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Environmental sustainability assessment update for habitats, assemblages and bycatch species in the Torres Strait Prawn Fishery

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Summary

A comprehensive sustainability assessment previously conducted in the Torres Strait for 2005 was updated using 2011 Vessel Monitoring System (VMS) annual effort data. This aimed to provide information on the potential environmental impact that the Torres Strait Prawn Fishery (TSPF) may have, considering the current effort levels and patterns, and to inform the decision making process about a possible trial of larger boats and gear in the fishery. The update showed that environmental risks were substantially reduced from 2005 to what could be considered negligible levels in 2011 due to reduced areal footprint of trawling and substantially lower effort.

In 2005, two of nine habitat types had moderate to high exposure, whereas in 2011 exposure of all habitats to trawling was low. Trawling was not a statistically significant modifier of seabed habitat state in the TSPZ.

In 2005, four of 12 species-assemblages had moderate to very high exposure to trawl grounds and three had moderate to extreme exposure to trawl effort swept-coverage — one assemblage differed statistically by ~1% in high trawl effort areas — whereas in 2011, two assemblages had moderate to high exposure to trawl grounds and one had moderate exposure to effort coverage.

In 2005, more than 50 species of the total 256 assessed had moderate to extreme exposure to trawl grounds and/or effort coverage, and of these, 19 had moderate to high estimates of annual catch of which two were extreme. In 2005, one species exceeded a limit reference point (≡Maximum Sustainable Yield) and three species exceeded sustainability reference points. As the method provides an upper estimate on the annual catch, risk was unlikely to be higher than indicated and so this species assessment is conservative.

In 2011, 12 species had moderate to high exposure to trawl grounds and only three had moderate exposure to effort coverage. Just one species had moderate annual catch and no species exceeded any reference points. This suggests that there are no sustainability concerns for bycatch or benthic species at the levels of trawl effort observed in 2011. For several additional species of interest to the traditional inhabitant sector limited available information permitted simpler assessments suggesting that risk was low in each case.

While all assessed risks were negligible or minimal in 2011, it should be noted that effort has been at historically low levels since 2009. Effort levels peaked through the 1990s and have been declining since. The 2005 assessment was conducted when effort was about half of peak levels, but more than four-times greater than in 2011. Effort in 2005 was close to the Australian effort cap and to the estimated effort at Maximum Economic Yield cap if that target was adopted in future. Hence, the 2005 environmental assessment is reasonably indicative of the potential environmental risks if the fishery recovers to these levels. At such levels, exposures would be higher than in 2011, and a few species were at risk in 2005. Consequently, should the fishery recover in future, it is likely that some management action may be required to ensure sustainability of all bycatch and benthos.

Background

The TSPF industry and managers are currently discussing a trial of larger boats and gear to address economic issues in the fishery. In order to support these discussions, PZJA agencies require updated information on the sustainability risk of non-target species that may be affected by trawling. The TSPF has undertaken a broad level-one risk assessment under the AFMA/CSIRO Ecological Risk Assessment for the Effects of Fishing (ERAEF) framework, called Scale, Intensity and Consequence Analysis (SICA). The framework also provides for more detailed level two or three assessments, and AFMA has elected to adopt the Sustainability Assessment for Fishing Effects (SAFE) method as the level 3 approach for Commonwealth fisheries. AFMA has not applied the SAFE method to the TSPF due to the current low level of effort in the fishery and the relatively high cost of such assessments. Nevertheless, an alternative sustainability risk assessment has been completed for the TSPF for 2005 ("*Torres Strait Seabed Mapping and Characterisation Project*", Pitcher et al 2007), which provides an analogous approach and equivalently effective quantitative level 3 outputs (Hobday et al 2011). The Torres Strait Scientific Advisory Committee (TSSAC) responded to the PZJA's needs for updated information as a priority and supported a cost-effective proposal, subsequently funded by AFMA, to update the 2005 assessment and provide the required information on the current sustainability risks in the TSPF.

The previous 2005 seabed mapping and characterization project provided a very detailed and comprehensive quantitative assessment of trawl exposure and environmental sustainability risk and was based on one of the most robust foundations in data on biodiversity distributions collected specially for the purpose. The assessment provided information on exposure and possible sustainability risks for all habitats across the TSPZ and outside-but-near areas and for several hundred bycatch and benthos species, and their assemblages, in the region. The current project used the detailed maps of the distribution of seabed habitats, species and assemblages — and relative catchability — from the previous project and based the updated sustainability assessments on a spatially gridded annual summary of the 2011 VMS effort data provided by the Australian Fisheries Management Authority (AFMA) and Queensland Department of Agriculture, Fisheries and Forestry (QDAFF).

The update has provided information about the current environmental sustainability of the TSPF and on the potential impact that the TSPF may be having on non-target species, giving consideration to current levels and pattern of effort — information that can be taken into account in making decisions about the proposed trial of larger boats and gear in the fishery.

Objectives

1. Acquire VMS trawl effort data for the TSPF, for the full year of 2011, interpolated at 0.01 degree resolution, and process to a format suitable for analyses.
2. Review the available fishing effort data and identify key annual trends and spatial patterns in effort for the fishery to place the updated assessment in context with past years, particularly 2005.
3. Using the VMS annual effort coverage (from #1), update the previous assessment of ecological risk to habitats, assemblages, and highest risk bycatch species (38 species as listed in Pitcher et al 2007, Table 9-1) — include species of interest as identified by QDAFF and AFMA to the extent possible (see methods).
4. Report on key implications of the updated assessment and current effort patterns of the TSPF.

For species having sufficient available data, an estimate of the proportion caught incidentally in 2011 could be made and the sustainability of their incidental harvest was estimated relative to MSY. For other a number of other species (including species of interest to the traditional sector), less data was available and simpler estimates of exposure and potential risk were calculated where possible.

These objectives address the following research priorities from the 2012 TSFSAC Operational Plan:

2b) Ecosystem effects of trawling (desktop study)

2c) Assess impact of trawl harvest on Islander subsistence fisheries.

Methods

This assessment update built on a previous study that surveyed and mapped biodiversity distributions on the shelf seabed of the 50,195 km² Torres Strait study area (Pitcher et al 2007). The survey sampled 1,549 bycatch species from 148 sites, using a research trawl; 1,551 benthic species from 166 sites, using an epibenthic sled; and 114 habitat elements at 173 sites, providing information and samples for detailed distribution and abundance data about habitats and species of plants, invertebrates and fishes on the seabed. Once the samples were sorted and identified, these data were analysed with environmental variables as predictors to produce distribution maps of species, assemblages and habitats at each of 41,285 grid cells (of size 0.01 degrees, ~1.11 km²) (see Pitcher et al 2007 for details).

Of 2,372 species sampled, ~256 occurred sufficiently frequently for analyses, prediction and mapping of distributions. These distributions were subsequently used to characterise and map 12 species-assemblages, each representing similar species composition within, and differing compositions between. Habitat types were characterised from data recorded from towed video, into 9 classes representing areas of seabed having similar mixtures of habitat elements within and different mixtures between. These predicted distribution maps underpinned several ecological assessments of the trawl fishery in the region.

The approach to this environmental sustainability assessment was to examine exposure of species and habitat distributions to the footprint of the trawl fishery, using a series of indicators of increasing sensitivity — successively accounting for spatial management zones, distribution of trawling, intensity of trawl effort, relative catchability of species in trawls, and in most cases species productivity potential. Details of these approaches are described below.

These quantitative methods were the same as used in the previous (2005) assessment, which also used several qualitative indicators (Pitcher et al 2007). While only one bycatch species was previously found to be caught in excess of an analogue of MSY, another four were close to MSY. Further, there was acknowledged uncertainty in the assessment, hence the top 20 species for each of five indicators (including qualitative indicators) were listed and recommended for management attention. Many species occurred in several lists and in total the final list comprised 38 species (Table 9-1 in Pitcher et al 2007). These 38 species were the focus of this updated assessment. In addition, several other species of interest to traditional sector were provided by QDAFF and AFMA and, where possible, were included in the current assessment. These additional species included: *Mugil cephalus, Siganus lineatus, Choerodon schoenleinii, Epinephelus quoyanus, Plectorhinchus chrysotaenia, Diagramma labiosum, Cephalopholis sonnerati, Acanthurus dussumieri, Naso unicornis, Panulirus ornatus,* white teetfish (*Holothuria fuscogilva*), seasnakes, turtles and dugong. Where these species were not included in the previous assessment, their exposure to trawling could be estimated only simply, according to the proportion of sites where these species were sampled and the intensity of trawling at these sites. For species not sampled previously, we can only report that such species were not caught as bycatch in survey data that we have available. In some cases, the current assessment could draw on other information in reports from other previous projects in Torres Strait.

Quantitative indicators:

A progressive series of indicators of exposure to trawling were estimated for habitat types, seabed assemblages and selected individual species. For habitats and assemblages the assessment was based on mapped area; for species, predicted biomass distributions had been mapped and biomass related indices were estimated. This series included:

1. estimates of the percentage of the distribution of each habitat, assemblage, and individual species, <u>located in areas open to trawling</u> under spatial management arrangements — without account of the distribution of trawl effort.
2. estimates of the percentage of the distribution of each habitat, assemblage, and individual species, <u>located in areas where trawl effort is present</u> — without account of the intensity of trawl effort.

3. estimates of the percentage of the distribution of each habitat, assemblage, and individual species, located in areas where trawl effort is present taking account of the intensity of trawl effort.

The intensity of trawl effort was taken into account as a coverage of the 0.01 degree grid cells. Given the typical swept width of gear and speed of trawling for prawns in the region, approximately eight hours of trawling would be required to cover a grid cell once, if trawling were conducted uniformly. Similarly, 4 hours would have 0.5× coverage and 16 hours would have 2× coverage. A given grid cell's contribution to the risk indicator was the estimated proportion by area or biomass of the respective biological attribute, multiplied by the estimated effort coverage. These estimates for all grid cells were summed to provide the overall indicator for the Torres Strait Protected Zone region. The effort intensity information for each grid cell was calculated by spatial processing of the 2011 fishery VMS data, provided by QDAFF & AFMA, to produce an estimate of average annual hours of trawl effort for each 0.01 degree grid cell.

Exposure to trawl effort may present varying levels of risk for different species depending on how effectively the trawl net catches any given species (catchability), or how much mortality is caused as a result of contact with the net. For example, a species that lives well down in the sediment, or one that moves up into the water column during the night, is unlikely to be directly affected by the pass of a trawl net. On the other hand, a slow moving species that lives less a metre from the seabed may be very effectively caught by a prawn trawl net. For species estimated to have higher levels of exposure, information on relative catchability was sought wherever possible. The previous study (Pitcher *et al.*, 2007) was able to provide relative catch rate information between the research trawl and the epibenthic sled. Wherever the sampling rate of the research trawl was less than the epibenthic sled, the prawn trawl was considered to catch that fraction (0-1) of the population present during a pass of the net. Wherever the trawl had a higher catch rate, the prawn trawl was considered to a relative catch rate of one. Similar information available from the Great Barrier Reef (GBR) Effects of Trawling Study (Poiner *et al.*, 1998), including prawn trawl catch rates relative to those of a fish trawl, was also used. If evidence was available that could demonstrate that catchability or mortality was <1, this information could reduce the estimated percentage of the biomass of a species exposed in indicator three above — i.e. multiplying trawl effort exposure by the relative catchability provided an estimate of the proportion of the total population caught. Note that this is an upper estimate of catch, as it effectively 'samples with replacement', and thus assessed risk for species is unlikely to be higher than indicated and this assessment is conservative.

Further, the TSPF is required to have turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) installed in the nets. TEDs are very effective in allowing larger animals such as turtles, rays and sharks to pass out of the trawl net, greatly reducing mortality (Robins-Troeger *et al.* 1995, Robins & McGilvray 1999). BRDs provide escape opportunities for smaller fish and reduce the catch rate of non-target species (bycatch) by varying amounts depending on the species. In the Queensland trawl fishery, over all species and different sectors, the average reduction achieved by BRDs is about 8% (Courtney *et al.* FRDC 2000/170 Report 2006), though greater reductions are possible (Courtney *et al.* 2006). As above, if evidence (from these or other sources) was available that demonstrated that TEDs and/or BRDs further reduce catchability or mortality, this information further reduced the estimated proportion of the total population caught.

Exposure to trawling, leading to estimates of the potential proportion of species populations caught annually is only one axis of vulnerability to trawling. The second axis is the ability of the species to recover from any reductions in population size. A species with a high recovery rate can sustain higher levels of incidental catch than a species with a low recovery rate. In this analysis — following the approach typical of many target species stock assessments — the natural mortality rate of species was used to indicate population recovery potential. Thus, a sustainability indicator was estimated by dividing the estimated proportion of total population caught by natural mortality, where available as estimated by Brewer *et al*. (2007) and other published sources (see in Pitcher *et al* 2007). This is analogous to the approach of Zhou & Griffiths (2008), but with the benefit of more detailed distribution maps, and both were based on the Schaffer surplus production model, where for a population at MSY, fishing mortality (F) is equal to natural mortality (M), that is F/M=1. This is regarded as a limit reference point and should not be exceeded. Zhou & Griffiths (2008) consider reviews of exploited species that suggest F=0.8M ($\equiv F/M$=0.8) is a more conservation reference point. In addition, Gulland (1983) suggested a conservative MSY of $0.3MB_0$ in data limited situations, which (as $B_{MSY} = 0.5B_0$) corresponds to F/M=0.6. These three reference points are considered in this assessment. Where exploitation is low, *F* is approximately equal to exploitation — the estimated proportion of the total population caught — thus, the indicator calculated herein is exploitation divided by natural mortality. Note that this method is a 'discrete time' approximation only, it is not an 'instantaneous time' stock assessment, and becomes increasingly uncertain with higher levels of exploitation and/or natural mortality (Hilborn & Walters 1992).

Results

The level of recorded effort in 2011 was the lowest since the fishery started in the 1980s (Figure 1), and less than 25% of the level in 2005 when the previous environmental assessment was conducted. The lower effort also corresponded to smaller total annual swept-area at fishery scale: in 2005, the estimated total swept area was 8,097 km² compared with 2001 at 2,033 km²; and the effective swept-area taking into account expected overlap of trawls due to aggregated effort was about halved (2005: 3,065 km² vs 2011: 1,425 km²). Thus a small fraction of the ~50,200 km² assessment area was exposed to trawling, and environmental risks in 2011 were expected to be lower than in 2005. Consistent with the much lower total effort and smaller total swept-areas, maps of the spatial patterns of total annual effort show substantial contraction of effort in 2011 compared with 2005, with few areas of intense effort (Figure 2).

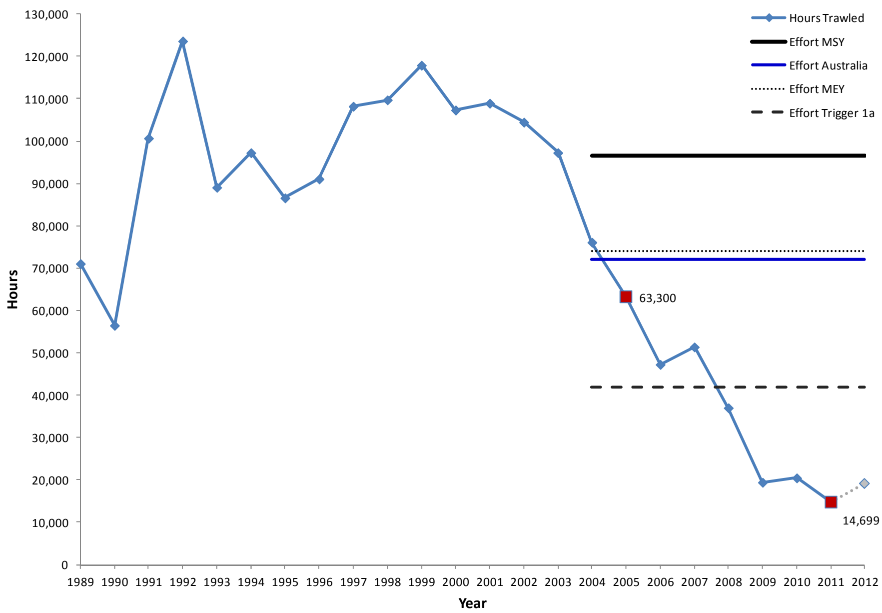

Figure 1. Annual logbook effort of the Torres Strait Prawn Fishery, highlighting effort in 2011 (the year of the current assessment) and 2005 when the previous assessment was conducted. Effort data for 2012 were incomplete. Also shown are: (—) the effort cap at MSY estimated by the last target species stock assessment, (—) the Australian share of the effort cap, (- -) the effort level corresponding to Trigger 1a of the harvest strategy when formal stock assessments would be re-instated, and (····) the effort level corresponding to the proxy (1.2 B_{MSY}) for maximum economic yield (this proxy is used when an accurate MEY estimate is not known) (AFMA 2010).

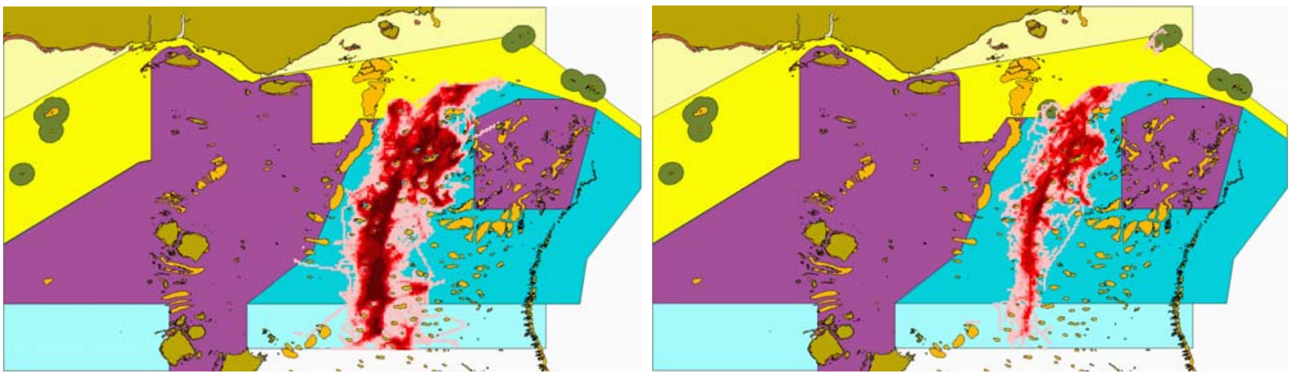

Figure 2. Spatial pattern of total annual effort of the Torres Strait Prawn Fishery in 2005 (left) and 2011 (right). Closed areas are shown in purple, Australian jurisdiction in blue(s) and PNG jurisdiction in yellow(s).

Habitat indicators:

Based on the previous characterisation and mapping of habitats from video data (Figure 3), the area-based exposure indicators were greatly reduced in 2011 compared with 2005 (Table 1). The first indicator was the area of each habitat type located in grid cells open or closed to trawling and the percentage protected from trawling by the closures. Two habitat types had less than 25% of their area in closures whereas other habitat clusters had moderate to moderate-high protection. The closures are unchanged between the two time periods.

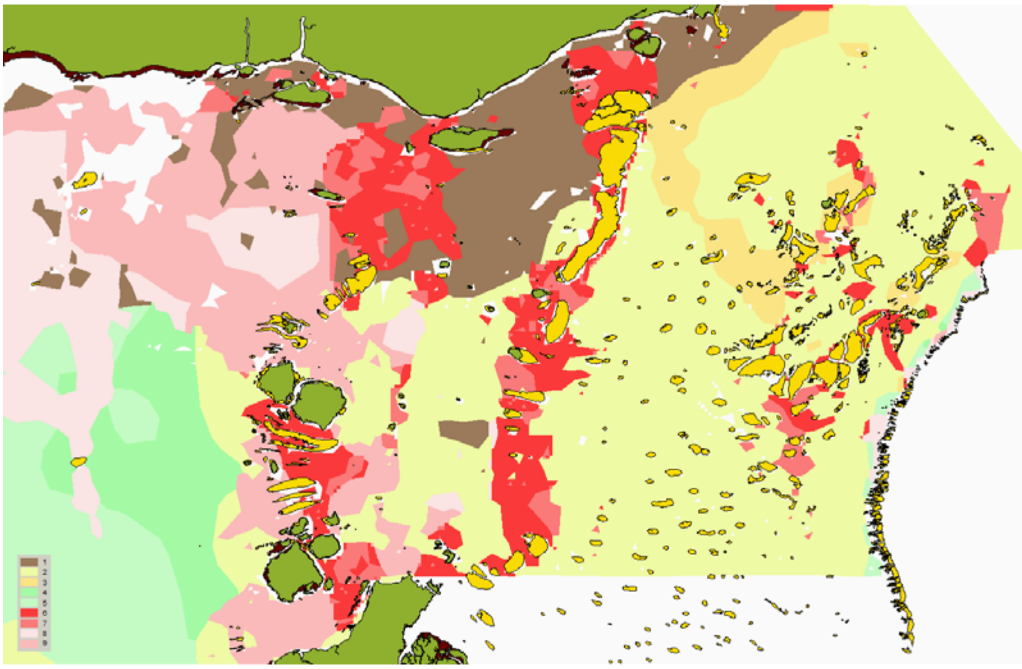

Figure 3. Map of broad seabed habitat types in the Torres Strait (see Appendix 4 for descriptions of habitat compositions, and Pitcher et al 2007 for more details).

Table 1. Estimates of area (km²) of habitat types mapped in Figure 2 and their exposure to trawling: by area open/closed to trawling indicating percent protected; by area trawled indicating percent area potentially exposed; by effort intensity indicating swept-area and percent area directly exposed to effort — for 2005 and 2011 (see Appendix 4 for descriptions of habitat compositions).

Habitat	Total	Open	Closed	% Protected	2005 Trawled	2005 % Exposed	2005 Effort exp.	2005 Effort exp. %		2011 Trawled	2011 % Exposed	2011 Effort exp.	2011 Effort exp. %
1	4626	2727	1899	41	0	0	0	0		0	0	0	0
2	20368	14873	5495	27	5695	28	7075	35		3240	16	1704	8
3	1932	1602	329	17	565	29	1017	53		423	22	327	17
4	2807	816	1992	71	0	0	0	0		0	0	0	0
5	3838	3174	664	17	0	0	0	0		0	0	0	0
6	4388	1916	2472	56	81	2	4	0		18	0	1	0
7	1827	778	1049	57	17	1	1	0		4	0	0	0
8	3905	2505	1401	36	6	0	0	0		0	0	0	0
9	6502	3098	3404	52	0	0	0	0		0	0	0	0

The second indicator was the percentage of area of each habitat type located in grid cells where trawl effort was present — irrespective of the intensity of effort in the grid cells (Table 1, % Exposed). In 2005, two video habitat clusters had more than 25% of their area in grid cells with trawl effort (pale orange) and the other habitat clusters had very low exposure of ≤2% to 0%. In 2011, exposure to trawled areas was reduced.

The third indicator was the percentage of area of each habitat type directly exposed to trawl effort taking into account the intensity of trawl effort as a swept-coverage (Table 1, Effort exposed %). In 2005, again, two of the 9 clusters had more than 25% of their area swept by trawl effort. For habitat type #3, the exposed 29% by area was trawled almost twice that year on average leading to a moderate-high swept-area effort exposure of 53%. This habitat type comprised primarily bare sand or muddy-sand with very little biological habitat in the form of vegetation or epibenthos gardens (e.g. see Appendix 1, photo *a*), distributed over most of eastern TSPZ — including the trawl grounds — and open areas of southern central TSPZ (Figure 3). The next highest exposure in 2005 was habitat type #2, where the exposed 28% by area was trawled 1.25× that year on average leading to a moderate swept-area effort exposure of 35%. This habitat type comprised primarily bare or bioturbated sandy-mud or sand with almost no cover of structural biological habitats (e.g. see Appendix 1, photo *b*), distributed across and along the Great Northeast Channel in eastern TSPZ (Figure 3) — also spanning part of the trawl grounds. The remaining habitats had zero exposure, or close to, and included the vast majority of the seagrass and algal beds, epibenthic gardens and harder substrata (e.g. see other photos Appendix 1). In 2011, the effort exposure of habitat types 2 & 3 was reduced by 3-4 times (Table 1).

Assemblage indicators:

Based on the previous characterisation and predicted mapping of species assemblages (Figure 4), area-based exposure indicators were estimated as per those for habitats above. The first indicator was the area of each assemblage located in grid cells open or closed to trawling and the percentage protected from trawling by the closures (Table 2). Half of the assemblages had moderate to high protection due to the closures and four had no, or almost no, protection.

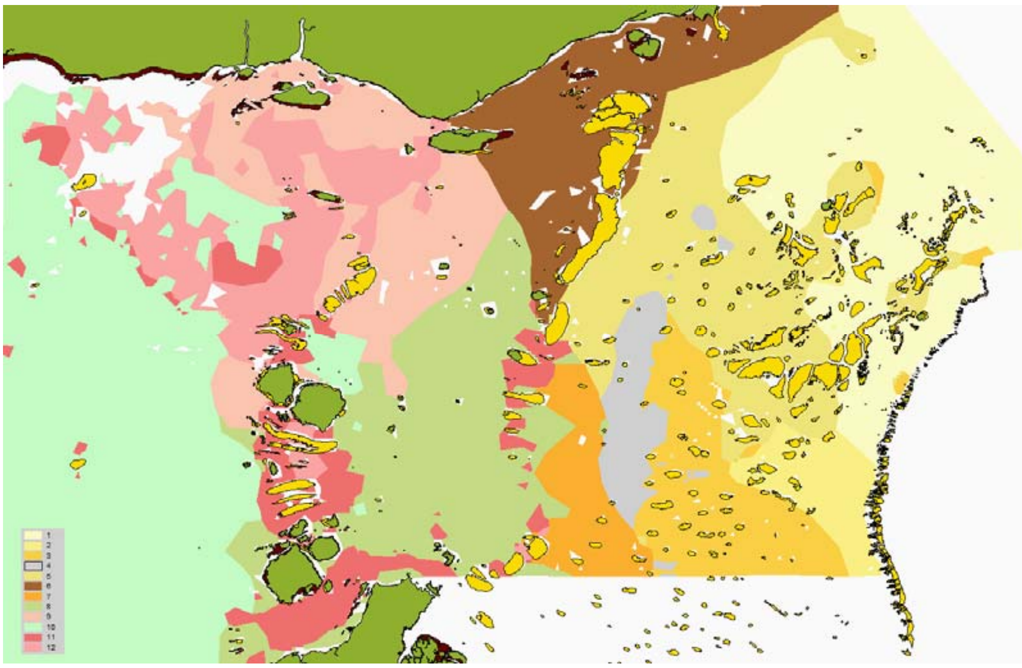

Figure 4. Map of seabed species-assemblages in the Torres Strait (see Appendix 5 for descriptions of assemblage compositions, and Pitcher et al 2007 for more details).

Four assemblages had moderate to high percentage by area located in grid cells where trawl effort was present in 2005 (Table 2, % Exposed) and one was located entirely within trawl grounds. The other eight assemblages had <10% in grid cells with trawl effort and five had 0% exposure.

The most exposed assemblage was trawled more than 3× on average in 2005 leading to a very high level of exposure to trawl effort taking into account the swept-coverage intensity of trawl effort (Table 2, Effort exposed

%). Two assemblages had moderate to high effort exposure, and most assemblages had very low to 0% exposure. The highest exposure in 2005, at 332% indicating very high potential risk, was Assemblage #4 which was characterised by bycatch species including *Scolopsis taeniopterus, Paramonacanthus choiro/otisensis, Priacanthus tayenus, Cynoglossus maculipinnis,* and *Euristhmus nudiceps* (see Pitcher et al 2007 for detailed descriptions). Two of these species were considered a potential sustainability risk in 2005 (see Species indicators section below). Assemblage #4 was distributed central to much of the trawl grounds, primarily in southern central-eastern TSPZ (Figure 4) — and was defined in part by the distribution of trawl effort >7.5 hours per grid-cell per year historically. The two other exposed assemblages were also characterised by common bycatch species, but represented a lower potential risk in 2005.

In 2011, the overlap of trawling with these assemblages was reduced and the swept-coverage effort exposure was substantially lower. In 2011, only Assemblage #4 remained substantively exposed, but at much lower levels than in 2005.

Table 2. Estimates of area (km²) of species-assemblages mapped in Figure 4 and their exposure to trawling: by area open/closed to trawling indicating percent protected; by area trawled indicating percent area potentially exposed; by effort intensity indicating swept-area and percent area directly exposed to effort — for 2005 and 2011 (see Appendix 5 for descriptions of assemblage compositions).

Assemblage	Total	Open	Closed	% Protected	2005 Trawled	2005 % Exposed	2005 Effort exp.	2005 Effort exp. %	2011 Trawled	2011 % Exposed	2011 Effort exp.	2011 Effort exp. %
1	6730	4678	2051	30	570	8	325	5	338	5	135	2
2	1159	1111	47	4	2	0	0	0	0	0	0	0
3	2682	2630	52	2	1239	46	142	5	310	12	38	1
4	1194	1194	0	0	1194	100	3962	332	1070	90	871	73
5	5592	4847	744	13	2384	43	3155	56	1689	30	959	17
6	3570	2909	660	18	0	0	0	0	0	0	0	0
7	1376	1376	0	0	867	63	485	35	263	19	26	2
8	5685	2052	3633	64	80	1	25	0	10	0	0	0
9	4173	902	3271	78	0	0	0	0	0	0	0	0
10	11739	7498	4241	36	0	0	0	0	0	0	0	0
11	2501	897	1604	64	22	1	0	0	2	0	0	0
12	3796	1393	2402	63	6	0	0	0	4	0	0	0

Species indicators:

Trawl exposure indicators and sustainability risk indicators were updated for 38 individual species that were ranked at highest potential risk by up to five indicators in 2005 (Pitcher et al 2007), based on predicted biomass distribution maps (e.g. Figure 5). The results for these species are shown in Table 3. Due to the selection of species with higher trawl exposure, most of these 38 had relatively small proportions of their biomass distributed in trawl closure areas (Table 3). The lowest level of protection was 7% of biomass for a number of bycatch species and the highest level of protection was 49% of biomass for a species of sponge.

In 2005, most of these 38 species had moderate to high overlap with trawl grounds; the percentage of species biomass located in grid cells with recorded trawling was >50% for three species, between 25–50% for 26 species and <25% for only nine species. Most of these species also had high proportions of their exposed biomass in areas of high effort, so that their total trawl effort swept-coverage biomass was greater than their biomass in trawl grounds. Several species appeared to have very high levels of exposure. Three species had more than 100% of their standing biomass swept by trawl effort in 2005. The highest exposure was for a Priacanthid fish *Priacanthus tayenus* (the Purplespotted Bigeye), with 60% of its biomass in cells with recorded effort that was trawled an average of ~2.7 times giving a total of 163% exposure to trawling (Figure 5). The second most exposed species was a crustacean *Portunus gracilimanus* (a swimmer crab), with 47% of its biomass in cells with recorded effort that was trawled an average of ~2.8 times giving a total of 130% exposure to trawling. And third most exposed was a Monacanthid fish *Paramonacanthus choiro/otisensis* (a Leatherjacket), with 32% of its biomass in cells with recorded effort that was trawled an average of ~3.2 times giving a total of ~101% total direct exposure to trawling. Another three species had high exposure (89-95%), 15 species had between 75%–50% exposure and 13 species had between 50%–25% exposure in 2005.

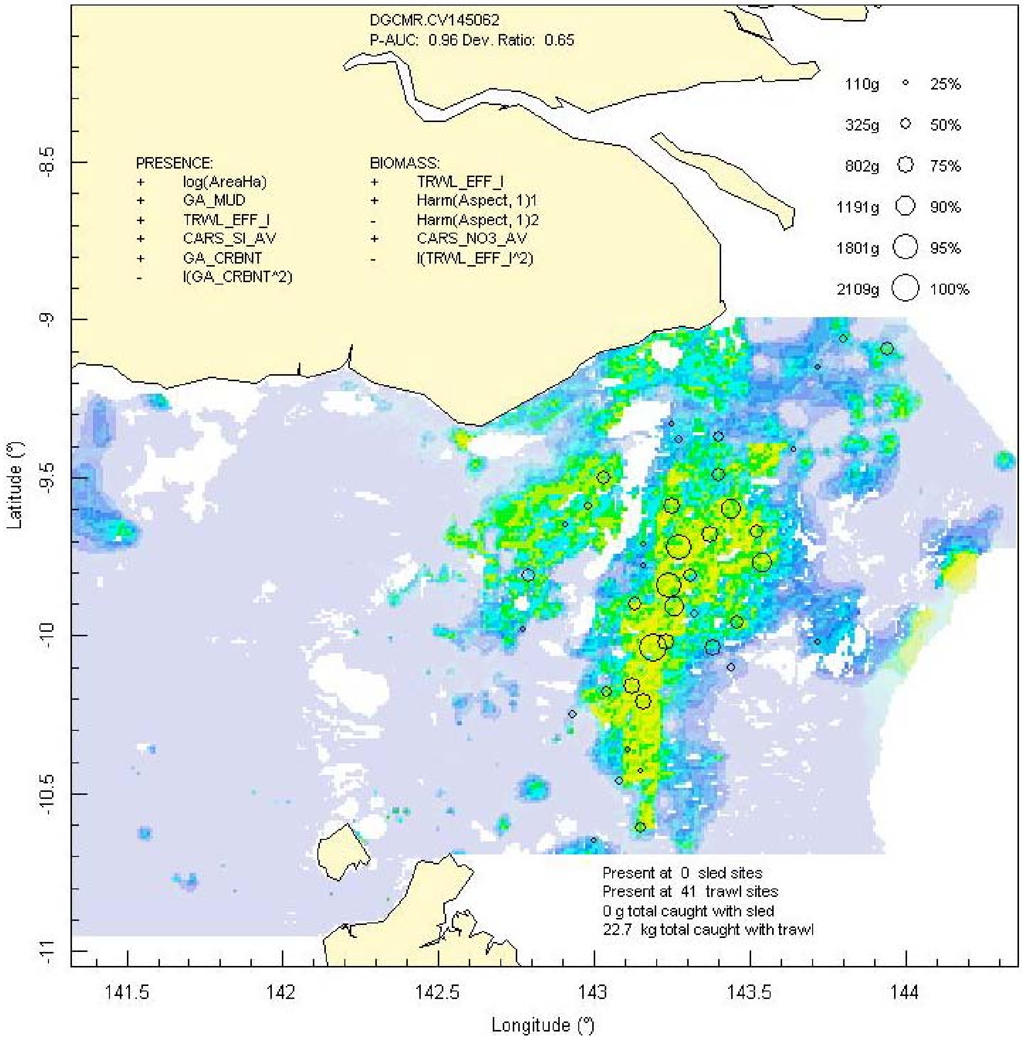

Figure 5. Predicted biomass distribution map of the small fish species *Priacanthus tayenus* (Purple-spotted bigeye) in the Torres Strait (see Pitcher et al 2007 for more details).

These quantitative trawl exposure estimates were developed further, with additional information from the previous project, by multiplying the trawl effort swept-coverage exposure by the relative catch rate and BRD effect, where appropriate, to estimate of the percentage of species populations caught annually (Table 3). While there was considerable uncertainty in relative catch rate among sources (see Pitcher et al 2007), the estimated relative catch rate usually was less than 1 and the estimated percentage of populations caught annually usually was less than the estimated percentage exposed to trawl effort. The large differences in relative catch rate among species substantially altered the ranking of species potentially at risk in terms of estimated percentage caught. At this point, the highest ranked species remained the Priacanthid (bigeye) fish *Priacanthus tayenus* (~150% caught), but most other highly exposed species had much lower estimates of proportion caught. The subsequent highest species were other small fishes *Scolopsis taeniopterus* (87%), *Euristhmus nudiceps* (64%), *Saurida argentea/tumbil* (63%), *Grammatobothus polyophthalmus* (55%) and the scallop *Amusium pleuronectes* cf (50%). Thirteen species had 50%–25% and 19 had 25%–2% caught. While these estimates of potential relative incidental (or in some cases target) catch make a critical contribution to understanding potential environmental risk, they do not provide a definitive indication of sustainability risk — for this, some indication of population recovery (the propensity for the population to replenish) is required.

Table 3. Estimates of species biomass (kg) exposure to trawling for the top 38 of 256 species ranked by Pitcher et al (2007), for 2005 and 2011: biomass open/closed to trawling indicating percent protected; biomass exposed to trawl grounds; biomass swept by effort intensity; and also showing estimated relative catchability; estimate of potential percentage of population caught annually (including BRD effect); natural mortality estimates (M) where available; and a sustainability indicator as proportion Caught/M (where C/M=1 ≈ MSY).

Class	Genus	Species	Total kg	Open kg	Closed kg	% Protected	2005 Trawled kg	2005 % Exposed	2005 Effort exp kg	% Effort exp	Rel. Catch	2005 % Caught	M est	2005 C/M	2011 Trawled kg	2011 % Exposed	2011 Effort exp kg	% Effort exp	2011 % Caught	2011 C/M
Actinopterygii	Priacanthus	tayenus	325414	274958	50456	16	194568	60	530267	163	1.00	150	1.2	1.25	164111	50	131294	40	37	0.31
Crustacea	Portunus	gracilimanus	188941	165221	23720	13	88423	47	244753	130	0.39	50	1.73	0.29	69818	37	64590	34	13	0.08
Actinopterygii	Paramonacanthus	choiro/otisensis	853441	603101	250341	29	271684	32	865804	101	0.25	23	2.54	0.09	212853	25	156652	18	4	0.02
Actinopterygii	Scolopsis	taeniopterus	519715	453864	65850	13	309925	60	492643	95	1.00	87	2.27	0.38	192968	37	106652	21	19	0.08
Actinopterygii	Grammatobothus	polyophthalmus	50912	46771	4141	8	29173	57	47031	92	0.64	55	1.19	0.46	20045	39	12895	25	15	0.13
Actinopterygii	Dactyloptena	papilio	54231	47802	6429	12	23167	43	48474	89	0.16	13	2.45	0.05	17876	33	12982	24	4	0.01
Actinopterygii	Cynoglossus	maculipinnis	52067	39386	12682	24	21748	42	38011	73	0.14	10	0.59	0.16	14174	27	8892	17	2	0.04
Crustacea	Penaeus	esculentus	475506	357610	117896	25	156373	33	334503	70	0.16	11	2.35	0.05	110536	23	86735	18	3	0.01
Actinopterygii	Euristhmus	nudiceps	389381	312151	77230	20	160979	41	269675	69	1.00	64	0.89	0.72	99989	26	53520	14	13	0.14
Bivalvia	Amusium	pleuronectes cf	47769	42335	5434	11	19715	41	32973	69	0.73	50	1.08	0.46	13501	28	8900	19	14	0.13
Actinopterygii	Saurida	argentea/tumbil	179570	138304	41266	23	73779	41	122905	68	1.00	63	1.1	0.57	48268	27	30967	17	16	0.14
Actinopterygii	Nemipterus	peronii	455278	398084	57194	13	190549	42	293349	64	0.62	37	0.66	0.56	134265	29	90700	20	11	0.17
Actinopterygii	Pseudorhombus	elevatus	110144	83855	26289	24	40095	36	65553	60	0.38	21	0.62	0.33	28503	26	20324	18	6	0.10
Bivalvia	Placamen	calophyllum	6227	5094	1133	18	2188	35	3551	57	0.04	2			1420	23	857	14	1	
Actinopterygii	Repomucenus	belcheri	39358	34642	4716	12	15221	39	22160	56	0.42	22	1.11	0.20	9336	24	5166	13	5	0.05
Crustacea	Portunus	tenuipes	660299	577822	82477	12	281994	43	362328	55	0.68	37	1.73	0.22	168498	26	108250	16	11	0.06
Demospongiae	Mycale (arenochalina)	mirabilis	62941	31886	31055	49	10188	16	34173	54	0.07	4			8699	14	8043	13	1	
Actinopterygii	Nemipterus	hexodon	229119	201293	27826	12	78926	34	124071	54	1.00	50	0.96	0.52	53691	23	32443	14	13	0.14
Actinopterygii	Apistus	carinatus	41293	38342	2951	7	15604	38	22273	54	0.34	17	1.35	0.12	10195	25	7102	17	5	0.04
Actinopterygii	Leiognathus	leuciscus	124480	87179	37301	30	47760	38	65588	53	0.43	21	2.41	0.09	30040	24	17317	14	5	0.02
Actinopterygii	Choerodon	sugillatum	380087	287368	92719	24	130982	34	199012	52	0.15	7	1.05	0.07	81841	22	47913	13	2	0.02
Actinopterygii	Nemipterus	nematopus	360775	335696	25078	7	90428	25	177212	49	0.61	28	1.07	0.26	63952	18	50496	14	8	0.07
Actinopterygii	Apogon	truncatus	333081	275992	57089	17	105894	32	162733	49	0.42	19	1.73	0.11	67659	20	44149	13	5	0.03
Crustacea	Portunus	argentatus	1331776	943975	387801	29	145166	11	629120	47	0.62	29	1.73	0.17	137425	10	181969	14	8	0.05
Actinopterygii	Torquigener	cf pallimaculatus	73598	48409	25189	34	16552	22	34677	47	0.63	28	1.08	0.25	11433	16	8243	11	7	0.06
Actinopterygii	Saurida	grandi-undosquamis	750210	641576	108634	14	265316	35	344298	46	1.00	42	1.1	0.38	161144	21	99241	13	12	0.11
Actinopterygii	Lagocephalus	sceleratus	239246	194430	44816	19	64278	27	99617	42	1.00	38	2.54	0.15	40064	17	26033	11	10	0.04
Crustacea	Charybdis	truncata	83384	66034	17350	21	24101	29	34179	41	0.39	16			14818	18	8753	10	4	
Holothuroidea	Holothuria	ocellata	69811	50420	19391	28	18955	27	27187	39	0.10	4			11568	17	6660	10	1	
Actinopterygii	Nemipterus	furcosus	908510	709361	199148	22	241849	27	339104	37	1.00	34	0.53	0.65	148032	16	85129	9	9	0.16
Actinopterygii	Sorsogona	tuberculata	408670	338602	70069	17	117457	29	138942	34	0.65	20	0.62	0.33	65515	16	38618	9	6	0.09
Actinopterygii	Parapercis	nebulosa	134741	100744	33997	25	53860	40	44175	33	1.00	30	1.24	0.24	26265	19	11124	8	8	0.06
Cephalopoda	Sepia	elliptica	56061	46556	9505	17	12743	23	17293	31	1.00	31	1.25	0.25	8072	14	4803	9	9	0.07
Cephalopoda	Sepia	pharaonis	119985	87351	32634	27	13314	11	31781	26	1.00	26	1.25	0.21	9916	8	6360	5	5	0.04
Actinopterygii	Fistularia	petimba	26935	20750	6185	23	6640	25	6322	23	1.00	22	0.26	0.83	4114	15	2133	8	7	0.28
Chondrichthyes	Dasyatis	leylandi	100127	69656	30471	30	16210	16	18783	19	1.00	19	0.41	0.46	8470	8	4316	4	4	0.11
Actinopterygii	Pristotis	obtusirostris	362516	233643	128873	36	48292	13	59864	17	0.81	12	0.46	0.27	27729	8	15192	4	3	0.07
Cephalopoda	Sepia	smithi	347578	204295	143283	41	30113	9	33870	10	1.00	10			16692	5	8739	3	3	

In this assessment, the natural mortality rates of species were used to indicate population recovery potential and to calculate a sustainability indicator estimated as the proportion of population caught divided by natural mortality (C/M, Table 3). Where this indicator exceeded the reference points 0.6 and 0.8, and the limit reference point 1.0 (≈MSY), the indicator is highlighted (pale, orange, and red — respectively). In 2005, one species exceeded the limit reference point: *Priacanthus tayenus*, the Purplespotted Bigeye (at 1.25); one species exceeded the first conservative reference point: *Fistularia petimba*, the Rough Flutemouth (at 0.83); and two species exceeded the second conservative reference point: *Euristhmus nudiceps*, the Nakedhead Catfish (at 0.72) and *Nemipterus furcosus*, the Rosy Threadfin Bream (at 0.65). Images of these species are presented in Appendix 2.

In the 2011 update of the species assessment, the relative order of species exposure to trawling and sustainability risk was similar, but the levels were substantially reduced (Table 3) consistent with the reduced areal footprint of the fishery and amount of effort. Only one species had moderate high exposure to 2011 trawl grounds (*Priacanthus tayenus*, 50%); 11 species had 50–25% exposure and 26 species had exposure <25%. Exposure to effort as swept-coverage was even more markedly reduced (by about 4-fold), and as a consequence, estimates of proportions of populations caught were also substantially reduced, with no species having high levels of exposure or catch. Finally, in 2011, no species exceeded any of the sustainability reference points; the highest value (again for *Priacanthus tayenus*, at 0.31) was well below the second conservative reference point (0.6).

Other species of interest:

None of the additional listed species of interest to the traditional sector have predicted distribution maps available from the previous Torres Strait Seabed Project. Further, of these species, only three were sampled with sufficient frequency to compare with trawl effort (Table 4). Two of these species were sampled at sites with no record of trawling in 2005 or 2011, indicating no exposure in either year. Tropical rock lobster was sampled at one site with recorded trawling in both 2005 and 2011, indicating low exposure. The absence or low occurrence of these other species in the Seabed surveys is not because they are truly rare *per se*, as many are caught commonly by the traditional sector, but because they occur in other habitats and/or are not well sampled by sleds or trawls.

Table 4. Estimates of exposure to trawling of additional species sampled by Pitcher et al (2007); number of sites where sampled; sampled biomass (g) in sites open/closed to trawling indicating percent protected; sample exposed to trawl grounds; sample swept by effort intensity; for 2005 and 2011.

Genus species	# Sites	Open g	Closed g	% Protected	2005 Trawled g	2005 % Exposed	2005 Effort exp. g	2005 Effort exp. %	2011 Trawled g	2011 % Exposed	2011 Effort exp. g	2011 Effort exp. %
Choerodon schoenleinii	14	1408	6853	83	0	0	0	0	0	0	0	0
Epinephelus quoyanus	8	3451	1462	30	0	0	0	0	0	0	0	0
Panulirus ornatus	13	7390	4421	37	259	2	315	3	259	2	461	4

The QDPI Torres Strait Bycatch Surveys 2004-2006 (Turnbull & Rose, 2006) sampled only one of the additional listed species, *Epinephelus quoyanus*, at 1 site in the East Warrior Closure in 2006. None were sampled in 2005 or 2004.

Regarding tropical rock lobster, it is well known from other lobster research that most of the lobster population is distributed in central Torres Strait, primarily in areas closed to trawling (Appendix 3, Fig. A3(a)). Also, it is known that lobsters emigrate from their central Torres Strait habitat to breeding grounds in eastern Torres Strait and elsewhere, their path crossing the trawl grounds. In the past, migrating lobsters have been targeted by trawlers; however, this activity was banned in 1984 and there have not been any reported breaches for many years (Qld

Fishing & Boating Patrol).

The previous Torres Strait Seabed Project sampled only one snake (*Aipysurus duboisii*) and one Flatback turtle, both in open but untrawled sites; one Green turtle was sampled at a site closed to trawl. The QDPI Bycatch Surveys from the same time period included no snakes and no turtles. The additional listed species of interest appear to be rare on trawl grounds and/or in bycatch. Prior to the introduction of TEDs there were records of significant catches of turtles in trawl nets (Appendix 3, Fig.A3(b), as well as by communities in the vicinity of trawl grounds, Fig.A3(c)). However, since the introduction of TEDs in the TSPF there have been no significant catches of turtles in trawl nets and any caught are generally released alive. Further, overseas studies and studies in the Northern Prawn Fishery (NPF) indicated that the majority of turtles that interact with TEDs escape alive.

Regarding dugong, the aerial surveys show their distribution to the northwest in Torres Strait with essentially no overlap with the trawl grounds (Fig.A3(d)). The primary food source for dugong, the seagrass *Halophila spinulosa*, is also distributed in northwest Torres Strait and the 2005 assessment showed no exposure to trawl effort.

For completeness, the 2005 exposure of species related to the additional species was also examined. The assessment for all available congeneric fish species is shown in Table 5, and that for all available holothurians in Table 6. While some of these species had moderate exposure to trawl grounds and trawl effort in 2005, the estimates of percentage caught did not exceed any sustainability reference points, at least for fishes — and while natural mortality rates were not available for these holothurians their percentage caught was very low and unlikely to be unsustainable. In 2011, exposures and risk levels would have been substantively lower.

Table 5. 2005 assessment of exposure to trawling and sustainability risk for all available congeneric fish species (Class Actinopterygii), related to the additional species of interest: indicating percent exposed to trawl grounds; percent swept by effort intensity; relative catch rate; BRD effect; percent caught; natural mortality rate; C/M sustainability indicator (Pitcher et al 2007).

Genus	Species	% Exposed	Effort exp %	Rel. Catch	BRD	% Caught	M est	C/M
Choerodon	sugillatum	34	52	0.15	0.92	7	1.05	0.07
Choerodon	monostigma	20	26	0.34	0.92	8	1.05	0.08
Diagramma	pictum	19	25	0.15	0.92	4	0.35	0.10
Siganus	canaliculatus	7	13	0.16	0.92	2	2.96	0.01
Choerodon	cephalotes	9	12	0.23	0.92	2	1.05	0.02

Table 6. 2005 assessment of exposure to trawling and potential risk for all available holothurians (Class Holothuroidea), related to the additional species of interest: indicating percent exposed to trawl grounds; percent swept by effort intensity; relative catch rate; BRD effect; percent caught; natural mortality rate; C/M sustainability indicator (Pitcher et al 2007).

Genus	Species	% Exposed	Effort exp %	Rel. Catch	BRD	% Caught	M est	C/M
Holothuria	ocellata	27	39	0.10		4	n/a	-
Pseudocolochirus	violaceus	18	24	0.23		5	n/a	-
Stichopus	horrens	10	9	0.07		1	n/a	-
Cercodemas	anceps	7	9	0.06		1	n/a	-

Discussion

Updated quantitative trawl exposure indicators were estimated for nine seabed habitat types, 12 species-assemblages, and 38 individual species assessed as higher exposure and/or risk in 2005. The update was based on distribution maps from a previous project (Pitcher et al 2007) and 2011 VMS effort data provided by QDAFF & AFMA. The area of trawl footprint was reduced and total effort much lower in 2011 than in 2005. The

2011 updated assessment was compared with the 2005 assessment and in all cases the levels of trawl exposure and potential environmental risk were substantively reduced.

For the nine seabed habitat types, area-based trawl exposure indicators were estimated. In 2005, two habitat types had moderate to high exposures; the other seven had very low exposures. The highest exposures were for the two most barren habitat types, characterised by mostly bare or bioturbated muddy–sandy habitats with little biological structure, having negligible vulnerability to trawl impact. The remaining habitat types, including structural habitats, such as seagrass and algal beds and epibenthos, were virtually unexposed, so that their level of risk would be negligible. There was no habitat type uniquely associated with trawled areas and trawl effort was not statistically significant determinant of habitat, suggesting that trawling has not been a dramatic modifier of seabed habitat state in the TSPZ. The negligible risks in 2005 were substantively reduced in 2011 when no habitats had high exposure to trawling.

Area-based trawl exposure indicators were also estimated for 12 species-assemblages representing characteristic compositions of species that were sampled sufficiently frequently for mapping. In 2005, most of these assemblages had very low to zero exposures to trawl effort. However, three had exposures >25%, of which one had an exposure of 35%, one at 56% and the highest was 332% due to being trawled more than 3 times on average in 2005. Species having highest affinity for these exposed assemblages were identified and a number of species were observed to occur repeatedly across the more exposed assemblages; these species were addressed in the individual species assessments. The species composition of the most exposed assemblage differed subtly from neighbouring assemblages and the previous statistical analysis implicated historical trawl effort at levels greater than ~1× coverage/cell/year. This suggested that trawling may have been responsible for modifying the composition of seabed species. In 2011, assemblage exposures were substantively reduced and only the trawl modified assemblage remained significantly exposed albeit at much lower levels than in 2005.

Biomass-based trawl exposure indicators were estimated for 38 individual species assessed as higher exposure and/or risk in 2005. In 2005, 38 species had moderate to high exposure to trawled grounds and 56 had moderate to high exposure to trawl effort coverage. Six species had very high exposure to effort, of which three had estimated exposure greater than their estimated standing stock. The majority of highly exposed species were smaller fishes typical of bycatch. After taking into account relative catch rate information, the potential risks were much reduced for the majority of species. Only 19 species had moderate to high estimates of annual catch and two were very high. To understand the potential for species to sustain these catch rates, they were compared with estimates of natural mortality rates. This enabled calculation of a sustainability indicator (catch/mortality), which could be compared against reference points, based on stock assessment approaches, and allowed further differentiation of species risk in relation to their recovery potential. The benefit was provision of an absolute estimate of sustainability as well as biological reference points. In 2005, one species exceeded the limit reference point (≡MSY), and three other species exceeded one or both conservative sustainability reference points. In 2011, species exposures were substantively reduced; only 12 species had moderate to high exposure to trawled grounds and only three had moderate exposure to trawl effort coverage. Just one species had moderate percentage of its population caught and no species exceeded any reference points. This suggests that there were no bycatch species or benthic species sustainability concerns at the levels of trawl effort in 2011.

For the additional species of interest to the traditional sector, the available information allowed only simpler assessments of potential risk. Nevertheless, for those species for which information was available, the evidence suggested that risk was low in each case.

While all assessed risks were negligible or minimal in 2011, it should be noted that the 2011 effort was at historically low levels. In comparison, the 2005 assessment was conducted when effort was close to the Australian effort cap and to the approximation for effort-at-MEY cap if such a target was adopted in future. Hence, the 2005 environmental assessment is reasonably indicative of the potential environmental risks if the fishery recovers to these levels. At such levels, exposures would be much higher than in 2011, and a few species were at risk in 2005. Consequently, it is likely that some management action may be required to ensure bycatch sustainability should the fishery recover in future.

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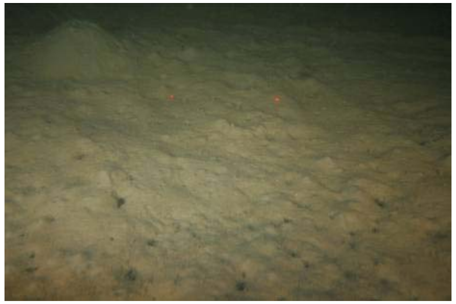
Appendix 1: Photos of some example habitat types observed by towed video camera.

a) Soft muddy seabed.



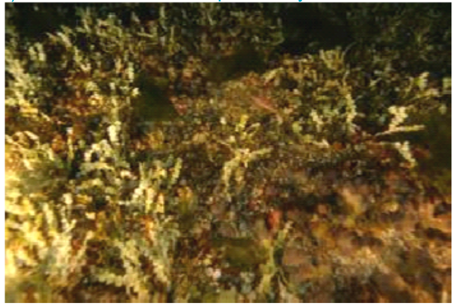
b) Bioturbated sandy-mud seabed

c) Mobile sand waves deposited by tidal currents

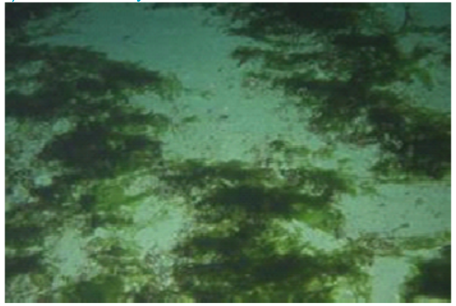
d) Coarse rubbly seabed

e) *Caulerpa* algae on sand

f) *Sargassum* and other bushy brown algae



g) *Halimeda* algae



h) *Ulva* growing on coralline algae in SE TSPZ

i) Sea whip garden, with other benthos

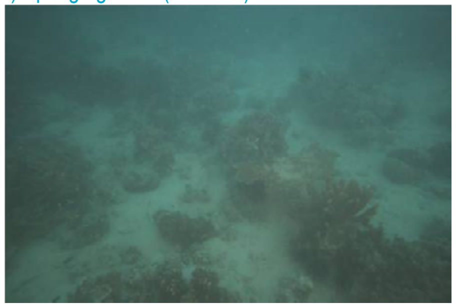
j) Gorgonian garden (sparse)

k) Sponge garden (*Ianthella*)

l) Hard coral (*Turbinaria*) garden

m) Seagrass (*Halophila spinulosa*) bed

n) Crinoids on sand in strong current area



o) Shoal reef with live coral

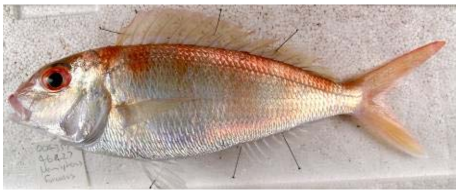
p) Rock outcrop in SE TSPZ

Appendix 2: Photos of selected bycatch species with highest risk sustainability indicators.

Priacanthus tayenus

Fistularia petimba

Euristhmus nudiceps



Nemipterus furcosus

Appendix 3: Supplementary figures from other sources.

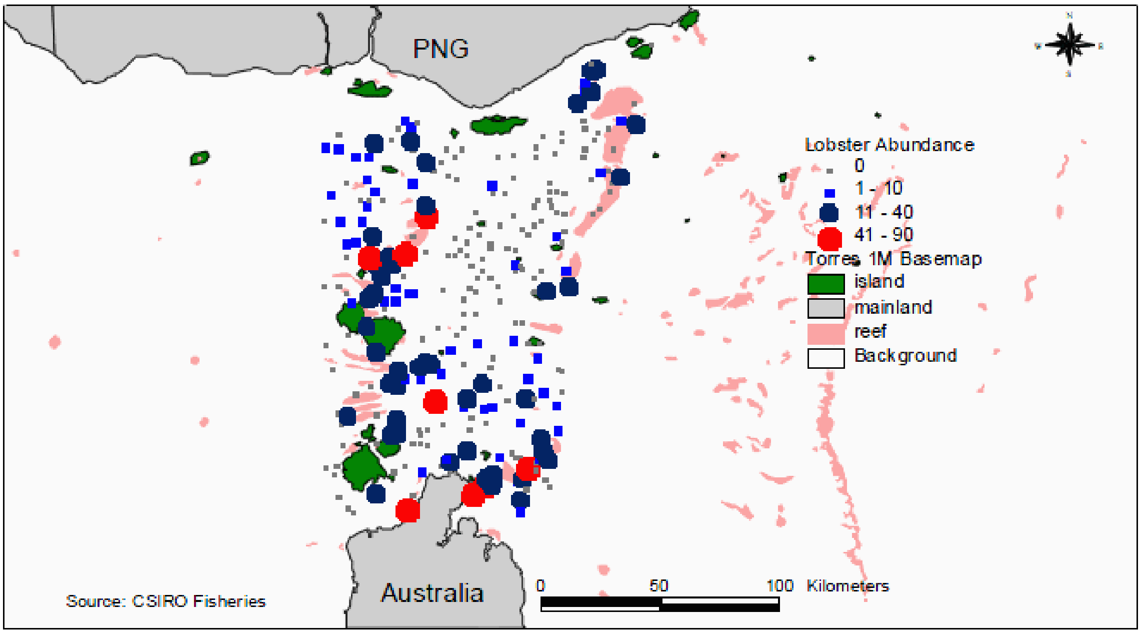


Figure A3(a). Distribution of Tropical Rock Lobster from research dive surveys (Source: Torres Strait GIS Metadata Inventory 1998).

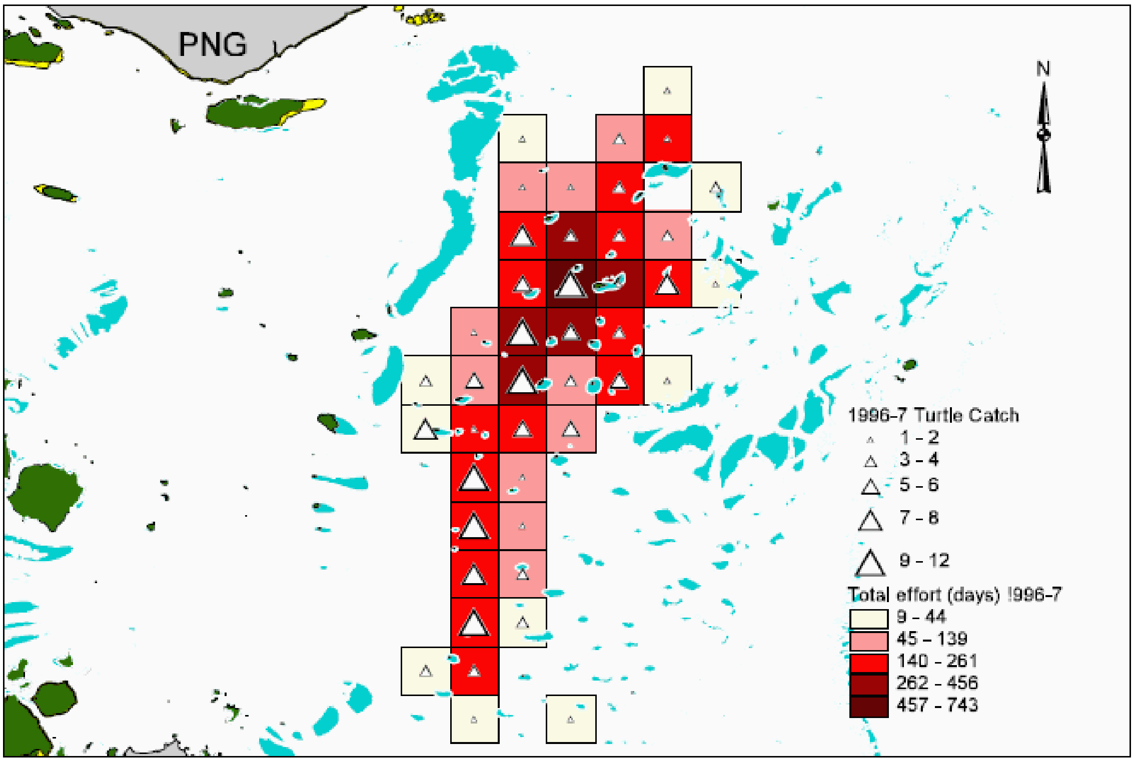


Figure A3(b). Distribution of trawl effort and pre-TED turtle catch (Source: Torres Strait GIS Metadata Inventory 1998).

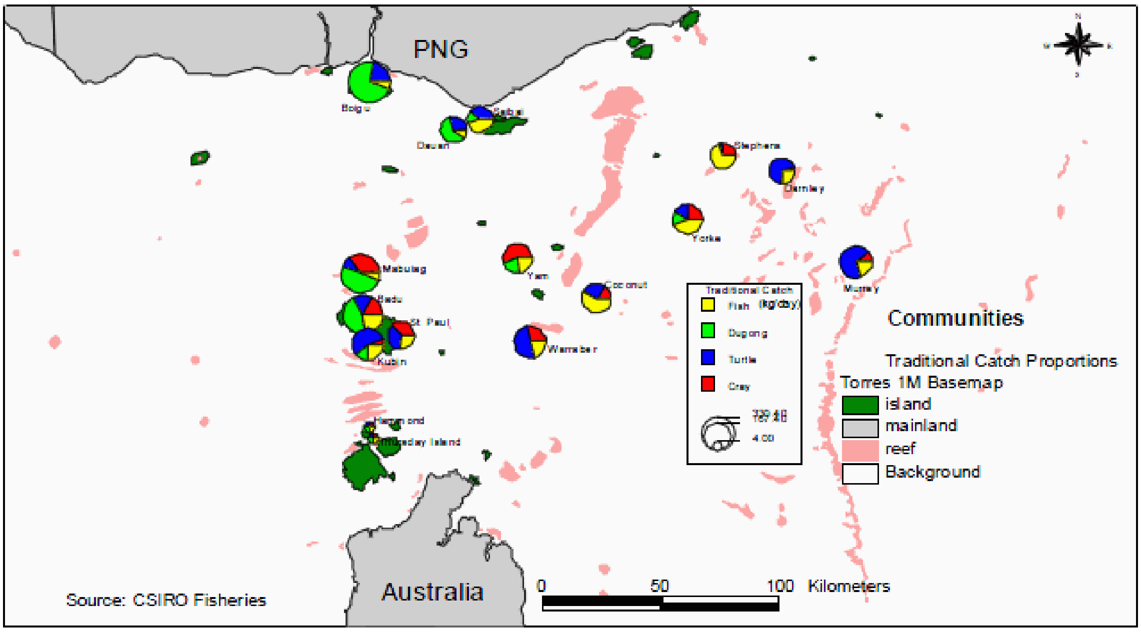


Figure A3(c). Catch of Island Communities 1983-1989 (Source: Torres Strait GIS Metadata Inventory 1998).

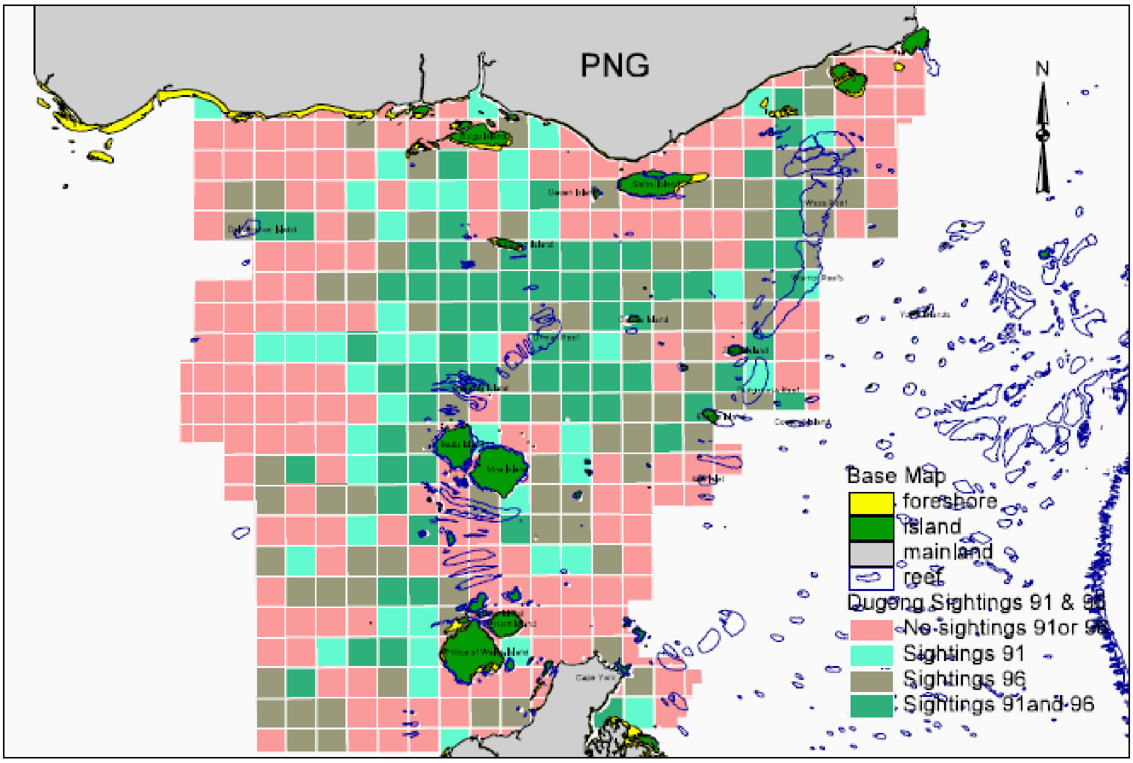


Figure A3(d). Aerial survey sightings of dugongs 1991 & 1992 (Source: Torres Strait GIS Metadata Inventory 1998).

Appendix 4: Descriptions of habitat type compositions from Pitcher et al (2007).

Habitat Type 1 was among the most barren seabed types, almost entirely bare and/or bioturbated with very little biohabitat — distributed in low current stress, low salinity, muddy–sandy areas adjacent to the PNG coast and extending south behind the Warrior Reefs.

Habitat Type 2 was somewhat similar to habitat types 1 & 3, being also very barren with little epibenthos or algae, though sandier and much less bioturbated — distributed in low current stress, high salinity, low phosphate, low silicate variability, sandy areas located over most of eastern TSPZ including the trawl grounds and open areas of southern central TSPZ.

Habitat Type 3 was very similar to habitat type 1, being also very barren with very little epibenthos or algae, though sandier with less bioturbation — distributed in low current stress, high salinity, low phosphate, high silicate variability, muddy-sand areas located across and along the Great Northeast Channel in north-eastern TSPZ and spanning part of the northern trawl grounds.

Habitat Type 4 was sandy with coarse sand and ~20% cover of each of seagrass, *Halimeda*, other algae, various epibenthos gardens, and bare areas — distributed in low current stress, high salinity, high phosphate, low silicate, coarse sandy areas located in open seabed of central western TSPZ.

Habitat Type 5 was mostly coarse sand with 25–30% cover of each of seagrass, mixed algae, and bare areas, and ~15% of various epibenthos gardens — distributed in low current stress, high salinity, high phosphate, high silicate, coarse sandy areas located in open seabed of south-western TSPZ.

Habitat Type 6 was mostly rubbly with ~30% cover of sponge and other epibenthos gardens interspersed with ~15% cover of mixed algae and ~45% bare areas — distributed in high current stress, low phosphate, low sand, rubbly areas located along the western and Warrior lines of reefs and islands, and some inter-reef area of eastern TSPZ.

Habitat Type 7 was similar to 6 though sandier with coarse sand and with ~45% cover of sponge and other epibenthos gardens interspersed with ~15% cover of mixed algae and ~40% bare areas — distributed in high current stress, low phosphate, high sand areas located along the western and Warrior lines of reefs and islands, and some inter-reef area of eastern TSPZ.

Habitat Type 8 was sandy with coarse sand and ~30% cover of algae, ~20% seagrass and ~40% various epibenthos gardens — distributed in high current stress, high phosphate, low oxygen variability, sandy areas located primarily in north-western TSPZ.

Habitat Type 9 was mostly coarse sandy with rubble and stones, and ~25% cover of algae, ~10% seagrass and ~30% various epibenthos gardens — distributed in high current stress, high phosphate, high oxygen variability, coarse sandy areas located in north-western TSPZ and extending south adjacent to the western line of reefs and islands.

Appendix 5: Descriptions of assemblages type compositions from Pitcher et al (2007).

Assemblage #1 occurred in areas of low variability in temperature and salinity with sediment carbonate <85%, distributed primarily in the northeast outer shelf of the TSPZ. Several species had very strong affinities for assemblage#1; those most aligned were Actinopterygii: *Fistularia petimba, Rogadius pristiger, Paramonacanthus filicauda, Upeneus* cf sp. 1 (Sainsbury), *Suggrundus macracanthus, Nemipterus* sp juv/unident, *Apogon septemstriatus, Onigocia* sp b; Crustacea: *Paguristes* sp2358-2, *Trachypenaeus curvirostris*, *Penaeus longistylus*; Asteroidea: *Luidia hardwicki*.

Assemblage#2 occurred in areas of low variability in temperature and salinity with very high sediment carbonate >85% distributed primarily on the southeast outer shelf of the TSPZ. Few individual species had strong affinities for assemblage#2; those most aligned were: Actinopterygii: *Apogon* sp9 (dg); Crustacea: *Trachypenaeus granulosus*.

Assemblage#3 occurred in areas of low variability in temperature and salinity with low turbidity and chlorophyll and low trawl effort, distributed primarily in southeast TSPZ in a mid-shelf position. Some of the most barren habitats occurred in some of these areas, although the sled and trawl revealed significant biodiversity. Few individual species had strong affinities for assemblage#3; those most aligned were: Crustacea: *Portunus tenuipes*, Actinopterygii: *Rhynchostracion nasus*, *Sorsogona tuberculata*.

Assemblage#4 occurred in areas of low variability in temperature and salinity with low turbidity and chlorophyll and high trawl effort, distributed primarily in southern-central eastern TSPZ, corresponding with a large part of the trawl grounds. Again, few individual species had strong affinities for assemblage#4; those most aligned were: Actinopterygii: *Scolopsis taeniopterus*, *Paramonacanthus choiro/otisensis*, *Priacanthus tayenus*, *Cynoglossus maculipinnis*, *Euristhmus nudiceps*.

Assemblage#5 occurred in areas of low variability in temperature and salinity with low turbidity and high chlorophyll, distributed primarily in the Great Northeast Channel straddling the trawl grounds from the Warrior Reefs to the Hibernia Reef matrix in central eastern TSPZ. At the species level, a relatively large number of species showed moderately strong affinities for assemblage#5; those most aligned were: Actinopterygii: *Grammatobothus polyophthalmus*, *Pseudorhombus elevatus*, *Nemipterus peronii*, *Nemipterus hexodon*, *Repomucenus belcheri*, *Priacanthus tayenus*, *Saurida grandi/undosquamis*, *Pegasus volitans*, *Leiognathus leuciscus*, *Apistus carinatus*, *Pentaprion longimanus*, *Apogon truncatus*; Crustacea: *Portunus gracilimanus*, *Portunus hastatoides*, *Charybdis truncata*, *Scyllarus demani*, *Penaeus esculentus*; Bivalvia: *Placamen calophyllum*, *Amusium pleuronectes* cf; Cephalopoda: *Sepia elliptica*.

Assemblage#6 occurred in areas of low variability in temperature and salinity with high turbidity, distributed primarily in the lee of the Warrior Reefs to the PNG coast and northeast towards the Fly River delta. At the species level, a few species had moderately strong affinities for assemblage#6; those most aligned were: Actinopterygii: *Torquigener whitleyi*, *Apogon fasciatus*; Crustacea: *Phalangipus filiformis*, *Thalamita sima*.

Assemblage#7 occurred in areas of high variability in temperature, low current stress, low phosphate and low variability in salinity, distributed primarily in central south eastern TSPA between the trawl grounds and southern line of Warrior Reefs. Individual species had only weak affinities for assemblage#7; those most aligned were: Actinopterygii: *Choerodon sugillatum*, *Euristhmus nudiceps*; Crustacea: *Lupocyclus rotundatus*.

Assemblage#8 occurred in areas of high variability in temperature, low current stress, intermediate phosphate and low variability in salinity, distributed primarily in south central TSPZ between the lines of the western reefs and islands and the Warrior line of reefs. A few individual species had moderately weak affinities for assemblage#8; those most aligned were: Anthozoa: *Dichotella* sp1; Gastropoda: *Murex brevispina*; Actinopterygii: *Stolephorus* sp juv/unident; Gymnolaemata: *Parasmittina* spp.

Assemblage#9 occurred in areas of high variability in temperature, (relatively) low current stress, low phosphate and high variability in salinity, distributed primarily in the northwest of central TSPZ. A few individual species had moderately weak affinities for assemblage#9; those most aligned were: Asteroidea: *Goniodiscaster rugosus* cf; Crustacea: *Myra australis*, *Parthenope* sp 67.

Assemblage#10 occurred in areas of high variability in temperature, (relatively) low current stress and high phosphate, distributed primarily over most of western TSPZ. Some of the most extensive seagrass and algal beds occurred in some of these areas. At the species level, a relatively large number of species showed strong to moderate affinities for assemblage#10; those most aligned were: Liliopsida: *Cymodocea serrulata*, *Halophila spinulosa*, *Halophila ovalis*, *Syringodium isoetifolium*, *Seagrass* sp2: Bryopsidophyceae: *Caulerpa racemosa*, *Caulerpa* sp1, Green sp7, *Halimeda cylindracea*, *Caulerpa taxifolia*, *Rhipilia* sp1; Demospongiae: *Stelletta clavosa*, *Dysidea arenaria*, *Dysidea* sp3; Actinopterygii: *Sillago ingenuua*, *Lethrinus genivittatus*, *Haliichthys taeniophorus*, *Hippocampus grandiceps*, *Selaroides leptolepis*, *Synodus sageneus*, Bivalvia: *Pinctada fucata*, *Spondylus wrightianus*, *Arca navicularis*, Crustacea: *Izanami (matuta) inermis*, *Myra australis*; Echinoidea: *Temnotrema bothryoides*; Phaeophyceae: *Sargassum decurrens*; Gymnolaemata: *Adeonella* sp2; Cephalopoda: *Sepiadariidae* sp2; Holothuroidea: *Cercodemas anceps*; Gastropoda: *Philine angasi*.

Assemblage#11 occurred in areas of high variability in temperature, very high current stress and relatively low oxygen, distributed primarily in and adjacent to the passages between reefs and islands of the southern parts of the western and Warrior lines of reefs and islands. Some of the most extensive epibenthic faunal gardens occurred in some of these areas. At the species level, a number of species showed strong to moderate affinities for assemblage#11; those most aligned were: Demospongiae: *Demospongiae conglomerate*, *Hyattella* sp2, *Reniochalina stalagmitis*, *Oceanapia* tubes, *Ianthella flabelliformis*, *Mycale (arenochalina) mirabilis*, *Ianthella quadrangulata*; Florideophyceae: *Lithophyllum kotschyanum*; Anthozoa: *Turbinaria* spp, *Dendronephthya* spp, *Cyphastrea* spp; Ophiuroidea: *Ophiolepis superba*; Actinopterygii: *Monacanthus chinensis*, Phaeophyceae: *Stypopodium* sp.

Assemblage#12 occurred in areas of high variability in temperature, very high current stress and high oxygen, located primarily in northwest TSPZ and some passages between reefs. Again, some significant epibenthic faunal gardens occurred in some of these areas. At the species level, a few species showed moderately strong affinities for assemblage#11; those most aligned were: Echinoidea: *Prionocidaris bispinosa*, *Nudechinus* spp; Phaeophyceae: *Sargassum* sp12; Asteroidea: *Euretaster insignis*, *Goniasteridae* sp5; Actinopterygii: *Apogon melanopus*; Demospongiae: *Hyattella* sp2.

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