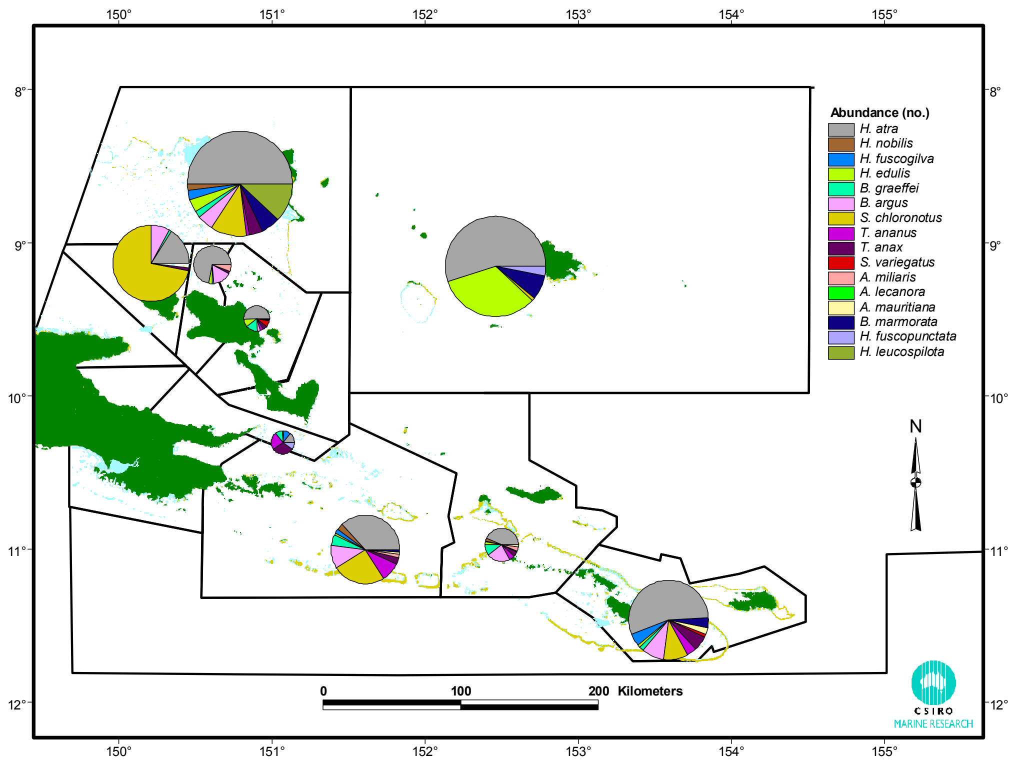

Figure 9.2. Milne Bay showing total abundance of commercial holothurians sampled during the survey in November 2001. The area of the pie diagram is proportional to the total commercial holothurian abundance (no.) in each LLG. (Range 2.9M (Kiriwina LLG) to 0.02M (Maramatana LLG)).

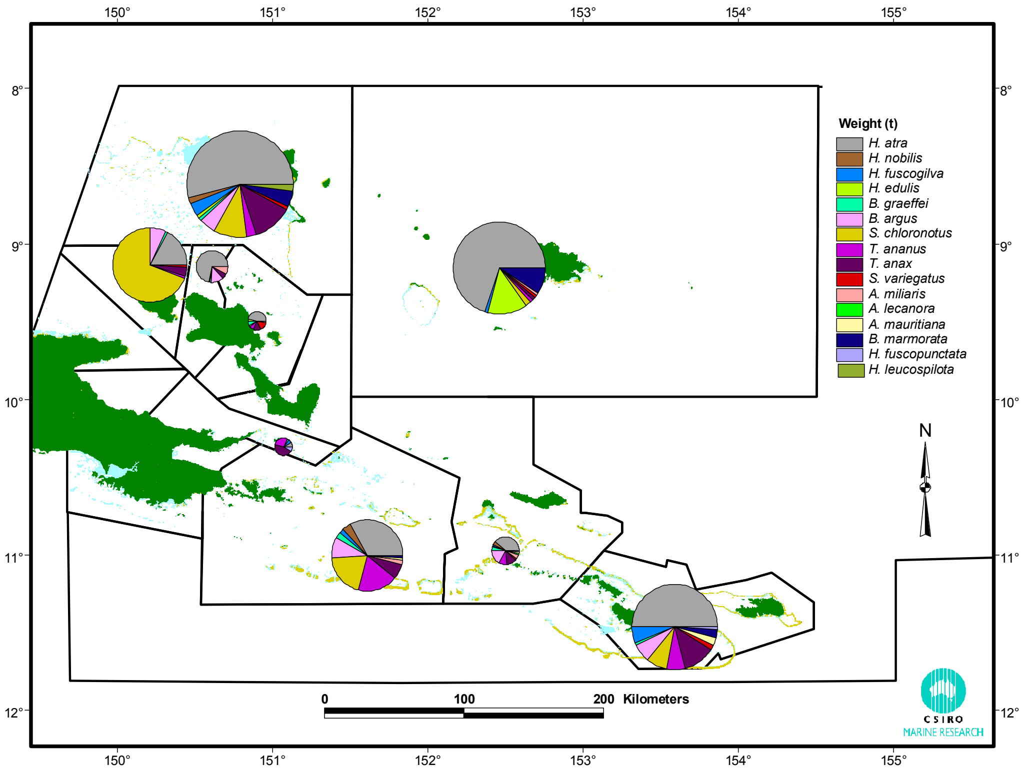

Figure 9.3. Milne Bay showing total biomass of commercial holothurians sampled during the survey in November 2001. The area of the pie diagram is proportional to the total commercial holothurian biomass (t) in each LLG. (Range 4253.3 t (Kiriwina LLG) to 65.1 t (Maramatana LLG)).

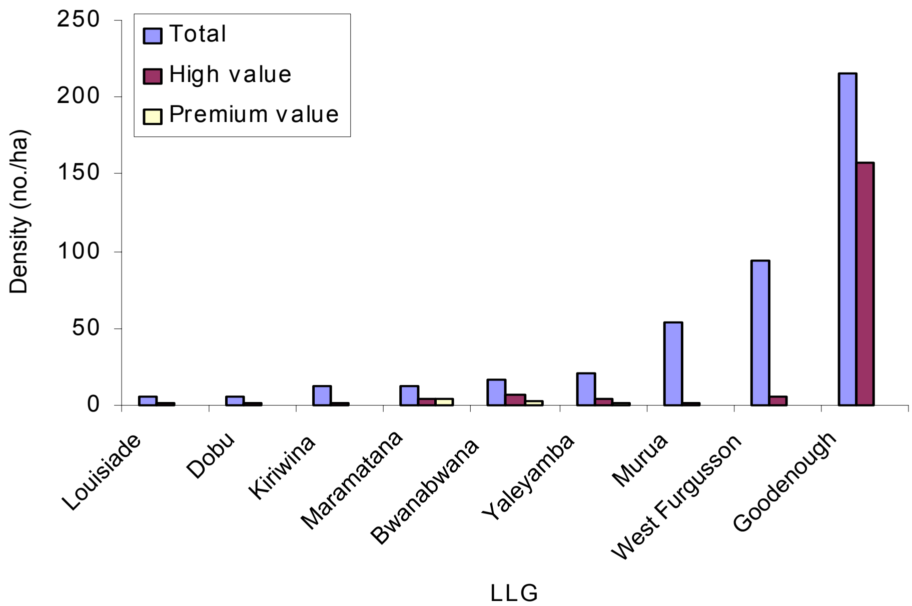

Figure 10. Density (number per ha) of all commercial holothurians (Total), medium and high value holothurians (as per PNG NFA National management plan) and premium value species (see Appendix E) for each LLG.

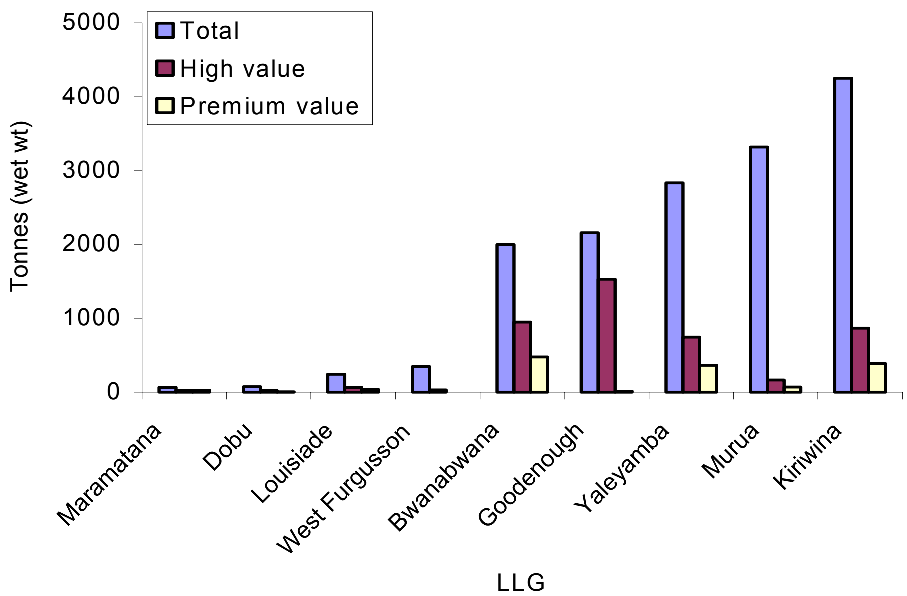

Figure 11. Standing stock (tonnes wet weight) of all commercial holothurians (Total), medium and high value holothurians (as per PNG NFA National management plan) and premium value species (see Appendix E) for each LLG.

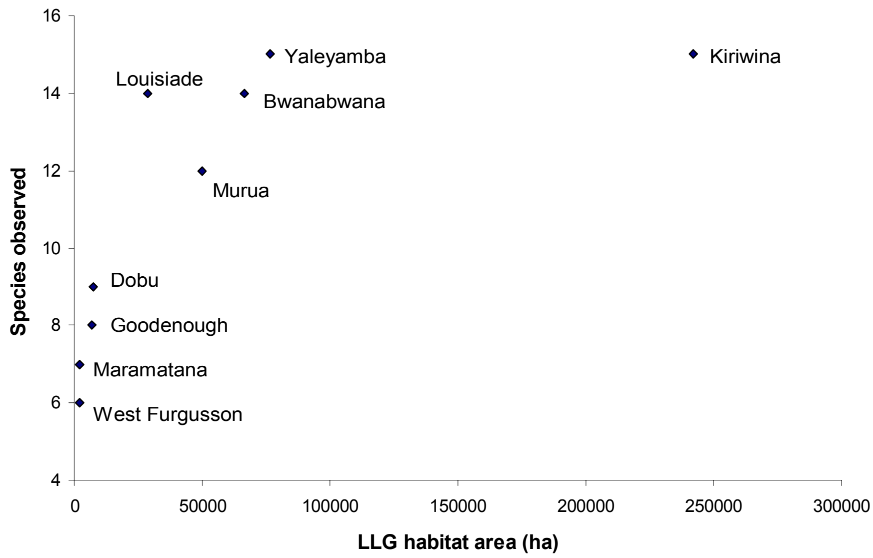

Figure 12. Relationship between number of species observed during the survey and the size of the habitat area for each LLG.

Stock status

The overall population estimate of 15,347 tonnes (± 4,082 tonnes, 90% CI) (Appendix E) or approximately 920 tonnes (± 245 tonnes, 90% CI) of dried beche-de-mer is reasonably encouraging given historical catch rates (up to 209 tonnes dry wt per year by 2001). However, the overall density of commercial species in Milne Bay of 21.2 per ha is very low when compared to a similar multispecies fishery in eastern Torres Strait and the northern GBR at 161.7 per ha (Long *et al.*, 1996) and 147.1 per ha (Skewes *et al.*, 2002), and similar to heavily depleted fisheries such as the Timor MOU Box (26.8 per ha; Skewes *et al.*, 1999).

This difference in overall density could be related to habitat differences between the three areas, for example the lack of extensive shallow sandy reef top habitat in Milne Bay (this study) that occurs in Torres Strait (Long *et al.*, 1996). This type of habitat can have high densities *Holothuria leucospilota* (snakefish), a very low value species that is abundant in Torres Strait and in the Timor Box but is not common in Milne Bay. However, the three study areas do contain similar habitats, one common habitat being the shallow reef edge. Milne Bay and East Torres Strait reef edges were very similar in their habitat components (eg cover of live coral; Milne Bay 10.87 %, Torres Strait 10.92 %, Timor MOU Box 10.2 %). The estimated holothurian density for Torres Strait reef edge habitat is 108.68 per ha compared with the Milne Bay estimate of 21.22 per ha again indicating a severe depletion.

Another indication that fishing pressure is the cause of low densities is the variation in density between LLGs and its relationship to fishing pressure. Areas that have been traditionally fished heavily are the most depleted. For example, the fishers of the Louisiade Archipelago, and in particular the Calvados Chain, are historically among most active beche-de-mer fishers in the province. The Louisiade Archipelago was reported to be the only area of Milne Bay being fished in the late 1970s (Kinch, 2002). This historical high fishing pressure corresponds to a very low overall density of holothurians in the Louisiade LLG of 4.9 per ha (Fig. 9.1, Fig. 10). However, not as many people fish the far eastern regions, such as the Goodenough LLG, due to various factors including low population density, high shark abundance and deep water (Kinch, 2002; D. Young, *pers comm*). These lightly fished areas have overall holothurian densities (e.g. 216.1 per ha) comparable to relatively lightly fished regions such as Torres Strait. This indicates that the LLGs with low stock abundance are grossly over-exploited.

Another indicator of heavy exploitation levels is the reduction in the proportion of the catch of premium value species (*H. nobilis*, *H. fuscogilva*, *H. scabra*, *T. ananus*; Fig. 13, Appendix F) from around 36% in the early 1990s to about 15% by 2002. The medium and high grade species (as per the PNG National Fisheries Management Plan) also dropped from over 60% in the early 1990s to 38.5% in 2001 (Fig. 13).

The total number of species exported has also increased from 14 in 1993 to 18 in 2001. All additional species were low value species such as *Bohadschis similes* (chalkfish), which is a very low value species with a low conversion rate. This species in particular has been fished in very high amounts during 2000 and 2001. It has a similar distribution to *H.scabra* (sandfish) and, given the low conversion rates, these catch levels would be a serious cause for concern for the fishery status of this species.

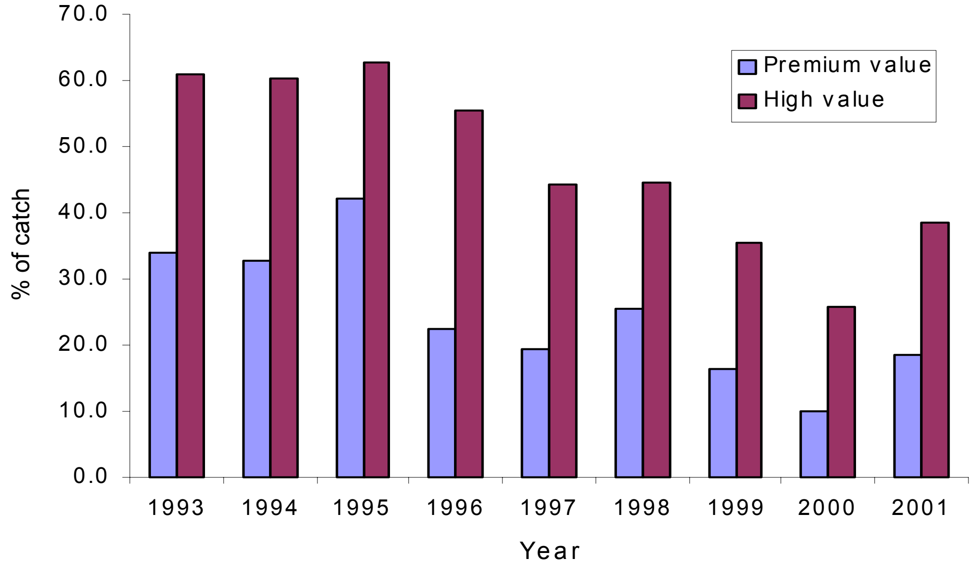

Figure 13. Proportion of the catch made up of premium value species (*H. nobilis, H. scabra, H. fuscogilva, T ananus*) and medium and high grade species (as per National Beche-de-mer Management Plan).

Holothuria scabra (sandfish)

Holothuria scabra (sandfish) were not recorded during the survey (although they were observed off transect in the both the Trobriands and Woodlark lagoons). The distribution of this species is likely to be restricted to inshore habitats, usually those protected by fringing reefs and containing fine sediment or mud and often associated with areas of seagrass meadows (Hammel *et al.*, 2001). Substantial sampling effort was carried out in such suitable habitat in the Kiriwina lagoon, Woodlark lagoon and the Sudest south coast during this survey.

This species often partially or fully burrows into the sediment, making them difficult to visually survey (Hammel *et al.*, 2001). We have found, during surveys of *H. scabra* in Torres Strait, that surveying the population during the day can underestimate the true abundance by 25 % to 60% (Skewes *et al.*, 2000). It is possible therefore, that we didn't observe them during the survey due to burrowing, however, it is unlikely that we would see none on the transects if they were present in substantial densities. The more likely explanation is the sandfish population is heavily depleted.

Some historical catch figures also indicate a severe depletion. In 1987, a fishing company was formed to exploit the Trobriands Islands sandfish population. During the first six months of operations, 47.1 tonnes of dried sandfish was produced and it eventually yielded an estimated 96 tonnes (Kinch, 2001). The fishering operation closed soon after and the population was reported as being severely depleted at that time. This compares with the current yield of ~3 tonnes in 2001 which indicates that *H. scabra* in Milne Bay are grossly overexploited. It is likely that the population in the Trobriands lagoon has remained depleted ever since the fishery in 1987.

This historical catch data indicates that the Trobriands sandfish habitat has a similar carrying capacity to the Torres Strait sandfish fishery, where approximately 140 tonnes (dry weight) was fished in 1996 from a 5,191 ha area in Torres Strait (Skewes *et al.*, 2000) compared to ~2,500 ha area of sandfish habitat in Kiriwina (this study). This catch of sandfish also severely depleted the Torres Strait sandfish fishery. The Woodlark Island sandfish habitat is an enclosed lagoon with an area of approximately 6,000 ha and is also likely to have a similar carrying capacity as Torres Strait and Trobriands as the environment is very similar with a high proportion of terrigenous mud and extensive seagrass meadows. This area would also be considered as being in a very depleted state.

H. scabra is currently the highest value species and is usually the first to be depleted in most fisheries throughout the world. It has been depleted in Torres Strait (Australian and PNG jurisdictions; Skewes *et al.*, 2000; Lari, 2001), the East coast of Qld (QFS).

Holothuria nobilis **(black teatfish)**

Holothuria nobilis (black teatfish) were found in very low abundance throughout the Province apart from Bwanabwana LLG. The densities observed during the survey (0.18 per ha) are far lower than comparable fished reefs in Torres Strait (4.1 to 12.5 per ha, by-reef averages; Long *et al.*, 1996; 2.37 per ha, Skewes *et al.*, 2002) and similar to depleted fisheries such as the Timor MOU Box fishery (0.23 per ha; Skewes *et al.*, 1999). Even the east Torres Strait *H. nobilis* population is considered as overexploited at this density (Skewes *et al.*, 2002). The experience observed in other beche-de-mer fisheries in the South Pacific Region, including the Australian east coast fishery (Uthike and Benzie, 2000) and the Coral Sea beche-de-mer fishery (Hunter *et al.*, 2002) has shown that this species is also easily depleted because of its easy accessibility and high value.

CONCLUSIONS

This study has shown that while there is still a significant population of commercial holothurians in Milne Bay Province, the resource is grossly overexploited for some species at least, and for some LLGs. Management measures should be implemented immediately to curb fishing effort in depleted LLGs such as the Loiusiade LLG, and on depleted species such as *Holothuria scabra* (sandfish) and *H. nobilis* (black teatfish). Measures will have to be considered that ensures that fishing effort is not transferred from protected species/areas to more abundant species/areas in the province.

When managing holothurian stocks, it is important to identify the unit stock, and the interactions between them. Holothurians, like many sedentary benthic invertebrates, most likely have a have relatively small spatial scale to their stock structure, due to restricted spatial extent of preferred habitats and differential fishing pressure, with a relatively high probability of metapopulations (Perry *et al.*, 1999). There is increasing evidence that holothurian metapopulations exist on relatively small spatial scales of 10 - 100 km. These metapopulations are likely to be self recruiting given the complexity of the physical larval movement vectors (water currents), the short larval life of holothurians, and the discontinuous nature of the reef habitats in the Milne Bay area (Sponaugle *et al.*, 2002). From this standpoint, managing holothurian populations at the LLG level would appear to be an appropriate spatial scale.

There was a high variation in holothurian density and diversity of habitats in the province, reinforcing the need for management at a smaller spatial scale, at least to LLG level. While some LLGs were heavily depleted, some showed little signs of depletion. The role of these less depleted areas for recruitment back to the depleted areas cannot be predicted at this stage, however, a precautionary approach would be to protect these areas from gross overfishing that has occurred in other areas. Some recent research indicated that recruitment over large distances is possible for some species at least (Uthicke and Benzie, 2000), but that populations may be essentially self seeding with respect to overall abundance levels (Uthicke, *pers. comm.*).

Determining future exploitation rates and/or sustainable yields from the fishery given the depleted state of some species, and their spatial variability, is difficult. One method to calculate indicative maximum sustainable yield (MSY) that has been used for new and developing invertebrate fisheries where there is little data to formulate a stock-recruitment relationship, is a version of the surplus production model that requires only the biomass estimate (usually assumed to represent virgin biomass) and natural mortality (M) (Gulland, 1983) such that MSY = ½ MB_0. The model is based on the logistic function that assumes that maximum population growth is highest at intermediate population sizes. In practice the proportion of the breeding population required for MSY may be larger than this, and various authors have suggested that the scaling factor should be reduced to 0.2 (Perry *et al.*, 1999). This model has several assumptions, in this case the most important being that there is no spatial stock structure. Another problem with this approach is that holothurian recruitment is probably highly variable; recruitment has been reported as low and sporadic (Conand, 1990). Also, when populations are substantially below virgin biomass, recruitment may become depressed and the assumptions underlying the model are further breached. However, it may be useful as a first cut, and at least an indicator of upper MSY limits. This approach has been used to produce MSY estimates for beche-de-mer fisheries in Alaska (Woodby *et al.*, 1993) and Moreton Bay (Skewes *et al.*, 2002*b*), and rock lobsters in Torres Strait (Pitcher *et al.*, 1989).

Besides a robust stock estimate, the other parameter needed to calculate indicative MSY in this way is an estimate of natural mortality (M). Some estimates of natural mortality have been produced for some holothurian species, and while it probably varies by species, by age, and even spatially and temporally, a range of M = 0.8 - 1 (≡ 45 % - 37 % survival annually) appears to be a reasonable overall estimate of natural mortality for tropical holothurians (Conand, 1990; Preston, 1993).

By adopting a precautionary approach, a conservative estimate of biomass would be to use the lower 90% confidence interval of the survey population estimate (ie there is therefore a 95% chance that the true value is larger than the estimate) of 675 tonnes (dry weight). Using the surplus production model of MSY = 0.2 MB_0 indicates a potential sustainable yield of 108 t - 135 t dry weight for the Milne Bay study area.

Another approach to determining optimal catch rates is to use an estimate of the optimal fishery mortality rate (F_{opt}) based on natural mortality, such that $F_{opt} = 0.6\,M$ (Walters, 1998), which has been suggested as a robust method for TAC calculation for a broad range of species. In this case, assuming M = 0.8 - 1, then F_{opt} = 0.48 - 0.6. The exploitation rate, u, being the proportion of the population fished for a given F can be calculated using the formula $u = F/Z(1\text{-}e^{-Z})$, where Z is the total mortality rate (M+F). Using this formula, u = 0.27 - 0.3. The TAC can then be calculated using the conservative estimate of biomass B, such that TAC = $u \times B$, or about 182 t - 203 t dry weight.

These estimates of MSY should only be used as an indicator of the potential annual yields that could be gained from this fishery given stable recruitment and no wastage, and assumes a unit stock. We have seen that some LLGs and some species are heavily depleted therefore there may be a breakdown of the simple surplus production models used to calculate these indicative MSY estimates.

Also, depleted holothurian populations risk dilution effects hampering recruitment at low stock levels. This effect is likely to occur for broadcast spawners at low abundances such that the fertilization success in the water column is much reduced due to the dilution of the gametes in the water column. Therefore it is likely that the optimal catch rate is substantially less than the calculated rule of thumb MSYs. That the recent catches (> 209 t) have exceeded even the highest MSY estimates is a great cause for concern. Continued catches rates of this magnitude will see the overall status of the Milne Bay beche-de-mer population put at grave risk.

The current total allowable catch (TAC) for the fishery of 140 t is substantially higher than the lower limits of estimated maximum sustainable yields (108 t). Given the recent history of the TACs being exceeded in the Province, the catch should be monitored carefully and TAC strictly enforced.

Given that the beche-de-mer fishery is made up of many different species, all of which have to be fished sustainably in their own right, a 140 t TAC assumes that the catch is composed proportionately the same as the population composition, that is, the majority of the catch should be made up of low value species such as *H.* atra (lollyfish, 49 %) and *S. chloronotus* (greenfish, 17 %). The medium to high-grade species that appear in the beche-de-mer management plan would make up 28 % of the catch, or 39.2 t. The premium values species would make up only 9 % of the catch, or 12.6 tonnes. As we propose a ceasing of fishing on black teatfish and sandfish, this would bring the TAC on the remaining premium value species to 10.7 tonnes. A new category that would contain the medium value species only would make up 19 % of the catch or 26.7 t. We recommend that at least this level of demarcation of species be represented in the management plan.

The current TAC (140 t) is probably too high to allow for a rapid recovery of depleted areas and species, and for a subsequent increase in yield from the fishery. The current holothurian density is most likely substantially lower than virgin biomass levels, perhaps by a factor of several times, and for the high value species such as *H. scabra* (sandfish) and *H. nobilis* (black teatfish), and some depleted LLGs, an order of magnitude lower. There is also little doubt that higher sustainable catches would be achieved at higher abundance levels than currently exist. This would depend on rebuilding the population densities, and then fishing them in a sustainable fashion.

Stopping all fishing for a number of years will naturally allow the population to recover more quickly. However, we acknowledge that current management needs to be a compromise between addressing the current needs of the inhabitants of Milne Bay by allowing some fishing but at a risk of not allowing the fishery to rebuild and also with the increased risk of stock collapse. We do not want to underestimate the difficulty of this task, however, we feel that there is a chance that beche-de-mer populations could recover with modest fishing pressure and considerate use of the resource. The alternative is a probable stock collapse and long periods of very low or even no catches, as has already occurred in many beche-de-mer fisheries in the South Pacific.

In this regard, what would be the target densities for maximizing sustainable catches. This is difficult to determine, however, depleted LLGs should be allowed to replenish to densities approaching half their estimated carrying capacity, at least of the order of 50 holothurians per ha, and then the allowable catches should reflect the species composition of the population. Monitoring population density is essential to determining the population trends and allow for management to be adapted to meet the needs of the fishery.

There are still risks of overexploitation associated with management by TAC. These risks are lowered by adopting complimentary management strategies, such as size limits and effort limitations (closed seasons, gear restrictions).

Size limits are often designed to protect individuals until they have the opportunity to breed once, that is, to prevent recruitment overfishing. This appears to be an appropriate management measure for the Milne Bay Province beche-de-mer fishery, and the size limits currently imposed appear to be adequate for the most part given published size at maturity data for most species (Preston, 1993). However, some species minimum sizes appear to be lower than estimated size at maturity, such as black teatfish (*H. nobilis*) (spawning 26 cm, harvest 22 cm), curryfish (*S. variegatus*) (spawning 27 cm, harvest 25 cm) and prickly redfish (*T. ananus*) (spawning 30 cm, harvest 25 cm). The minimum size for these species should be increased to a size greater than size at maturity, and the new minimum sizes enforced.

The other consideration for size limits is yield per recruit (YPR), such that the yield per individual is the balance of growth and natural mortality. In any case, the high natural mortality rates for tropical holothurians (Preston, 1993) usually results in maximum YPR at a size lower than the size at first sexual maturity (Hunter *et al.*, 2002). It is essential that fishers are educated to the utility of size limits for ensuring recruitment back to the fishery. The concept of letting an animal breed before harvesting generally has a high acceptance among fishers. They are generally easy to enforce, however, if this is done at the processor then it is generally too late, as the animal is processed by that stage.

There has been some evidence of rejected beche-de-mer due to undersize and/or poor processing techniques such as appears to have occurred often in the chalkfish (*B. similis*) fishery in the Trobriand Islands (Rawlinson, *pers comm.*). Besides the potential for recruitment overfishing, this also has the deleterious effect of unreported catch and possible overshoot of the TAC, and also represents a loss of potential income. All efforts should be made to provide extension officers that educate and enforce the minimum size restrictions, and education in the collection, processing and storage of beche-de-mer be carried out. It is essential that the measurement of size be done in the field at the point of capture.

The current gear limitation, that is restricting the use of underwater breathing apparatus, will have some effect of protecting the deeper populations therefore should be maintained and enforced. This is particularly for the case of *H. fuscogilva* (white teat fish), *H. fuscopuctata* (elephant truck fish), and to a lesser extent, *T. ananus* (prickly redfish) and *S. variegatus* (curryfish). However, these population can still be severely depleted using other technology such as "bombs" (weighted spears on ropes) and by free diving.

Closed areas, either permanent or rotational, while having some advantages for restricting the exploitation rate by protecting a proportion of the population from exploitation, may also have potential for regulating the overall effort on the fishery and for providing areas where density of individuals can build up and increase recruitment to depleted areas. However, important considerations that limit the utility of closed areas includes: identifying possible source and sink populations/areas; overexploitation of open areas and resultant low recovery; enforcement of closed areas and potential for disputes (Kinch, 2002). This requires detailed surveys to describe populations in possible closed areas, an understanding of recruitment mechanisms, and a suitable enforcement regime. There is also increasing evidence to suggest that a significant proportion of the population has to be protected to be of any utility for ensuring sustainable exploitation of the resource (Perry *et al.*, 1999). Given this uncertainty, and the difficulty to identify, establish and enforce closed areas, we don't recommend them at this stage. We feel it is better to try and spread effort both spatially and temporally.

Some of the management problems associated with this fishery, especially if managed by LLG-based TACs, are; monitoring catches and closing the fishery when TACs are reached; allocation of resources to groups of inhabitants throughout Milne Bay (dispute resolution); protecting populations that are remote; minimizing wastage; education and enforcement of minimum sizes; monitoring the resource to detect trends in abundance. These animals can be stockpiled, therefore fishery closures will require an increased effort in communication, education and enforcement.

There is a clear need for community based management (CBM) in this fishery, this should be coupled with local level data gathering. This is because it is extremely difficult for a centralized agency such as NFA to deal with the fishery at the local level. Other problems that could be addressed by CBM include resource allocation issues and mitigating local depletion. Local people require the imprimatur to deal with fisheries issues at the local level. This will not be easy, given various systems of marine tenure that exist in the Province. Need to think of innovative ways to manage effort. Differences occur over the province in terms of the interaction between the local communities and the marine environment therefore community based management structures must be tailored to each location.

There are currently several CBM projects in Milne Bay, including the Community-Based Coastal and Marine Conservation Program (CMCP) and a project based on the Obulaku village in the Trobriand Islands "Sustainable artisanal Beche-de-mer fisheries through the incorporation of socioeconomic considerations in the development of community based beche-de-mer fisheries management plans" being run by the Australian Maritime College (AMC). The outputs of this survey should assist with these CBM projects in particular for the education of the people in the communities of the principals underlying sustainable exploitation of marine invertebrates. These programs should be supported and their recommendations implemented.

To assist with implementing restricted fishing measures to some areas, alternative livelihoods may also be the focus for research and support by management and aid agencies. This includes a range of marine farming options (clam, seaweed) and tourism. Finfish could also supply an income if strictly managed – though this fishery requires some additional research.

The depleted state of the *H. scabra* fishery raises the possibility of reseeding as a viable option to assist recovery, and subsequently increase the sustainable yield. This species has been successfully propagated by several agencies, including ICLARM in the Solomon Islands (now based in New Caledonia). Other species may also be viable candidate for reseeding in the medium term (eg black teatfish).

Management recommendations

- Close the *H. scabra* (sandfish) and *H. nobilis* (black teatfish) fishery.
- Strictly enforce the current TAC (140 t) given it is substantially greater than the lowest estimated maximum sustainable yield (108 t) and the recent history of the TACs being exceeded in the Province. Consideration should be given to reducing the TAC in 2003, given the depleted state of some species and LLGs, and the possibility of stock collapse.
- Divide the total TAC into three categories, high, medium and low value (see conclusions for species composition), and restrict the catch of each category as follows: high value 7%, medium value 18%, low value 75%.
- Consider mechanisms for managing the Milne Bay fishery at the level of individual LLGs such as individual LLG catch limits. Heavily depleted LLGs such as the Louisiade LLG should see a drastic reduction in fishing effort.
- Ensure minimum sizes are larger than published size at maturity for each species in the fishery. Enforce minimum size limits, and educate fishers to return undersize animals alive.

Future research and data needs

Fishery catch data

Comprehensive fishery data essential for monitoring catches to enforce TAC limits, and for monitoring individual species to assess stock status. Requires adequate resourcing of the data collection infrastructure in the Provincial and National Fisheries bodies. This should include enforcement and compliance. Besides catch weight for each species, catch data should also endeavor to contain the following:

- Location. At least to a LLG level.
- Effort (hours or days fished). Useful for monitoring abundance (CPUE) but probably impractical for this fishery.
- Size. Size frequency data should also be collected and can shed some light on stock status.

There is still some doubt about some species common names. Positive identification is required and catch data should be collected by single species. Research on the morphometric relationships between the different stages of the processed animal for each species is also required.

Monitoring.

The fishery should be monitored to allow for adaptive management of the fishery depending on the results of monitoring surveys. The relative abundance of the population could be monitored yearly with a high precision by surveying a limited number of repeated measures sites (100 or so) at several locations throughout the province. This technique has already been used to monitor the *H. scabra* fishery in Torres Strait (Skewes *et al.*, 2000). Higher density sampling could also be carried out at specific areas of interest such as the Trobriands and Woodlarks sandfish fishery. These surveys would require a reasonable level of rigor and would have to be carried out by trained staff, possibly from the Provincial level fisheries Authorities.

Environmental monitoring using the environmental parameters collected during this study as a baseline could also be done. This has the potential to measure changes in the gross environmental parameters at least, as has been done in Torres Strait (Skewes *et al.*, 1998).

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Appendix A. Strata mean abundance and variance estimates of commercial holothurians by Zone, and Strata for the calculation of standing stock estimates. Column headings correspond to the formula in Appendix F.

LLG	ZONE	STRATA		Sites n_h	Area (ha)	Y_h (No./ha)	S^2_h (No./ha)
Bwanabwana	Bramble Haven	Reef	Edge	18	1036.13	6.94	96.00
Bwanabwana	Bramble Haven	Reef	Top	21	4457.94	12.50	1796.88
Bwanabwana	Conflict	Reef	Edge	23	721.50	6.98	179.01
Bwanabwana	Conflict	Reef	Top	19	3323.21	9.87	548.25
Bwanabwana	Engineers	Reef	Edge	24	1512.90	16.15	359.77
Bwanabwana	Engineers	Shoal	Edge	3	4654.59	37.50	1093.75
Bwanabwana	Engineers	Reef	Top	18	3609.25	14.58	703.13
Bwanabwana	Engineers	Shoal	Top	3	18765.66	4.17	52.08
Bwanabwana	Nabaina	Reef	Edge	20	3421.11	18.64	335.93
Bwanabwana	Nabaina	Reef	Top	51	10091.22	22.06	2784.93
Bwanabwana	Nagobi	Reef	Edge	24	1968.64	13.54	392.89
Bwanabwana	Nagobi	Reef	Top	34	6888.61	25.74	3815.73
Bwanabwana	Ware	Reef	Edge	12	2369.70	22.92	2410.04
Bwanabwana	Ware	Reef	Top	12	3790.48	43.75	12173.30
Dobu	Ampletts	Shoal	Edge	8	363.21	42.19	265.07
Dobu	Ampletts	Shoal	Top	7	1161.09	8.93	558.04
Dobu	Dobu Island	Reef	Edge	3	255.09	25.00	1875.00
Dobu	Dobu Island	Shoal	Edge	4	1537.19	0.00	0.00
Dobu	Dobu Island	Reef	Top	3	544.29	20.83	1302.08
Dobu	Dobu Island	Shoal	Top	10	3466.26	0.00	0.00
Goodenough	Goodenough plateau	Shoal	Edge	4	1123.31	46.88	455.73
Goodenough	Goodenough plateau	Shoal	Top	3	5603.41	250.00	105468.75
Kiriwina	Lusencay	Reef	Edge	18	1271.71	43.75	1824.45
Kiriwina	Lusencay	Reef	Top	11	1912.21	6.82	355.11
Kiriwina	Lusencay plateau	Shoal	Edge	5	2870.55	217.50	32312.50
Kiriwina	Lusencay plateau	Reef	Top	2	782.27	0.00	0.00
Kiriwina	Lusencay plateau	Shoal	Top	2	10210.13	31.25	1953.13
Kiriwina	Trobraind Plateau	Reef	Edge	3	637.54	29.17	52.08
Kiriwina	Trobraind Plateau	Shoal	Edge	6	21498.34	6.25	46.88
Kiriwina	Trobraind Plateau	Reef	Top	2	2112.69	0.00	0.00
Kiriwina	Trobraind Plateau	Shoal	Top	25	143357.14	5.50	92.19
Kiriwina	Trobriand	Reef	Edge	7	4562.82	16.07	1026.79
Kiriwina	Trobriand	Shoal	Edge	8	12461.25	3.13	33.48
Kiriwina	Trobriand	Reef	Top	22	9709.12	45.45	14576.57
Kiriwina	Trobriand	Shoal	Top	27	28409.88	12.50	1682.69
Kiriwina	Trobriand Reef	Reef	Edge	18	597.66	18.73	641.75
Kiriwina	Trobriand Reef	Reef	Top	8	1373.53	39.06	12207.03
Louisiade	Calvados	Reef	Edge	40	3538.65	9.69	204.23
Louisiade	Calvados	Reef	Top	35	9724.09	4.29	220.06
Louisiade	Deboynes	Reef	Edge	27	1835.29	2.78	40.06
Louisiade	Deboynes	Reef	Top	26	7749.28	0.48	6.01
Louisiade	Kimuta	Reef	Edge	8	353.61	12.50	267.86
Louisiade	Kimuta	Reef	Top	2	1370.49	0.00	0.00
Louisiade	Woli woli	Reef	Edge	19	955.21	18.42	544.59
Louisiade	Woli woli	Reef	Top	12	3458.53	10.42	591.86
Maramatana	Nuakata	Reef	Edge	4	148.77	25.00	2500.00
Maramatana	Nuakata	Shoal	Edge	7	1344.37	10.71	230.65
Maramatana	Nuakata	Reef	Top	2	447.68	12.50	312.50
Murua	Egam	Reef	Edge	11	792.33	5.68	355.11
Murua	Egam	Shoal	Edge	9	2237.34	5.56	277.78
Murua	Egam	Reef	Top	8	1134.51	46.88	17578.13
Murua	Egam	Shoal	Top	6	3230.64	10.42	651.04
Murua	Woodlark	Reef	Edge	26	6087.50	36.06	22091.59
Murua	Woodlark	Shoal	Edge	5	7297.15	0.00	0.00
Murua	Woodlark	Reef	Top	98	11793.43	181.44	654046.59
Murua	Woodlark	Shoal	Top	5	17225.56	12.50	781.25
West Furgusson	Fergusson plateau	Shoal	Edge	4	765.16	71.88	2955.73
West Furgusson	Fergusson plateau	Shoal	Top	3	1557.11	104.17	1302.08
Yeleyamba	Junet	Reef	Edge	16	3100.69	19.53	541.02
Yeleyamba	Junet	Reef	Top	17	6771.69	7.35	430.84
Yeleyamba	Rossel	Reef	Edge	43	3460.24	26.12	5064.69
Yeleyamba	Rossel	Shoal	Edge	2	3227.04	6.25	78.13
Yeleyamba	Rossel	Reef	Top	33	11756.88	3.79	229.34
Yeleyamba	Sudest Barrier	Reef	Edge	71	7298.19	25.77	1750.64
Yeleyamba	Sudest Barrier	Reef	Top	68	24835.25	6.43	1182.34
Yeleyamba	Sudest Inshore	Reef	Top	25	9649.26	82.50	50039.06
Yeleyamba	Sudest Inshore	Shoal	Top	6	6323.48	31.25	1171.88

Appendix B. Standing stock estimates and 90% confidence intervals by Strata in the study area for commercial holothurians.

STRATA	n	Area (ha)	y_{st} (n/ha)	$v(Y_{st})$	Total abundance	Weight (t)	95% CI %
Shoal edge	65	59379.5	19.24	18.89	1142174	2108.8	37.7
Shoal top	97	239310.3	14.88	24.35	3560843	4911.1	55.1
Reef edge	435	45925.3	21.22	18.67	974680	2014.7	33.6
Reef top	529	137285.9	33.03	64.52	4534605	6312.5	40.1

Appendix C. Standing stock estimates and 90% confidence intervals by Zone in the study area for commercial holothurians.

LLG	ZONE	n	Area (ha)	y_{st} (n/ha)	$v(Y_{st})$	Total abundance	Weight (t)	95% CI %
Bwanabwana	Bramble Haven	39	5494.07	11.45	56.52	62920	92.6	110.6
Bwanabwana	Conflict	42	4044.71	9.35	19.73	37828	55.3	79.9
Bwanabwana	Engineers	48	28542.39	11.55	17.87	329799	660.1	61.4
Bwanabwana	Nabaina	71	13512.33	21.19	31.53	286357	489.2	44.2
Bwanabwana	Nagobi	58	8857.25	23.03	68.69	203939	355.8	60.2
Bwanabwana	Ware	24	6160.18	35.74	413.81	220139	344.4	97.4
Dobu	Ampletts	15	1524.30	16.85	48.14	25690	52.5	72.2
Dobu	Dobu Island	20	5802.84	3.05	5.03	17717	22.1	126.6
Goodenough	Goodenough plateau	7	6726.72	216.08	24398.19	1453507	2153.1	137.0
Kiriwina	Lusencay	29	3183.92	21.57	27.81	68675	157.4	41.5
Kiriwina	Lusencay plateau	9	13862.95	68.05	806.82	943411	1114.5	76.5
Kiriwina	Trobraind Plateau	36	167605.70	5.62	2.83	941424	1525.5	50.5
Kiriwina	Trobriand	64	55143.06	16.48	38.30	908720	1341.5	62.7
Kiriwina	Trobriand Reef	26	1971.19	32.90	744.15	64845	114.4	141.4
Louisiade	Calvados	75	13262.74	5.73	3.74	75955	128.4	56.3
Louisiade	Deboynes	53	9584.57	0.92	0.21	8824	12.2	82.4
Louisiade	Kimuta	10	1724.10	2.56	1.41	4420	7.5	83.9
Louisiade	Woli woli	31	4413.75	12.15	31.63	53622	93.7	78.5
Maramatana	Nuakata	13	1940.82	12.22	27.80	23719	65.1	76.4
Murua	Egam	34	7394.82	14.03	75.62	103764	178.8	104.8
Murua	Woodlark	134	42403.63	60.72	559.54	2574660	3139.6	64.5
West Furgusson	Fergusson plateau	7	2322.26	93.53	275.35	217194	344.8	33.6
Yeleyamba	Junet	33	9872.37	11.18	15.26	110352	280.0	59.1
Yeleyamba	Rossel	78	18444.16	8.41	8.17	155089	291.9	56.6
Yeleyamba	Sudest Barrier	139	32133.45	10.83	11.66	347894	714.0	52.2
Yeleyamba	Sudest Inshore	31	15972.74	62.21	761.07	993673	1549.2	75.2

Appendix D. Standing stock estimates and 90% confidence intervals by LLG in the study area for commercial holothurians.

LLG	n	Area (ha)	y_{st} (n/ha)	$v(Y_{st})$	Total abundance	Weight (t)	95% CI %
Bwanabwana	282	66610.93	17.13	9.79	1140982	1997.4	30.1
Dobu	35	7327.13	5.92	5.24	43406	74.6	65.3
Goodenough	7	6726.72	216.08	24398.19	1453507	2153.1	137.0
Kiriwina	164	241766.82	12.11	6.06	2927074	4253.3	33.6
Louisiade	169	28985.16	4.93	1.54	142822	241.9	41.7
Maramatana	13	1940.82	12.22	27.80	23719	65.1	76.4
Murua	168	49798.46	53.79	407.37	2678424	3318.5	62.1
West Furgusson	7	2322.26	93.53	275.35	217194	344.8	33.6
Yeleyamba	281	76422.72	21.03	36.04	1607008	2835.1	47.1

Appendix E.

Standing stock estimates and 90% confidence intervals by LLG and for the entire study area for large holothurians. Also included is an estimate of total standing stock of all commercial holothurians, premium value species, and high value species as per the National management plan in tonnes wet weight.

Species	LLG	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Wet weight (tonnes)	90% CI (%)
Commercial species	Bwanabwana	17.13	9.79	1140982	1997.4	30.1
	Dobu	5.92	5.24	43406	74.6	65.3
	Goodenough	216.08	24398.19	1453507	2153.1	137.0
	Kiriwina	12.11	6.06	2927074	4341.4	33.6
	Louisiade	4.93	1.54	142822	241.9	41.7
	Maramatana	12.22	27.80	23719	65.1	76.4
	Murua	53.35	403.70	2656589	3293.1	62.3
	West Furgusson	93.53	275.35	217194	344.8	33.6
	Yeleyamba	21.03	36.04	1607008	2835.8	47.1
	Total area	21.19	11.70	10212301	15347.2	26.6
Premium species (*H. nobilis*, *H. fuscogilva*, *H. scabra* *T. ananus*)	Bwanabwana	2.36	1.53	157229	474.3	86.6
	Dobu	0.23	0.03	1703	5.8	118.5
	Goodenough	0.52	0.27	3510	12.0	189.5
	Kiriwina	0.68	0.14	163291	384.8	90.9
	Louisiade	0.42	0.03	12144	35.2	66.8
	Maramatana	4.12	9.84	7997	23.9	134.9
	Murua	0.51	0.05	25475	66.9	72.6
	West Furgusson	0.00	0.00	0	0.0	-
	Yeleyamba	1.83	0.37	140191	363.0	54.7
	Total area	1.06	0.07	511541	1365.9	42.2
Medium to High-grade species. (*H. nobilis*, *H. fuscogilva*, *H. scabra* *T. ananus*) *A. mauritiana*, *A. miliaris*, *A. lecanora*, *S. variegates* *S. choronotus*)	Bwanabwana	7.10	3.35	472964	948.7	42.5
	Dobu	0.77	0.08	5675	19.3	61.3
	Goodenough	157.75	24396.01	1061170	1529.0	187.6
	Kiriwina	2.02	0.83	487223	866.2	74.8
	Louisiade	0.92	0.07	26604	63.2	46.0
	Maramatana	4.12	9.84	7997	23.9	134.9
	Murua	1.58	0.56	78772	165.5	78.6
	West Furgusson	5.15	26.50	11956	27.3	189.5
	Yeleyamba	4.73	2.26	361301	741.6	52.5
	Total area	5.22	5.09	2513662	4384.9	71.2
Holothuria nobilis (black teatfish)	Bwanabwana	0.47	0.09	31028	70.1	106.0
	Dobu	0.00	0.00	0	0.0	
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.19	0.03	45671	103.2	162.3
	Louisiade	0.14	0.01	4101	9.3	142.3
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.06	0.00	2927	6.6	165.4
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.03	0.00	2570	5.8	165.0
	Total area	0.18	0.01	86297	195.1	94.1

Appendix E. (cont.)

Species	LLG	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	90% CI (%)
Holothuria fuscogilva (white teatfish)	Bwanabwana	0.28	0.01	18846	37.9	59.3
	Dobu	0.00	0.00	0	0.0	
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.35	0.09	85547	172.1	139.6
	Louisiade	0.04	0.00	1106	2.2	165.4
	Maramatana	1.24	1.53	2401	4.8	177.1
	Murua	0.24	0.01	11887	23.9	80.3
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	1.05	0.25	80231	161.4	79.1
	Total area	0.42	0.03	200018	402.4	67.8
Holothuria edulis (pinkfish)	Bwanabwana	0.17	0.01	11473	6.1	78.8
	Dobu	0.58	0.34	4252	2.3	169.0
	Goodenough	0.52	0.27	3510	1.9	189.5
	Kiriwina	0.46	0.11	110552	59.2	119.1
	Louisiade	0.12	0.00	3469	1.9	84.3
	Maramatana	0.24	0.06	465	0.2	177.1
	Murua	17.76	162.76	884395	473.7	118.8
	West Furgusson	3.09	3.89	7173	3.8	120.9
	Yeleyamba	0.12	0.00	8994	4.8	89.8
	Total area	2.15	1.77	1034282	554.0	101.9
Bohadschia greaffei (flowerfish)	Bwanabwana	0.85	0.23	56662	50.2	92.5
	Dobu	0.91	0.24	6666	5.9	90.0
	Goodenough	2.09	0.73	14041	12.5	77.3
	Kiriwina	0.23	0.00	55858	49.5	42.7
	Louisiade	0.50	0.03	14386	12.8	54.5
	Maramatana	1.24	1.53	2401	2.1	177.1
	Murua	0.00	0.00	0	0.0	
	West Furgusson	1.03	1.06	2391	2.1	189.5
	Yeleyamba	0.33	0.01	25577	22.7	55.5
	Total area	0.37	0.01	177982	157.8	34.2
Bohadschia argus (tigerfish)	Bwanabwana	1.96	0.79	130680	170.8	74.8
	Dobu	0.23	0.01	1703	2.2	82.4
	Goodenough	17.88	301.45	120248	157.2	184.0
	Kiriwina	0.67	0.13	160797	210.2	88.5
	Louisiade	1.07	0.41	31072	40.6	98.5
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.18	0.02	8780	11.5	121.3
	West Furgusson	15.00	196.19	34831	45.5	176.9
	Yeleyamba	1.97	0.98	150462	196.7	83.1
	Total area	1.33	0.14	638572	834.6	45.9
Stichopus chloronotus (greenfish)	Bwanabwana	4.19	1.23	279367	396.7	43.6
	Dobu	0.00	0.00	0	0.0	
	Goodenough	156.19	24395.01	1050639	1491.9	189.5
	Kiriwina	1.28	0.49	308696	438.3	90.7
	Louisiade	0.02	0.00	628	0.9	165.4
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.77	0.46	38099	54.1	146.8
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	2.09	1.78	159366	226.3	105.5
	Total area	3.81	4.95	1836795	2608.2	96.1

Appendix E. (cont.)

Species	LLG	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	90% CI (%)
Thelenota ananus (prickly redfish)	Bwanabwana	1.61	1.42	107355	366.3	122.2
	Dobu	0.23	0.03	1703	5.8	118.5
	Goodenough	0.52	0.27	3510	12.0	189.5
	Kiriwina	0.13	0.01	32073	109.4	148.3
	Louisiade	0.24	0.01	6937	23.7	78.5
	Maramatana	2.88	8.31	5596	19.1	177.1
	Murua	0.21	0.02	10661	36.4	109.1
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.75	0.12	57391	195.8	75.3
	Total area	0.47	0.03	225226	768.4	65.1
Thelenota anax (amberfish)	Bwanabwana	0.52	0.05	34382	135.2	69.3
	Dobu	0.31	0.03	2270	8.9	90.3
	Goodenough	3.13	1.82	21062	82.8	81.5
	Kiriwina	0.53	0.05	128694	506.2	69.3
	Louisiade	0.24	0.01	6983	27.5	63.6
	Maramatana	3.71	6.63	7202	28.3	122.9
	Murua	0.21	0.02	10481	41.2	107.3
	West Furgusson	2.06	1.41	4782	18.8	109.4
	Yeleyamba	1.16	0.17	88559	348.3	59.3
	Total area	0.63	0.02	304415	1197.3	35.4
Stichopus variegates (curryfish)	Bwanabwana	0.00	0.00	0	0.0	
	Dobu	0.46	0.09	3405	12.2	110.6
	Goodenough	1.04	0.36	7021	25.1	109.4
	Kiriwina	0.03	0.00	7176	25.7	165.4
	Louisiade	0.04	0.00	1106	4.0	165.4
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.15	0.02	7599	27.2	164.6
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.20	0.00	15609	55.8	48.5
	Total area	0.09	0.00	41916	149.8	48.5
Actinopyga miliaris (blackfish)	Bwanabwana	0.32	0.09	21532	49.3	149.5
	Dobu	0.08	0.01	568	1.3	169.0
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.03	0.00	7176	16.4	165.4
	Louisiade	0.20	0.02	5683	13.0	109.5
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.15	0.02	7599	17.4	164.6
	West Furgusson	5.15	26.50	11956	27.3	189.5
	Yeleyamba	0.06	0.00	4861	11.1	135.3
	Total area	0.12	0.00	59374	135.8	71.4
Actinopyga lecanora (stonefish)	Bwanabwana	0.04	0.00	2468	2.9	165.0
	Dobu	0.00	0.00	0	0.0	
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.00	0.00	883	1.0	165.4
	Louisiade	0.17	0.02	4831	5.7	133.0
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.00	0.00	0	0.0	
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.00	0.00	0	0.0	
	Total area	0.02	0.00	8183	9.6	94.3

Appendix E. (cont.)

Species	LLG	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	90% CI (%)
Holothuria atra (lollyfish)	Bwanabwana	6.30	4.75	419740	664.9	57.1
	Dobu	3.04	4.40	22274	35.3	116.6
	Goodenough	34.71	301.17	233475	369.8	94.7
	Kiriwina	6.07	3.07	1466979	2323.7	47.8
	Louisiade	2.06	1.09	59679	94.5	84.0
	Maramatana	1.68	2.81	3254	5.2	177.1
	Murua	29.52	180.48	1470152	2328.7	75.3
	West Furgusson	67.20	221.64	156061	247.2	42.0
	Yeleyamba	11.73	33.02	896260	1419.7	80.9
	Total area	9.81	3.69	4727875	7489.0	32.2
Actinopga mauritiana (surf redfish)	Bwanabwana	0.19	0.03	12367	25.6	165.0
	Dobu	0.00	0.00	0	0.0	
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.00	0.00	0	0.0	
	Louisiade	0.08	0.00	2212	4.6	115.4
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.00	0.00	0	0.0	
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.54	0.11	41275	85.4	102.8
	Total area	0.12	0.00	55853	115.5	84.2
Bohadschia marmorata (brown sandfish)	Bwanabwana	0.20	0.04	13268	17.3	165.0
	Dobu	0.08	0.01	568	0.7	169.0
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.71	0.18	171823	224.6	99.2
	Louisiade	0.00	0.00	0	0.0	
	Maramatana	0.00	0.00	0	0.0	
	Murua	4.48	18.72	222918	291.4	159.9
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.88	0.74	67154	87.8	161.9
	Total area	0.99	0.27	475731	621.8	85.8
Holothuria fuscpunctata (elephant trunkfish)	Bwanabwana	0.03	0.00	1813	4.0	117.7
	Dobu	0.00	0.00	0	0.0	
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	0.03	0.00	6196	13.7	74.7
	Louisiade	0.02	0.00	628	1.4	165.4
	Maramatana	1.24	1.53	2401	5.3	177.1
	Murua	0.06	0.00	2927	6.5	165.4
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.08	0.00	6130	13.6	134.9
	Total area	0.04	0.00	20095	44.4	57.6
Holothuria leucospilota (snakefish)	Bwanabwana	0.00	0.00	0	0.0	
	Dobu	0.00	0.00	0	0.0	
	Goodenough	0.00	0.00	0	0.0	
	Kiriwina	1.40	0.03	338952	88.1	19.9
	Louisiade	0.00	0.00	0	0.0	
	Maramatana	0.00	0.00	0	0.0	
	Murua	0.00	0.00	0	0.0	
	West Furgusson	0.00	0.00	0	0.0	
	Yeleyamba	0.03	0.00	2570	0.7	33.0
	Total area	0.71	0.01	341522	88.8	19.6

Appendix F. Estimates of catch of beche-de-mer species in kg for the Milne Bay Province, 1993-2001 (from Kinch, 2002).

(**Note:** This Table is to be used as a guide only. All data supplied by the NFA database may be incomplete as the database is still under development and all entries may have not yet be included).

Species	1993*	1994*	1995*	1996+	1997+	1998+	1999+	2000+	2001+
Amberfish	1,035	703	1,077	1,241.2	2,077.1	9,195.2	3,972.0	10,035.6	21,426.0
Blackfish	2,088	231	1,334	1,116.1	301.6	1,724.2	541.0	1,198.4	2,691.6
Black teatfish	4,554	1,539	4,331	4,449.2	2,079.6	5,950.1	2,442.8	3,560.6	8,969.7
Brown sandfish	1,381	405	650	5,481.9	7,629.4	10,656.3	15,417.0	36,105.0	21,059.0
Caterpillar fish	Not exported until 1996			920.0	606.8	1,370.0	720.0	540.0	1,898.0
Chalkfish	Not exported until 2000							11,840.0	21,395.0
Curryfish	1,888	1,487	2,559	5,988.6	3,784.0	4,898.5	1,796.3	5,865.1	9,353.2
Deepwater redfish	584	-	-	-	-	-	-	-	-
Elephant trunkfish	1,523	784	2,714	6,146.4	3,175.7	10,321.2	4,390.0	8,356.4	15,554.1
Greenfish	3,565	1,689	3,038	4,432.5	1,892.0	4,660.7	2,256.0	6,908.6	10,479.2
Lollyfish	5,791	1,289	6,973	7,328.5	4,110.0	11,364.2	3,821.9	12,263.7	27,930.9
Pinkfish	Not exported until 2001								61.0
Prickly redfish	4,406	2,278	5,219	5,318.2	3,044.8	8,819.5	3,767.0	8,534.2	12,901.0
Surf redfish	5,350	2,989	4,338	5,412.3	2,437.5	6,033.8	2,658.9	4,646.0	7,044.6
Sandfish	4,007	2,027	7,410	1,047.4	726.5	2,570.3	320.0	2,351.4	3,614.2
Snakefish	Not exported until 1997				82.0	-	215.0	70.0	1,087.4
Stonefish	Not exported until 1996			4,499.8	1,515.6	3,385.0	2,634.9	10,213.6	12,153.2
Tigerfish	2,223	2,524	3,779	8,120.7	4,763.0	13,111.1	5,201.0	12,509.0	18,441.5
White teatfish	3,273	1,779	5,870	3,952.2	1,929.7	10,239.4	1,997.4	4,182.3	13,520.2
Unspecified	-	-	-	-	-	-	-	44,540.0	-
Total	**47,783**	**23,291**	**54,360**	**65,455.0**	**40,155.3**	**108,669.5**	**52,151.2**	**183,719.9**	**209,579.8**

*Lokani and Ada, 1998 (Compiled from NFA's Inspector's ledger)

+NFA Database (Note: The years1996-1999 will be underestimated; the years 2000-2001 will be accurate

APPENDIX G

Stratified sampling techniques. In stratified sampling the population of N units is divided into subpopulations of N1, N2, N3,... NL units respectively. If each stratum is homogenous in that the measurements vary little from one unit to another, a precise estimate of any stratum mean can be obtained in that stratum. These estimates can then be combined to give a precise estimate for the whole population. The notation of terms used for stratified sampling follows below:

N	total number of possible sampling units in the study area;
N_h	total number of possible sampling units in stratum *h;*
n_h	actual number of samples taken in stratum *h;*
y_{hi}	value obtained from *i*th unit in stratum *h;*
$W_h = \frac{N_h}{N}$	stratum *h* weight;
$f_h = \frac{n_h}{N_h}$	sampling fraction in stratum *h;*
$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$	stratum *h* mean;
$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$	stratified mean over all strata;
s_h^2	sample estimate of stratum *h* variance;

$$v(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{W_h^2 s_h^2}{n_h}\right) - \sum_{h=1}^{L}\left(\frac{W_h s_h^2}{N}\right)$$

estimated strata variance.

Samples were allocated randomly to reefs and strata. For future sampling, samples will be allocated to strata in proportion to variance and strata size. The estimated sample size required for fixed variance $v(\bar{y}_{st})$ is:

$$n = \frac{n_o}{\left(1+\frac{n_o}{N}\right)}$$

where $$n_o = \frac{N}{v(\bar{y}_{st})} \sum_{h=1}^{L} N_h s_h^2$$