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Synthesis of existing information, analysis and prioritisation of future monitoring activities to confirm sustainability of the red-legged banana prawn sub-fishery in the Joseph Bonaparte Gulf

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Synthesis of Existing Information, Analysis and Prioritisation of Future Monitoring Activities to Confirm Sustainability of the Red-legged Banana Prawn Sub-fishery in the Joseph Bonaparte Gulf
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2 Executive Summary

To evaluate the ecological sustainability of the at-risk species, habitats and ecosystems impacted by the Joseph Bonaparte Gulf (JBG) sub-fishery, we synthesized existing data and assessments, and detailed the changes that have occurred in the fishery in relation to temporal and spatial trends in effort, implementation of bycatch reduction devices and the scale of monitoring of the fishery bycatch by scientists and industry. Fishery effort data was sourced from Northern Prawn Fishery (NPF) logbooks and the vessel monitoring system (VMS) program and bycatch data was sourced from NPF logbooks, Australian Fisheries Management Authority (AFMA) scientific observer program and the NPF crew member observer (CMO) program. The key outcome of this project was the collation of information to inform an external review of the JBG sub-fishery's ecological footprint and the research required to address the key information gaps.

Background

The Joseph Bonaparte Gulf (JBG) sub-fishery is one of three sub-fisheries making up the 771,000 km^2 NPF. The fishery operates in an area known as the JBG box at the western limit of the NPF fishery (at Cape Londonderry) across both WA and NT waters. The JBG sub-fishery developed only in the early 1980s as an alternative to fishing in the Gulf of Carpentaria (GOC), in response to poor catches at the time. In contrast to the relatively benign conditions in the GOC, the JBG fishing grounds are characterised by a large tidal range (>7 m) and strong tidal flow (4 km hr^{-1}). The fishing grounds are also further off-shore, more exposed, and deeper (40-60 m), than in the GOC. For these reasons most of the fishing effort in the JBG sub-fishery occurs during the neap tides, when tidal flows are weakest. The fishing seasons are as defined for the NPF fishery; the Banana season (April to June) and the Tiger season (August to December). The main species caught is the red-legged banana prawn (*Penaeus indicus*) with a minor contribution of white banana prawns (*P. merguiensis*). The geographic distributions of these species within the fishery show little overlap (Somers 1994; Loneragan et al 2002). For management purposes the JBG sub-fishery is defined by the jurisdictional area and only by the *P. indicus* catch. The white banana prawn (*P. merguiensis*) and tiger prawn fisheries are managed separately as sub-fisheries. The JBG fishery is assessed using a dynamic model fitted to catch and effort data. Model results indicated that the red-legged banana prawn resource had been above B_{MEY} since ~2005.

This project was undertaken to synthesize available information on fishery effort, at-risk species, habitat distribution and ecosystem function to assess the fishery's ecological footprint and to identify information gaps precluding this assessment.

Aims/objectives:

1. Determine the feasibility of using and extending the existing observer coverage of the NPF to monitor the at-risk species identified through the ecological risk assessment (ERA) process.
2. Assess all available spatially-explicit information on habitats and their proxies (seascapes, bioregions, environmental envelopes, geomorphs etc) and develop a detailed plan to identify the nature, distribution and vulnerability of main habitat types in the JBG.
3. Assess whether existing information available is sufficient to understand key ecosystem elements (including target species, bycatch species and habitats) in the JBG sub-fishery.

Methodology

The spatial extent of the fishery was mapped using NPF vessel monitoring system (VMS) data and historical effort trends were plotted use NPF logbook data. Trends in historical catches of at-risk bycatch species were tabulated and plotted using data from NPF logbooks, AFMA scientific observer program and the NPF crew member observer program. No statistical analysis of the at-risk species catches was possible, mainly due to the implementation of bycatch reduction devices which reduce catch rates. The distribution of seabed habitats and the assumed vulnerability of habitats to trawling were assessed using data available in published reports and publications.

Results/key findings

Effort in the JBG sub-fishery has decreased steadily since the early 1980s, generally following that of the whole NPF, and due principally to the structural adjustments to the historical fleet to the current 52 vessels. Total vessel days (combined banana and tiger fishing seasons) have reduced from ~3000 days in 1982 to less than 500 days since 2006. The JBG sub-fishery was closed during the banana season (April-June) during 2007-2010. The spatial extent of fishing also decreased after 2005 and no new areas were fished post-2005 indicating that trawling impacts in the JBG have been consistent spatially but have declined in intensity temporally. Inter-annual trends in fishing effort in the JBG sub-fishery showed a steady spatial contraction from ~8% of the available nm^2 grids fished in 1999 to ~1.5% of grids fished in 2008, with a smaller peak in 2009 before declining to the 2008 level in 2012. The trend was similar for the fishing intensity per grid with the proportion fished at >10 $hours.nm^{-2}$ declining from ~3% to ~0.5%.

The listed threatened endangered protected (TEP) and 'at risk' bycatch species in the JBG sub-fishery are managed sustainably. These species have been monitored by three separate programs: NPF logbooks (since 1998 and ongoing), NPF CMO program (since 2003 and ongoing) and the AFMA scientific observer program (since 2005 and ongoing). The data from these ongoing programs was supplemented by a rigorous scientific assessment of the bycatch composition in the JBG sub-fishery by CSIRO during 2003-2005. A total of 23 TEP species (five marine turtle species, five sawfish and 13 sea snakes) have been recorded by these programs in the JBG sub-fishery. Since the introduction of turtle exclusion devices (TEDs) in 2000 only eleven turtles have been recorded in commercial trawls in the JBG sub-fishery and turtles are not listed as priority species by AFMA under Ecological Risk Management. The latest sustainability assessment for fishing effect (SAFE) found no elasmobranch species caught in the NPF had fishing mortality rates greater than their mean maximum sustainable fishing mortality F_{msm}. Further, although the observer catch data did not allow statistical assessment, there were no declining trends in catches recorded from the JBG sub-fishery. The sea snake species occurring in JBG waters also occur throughout the NPF. Under 2004-2006 levels of fishing effort, a SAFE assessment of sea snake sustainability in the NPF concluded that no species of sea snake was at risk of over-fishing or being unsustainable. The AFMA scientific observer program showed that 70% of incidentally caught sea snakes were returned alive.

Two invertebrate species (mantis shrimps) recorded from bycatch in the JBG sub-fishery are currently listed as priority species by AFMA under Ecological Risk Management: *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni*. They were identified in 2011 in JBG waters by the NPF CMO program but previous monitoring of these species was likely hampered by the difficulty of reliable identification. Their status across the NPF is under ongoing investigation. Another invertebrate species *Abralia amarta* (squid) has been found in the JBG sub-fishery but is not otherwise known from the NPF. This meso-pelagic species is reported widely in the Indo-Pacific, and it seems that it is rarely encountered in the fishery; it should not be a priority for the monitoring programs.

Since 2011 the NPF CMO program on its own has monitored the target number of trawls (2350) across the NPF suggested by FRDC Project 2002/035 to adequately detect a statistically significant decline in TEP and 'at risk' species abundance. For the JBG sub-fishery a total of 138 trawls were monitored in 2011 by the NPF CMO program and 81 trawls were monitored by the AFMA scientific observer program in 2013, yielding 84 and 23 TEP and 'at risk' species records, respectively. Given this level of coverage these programs could never yield sufficient data for a robust statistical analysis of catch trends. In general there is an obvious difficulty in assessing bycatch sustainability in the JBG sub-fishery and the NPF: achieving the goal of reducing bycatch directly through TED and BRD implementation and indirectly through the fishery structural adjustments has ultimately reduced the catch of non-target species that are data-poor. Ironically, bycatch reduction has inhibited our ability to make statistically robust conclusions about the status of TEP and 'at risk' species. This is particularly the case for rarely observed species.

The current (2006-2012) JBG sub-fishery operates in an area bounded to the north by a line between Cape Londonderry, WA and Cape Ford, NT. The footprint of the fishery lies within an area classified as flat, soft substrate infaunal-dominated plains with occasional rocky outcrops and scattered epifauna. There has been no high resolution mapping of the area fished but the documented preference of *P. indicus* for muddy substrates suggests that the fishery occurs in areas dominated by mud. Further, the area of the current JBG sub-fishery corresponds with modelled peak mud content in the JBG region. Regionally, the fishery occurs in one provincial bioregion (Northwest IMCRA Transition) and one meso-scale bioregion (Bonaparte Gulf) as determined by the Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0).

The information available for future modelling of the JBG ecosystem comes largely from the 30+ years of research conducted into the NPF and NT fisheries, and the National Marine Bioregionalisation of Australia and associated biodiversity conservation management. Most of the field-based data and information comes from the scientific surveys by the Australian government research agencies such as Geoscience Australia, CSIRO and AIMS. Abiotic information for the JBG is available from remote sensing and models based on increasingly sophisticated oceanographic, geological and atmospheric research. To date, to our knowledge, little marine ecosystem or biophysical ecological research has been done by state government departments or universities. To develop an approach for ecosystem-based management of the exploited (trawled) benthos of the JBG, the basic and critical information requirements are; (a) understanding the extent and nature of benthic habitats, (b) understanding the biophysical interactions between species affected by fishing, and (c) understanding the trophic structure of the food web.

The food web of the JBG is probably the least known aspect of the ecosystem. Relevant trophic models have been developed for the Gulf of Carpentaria, but the demersal species assemblage is significantly different in the JBG. Nevertheless, the species composition and dominance information is available for the JBG and could be used to develop a conceptual trophic model, which in turn could be used to highlight potentially vulnerable species and guilds.

Hence, the key missing ecosystem elements are food web data and direct surveys and measurements of ecosystem processes that drive the dynamics affecting fisheries production. Development of a qualitative system model should include determination of the unknown roles of the land-sea interactions as well as the environmental forcing of climate (e.g. cyclones) and ocean variability and change. These, we believe, will be critical to forecasting the continued future of fisheries production in the JBG.

Implications for relevant stakeholders

This synthesis project updated our understanding of the ecological impact of the JBG sub-fishery. The principal beneficiaries of this research are the NPF industry, AFMA and consumers who have confidence in the sustainability credentials of the fishery, particularly maintaining Marine Stewardship Council accreditation. The synthesis has provided guidance for the design of monitoring in terms of observer days necessary over time to better define the status of the bycatch species of interest.

The research is unlikely to increase the yield of the fishery. However, by providing increased confidence in the sustainability of the JBG sub-fishery, and the NPF as a whole, the research will provide enhanced value of the yield. NPF Industry has identified promotion and market penetration via sustainability as a key opportunity in domestic and international markets. Direct linkage of this project to other NPF-related research and management was achieved through participation of industry together with scientists who are or have been engaged in other NPF research.

Recommendations

Although this synthesis strongly indicates that the JBG sub-fishery is currently ecologically sustainable research that chould be undertaken to further develop assessment of the status of the at-risk species, habitats and communities in the JBG sub-fishery include: a sustainability assessment for fishing effects (SAFE) for the JBG sub-fishery, using all up-to-date scientific and crew member observer data; quantification of by-catch catch trends from scientific observer programs such as the use of video footage to confirm the presence of species excluded by bycatch reduction devices and habitat mapping in the JBG sub-fishery using opportunistic underwater video footage collection or grab samples to help to resolve regional habitat mapping in the JBG.

KEYWORDS: Joseph Bonaparte Gulf, Red-legged banana prawns, Observer program, Bycatch species, TEP species, At risk species, Monitoring, Habitat, Ecosystem

3 Introduction

3.1 Fishery Description

The Joseph Bonaparte Gulf (JBG) sub-fishery operates in an area bounded by the western margin of the 771,000 km^2 NPF fishery described as the JBG box. The JBG box , is the area bounded by the line: (a) commencing at the intersection of the northern shore of the mainland of Australia, in the vicinity of Cape Londonderry at low water mark, with the meridian of Longitude 126° 58' East; (b) then running north along that meridian to its intersection with the parallel of Latitude 13° 00'South; (c) then running east along that parallel to its intersection with the mainland of Australia, in the vicinity of Point Blaze at low water; and (d) then generally south westerly, southerly, westerly and north-westerly along that shore at low water to the point of commencement (see http://www.comlaw.gov.au/Details/F2010L01363).

The JBG sub-fishery developed only in the early 1980s, as an alternative to fishing in the Gulf of Carpentaria (GOC), acting as an "escape valve" for fishing effort during times of poor catches in the GOC (Loneragan et al. 2002). Unlike the relatively benign conditions in the GOC, the JBG fishing grounds are characterised by a large tidal range (>7 m) and strong tidal flow (4 km hr^{-1}). The fishing grounds are also further off-shore, more exposed, and in deeper water (40-60 m) than in the GOC. For these reasons most of the fishing effort in the JBG occurs during the neap tides, when tidal flows are weakest. Although the temporal patterns of effort are largely determined by tides and prevailing weather the fishing seasons are as defined for the NPF fishery; the Banana season (April to June) and the Tiger season (August to December).

In the JBG sub-fishery, the main species caught is the red-legged banana (*Penaeus indicus*) with a small contribution of white banana prawns (*P. merguiensis*). The geographic distributions of these species within the fishery show little overlap (Somers 1994; Loneragan et al. 2002). For management purposes the JBG sub-fishery is defined by the jurisdictional area and only by the *P. indicus* catch. The banana prawn (*P. merguiensis*) and tiger prawn fisheries are managed separately as sub-fisheries.

The life cycle of the banana prawns in the JBG sub-fishery was the focus of a field-based research project undertaken in 1997-98 (Loneragan et al. 2002). As shown for the adults, the authors documented clear differences in the geographic distribution of juveniles of these species. In the eastern JBG and Cambridge Gulf catches of juvenile banana prawns were dominated by red-legged banana prawns whereas in the western JBG over 93% of juvenile banana prawns were white banana prawns (Kenyon et al. 2004). For red-legged banana prawns there was a large distance (>100 km) between spawning grounds and nursery habitats suggesting that post-larvae must use tidal flows to reach their early benthic inshore habitat. For white banana prawns the distance between spawning and nursery habitats was smaller (~50 km). Nevertheless, the advective processes for both species have not been accurately determined and this remains a key information gap.

Catch and effort information is captured for the whole NPF fishery through the AFMA logbook database in 6 minute by 6 minute grids; there are an estimated 7281 grids in the area of the NPF (Source: http://www.afma.gov.au/managing-our-fisheries/harvest-strategies/harvest-strategy-for-the-nort). During the peak of effort in 1989, NPF-wide effort was reported in ~21% of grids; however, by 2010 grid coverage had fallen to ~10% of grids. The number of vessels recording catch in the NPF fell from 134 in 1995-96 to 52 in 2010, as a result of combined internal industry restructuring and the 2006 Commonwealth Structural Adjustment Program.

Assessment of the JBG red-legged banana prawn fishery uses a dynamic model fitted to catch and effort data (Plaganyi et al. 2012; Buckworth et al. 2013). Unlike the GOC area of the fishery there are no fishery-independent surveys conducted in the JBG and assessment of red-legged banana prawn stock status is completely reliant on the commercial catch and effort data. Fishing effort in the JBG sub-fishery increased to a peak of ~2500 boat days in 1986 down to ~500 days in 2011 and 2012. The JBG sub-fishery catch peaked at ~977 tonnes in 1997, decreasing to ~131 tonnes in 2007. During 2007-2010, the JBG was not fished during the banana prawn season (April to June). Historically the largest catches were taken during both the second quarter of the year (April – June) and the third quarter (July – September). In 1997 initial high catch rates decreased significantly during the year and remained low in 1998, suggesting that the catch for 1997 was unsustainable. However, since then catches have been less than half the 1997 catch, effort reduced markedly; as a result the resource has recovered (Plaganyi et al. 2012). Model results suggested that the red-legged banana prawn resource had been above B_{MEY} since ~2005, and equivalent TACs and TAEs were set using these estimates.

3.2 Ecological Impact Assessment

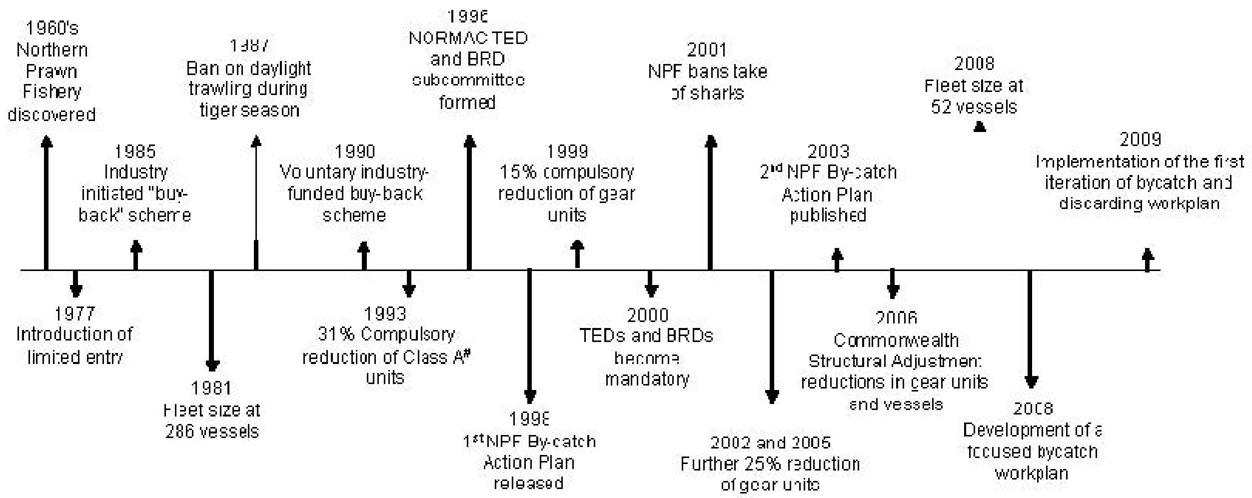
Although not specific to the JBG sub-fishery, several extensive research projects have been conducted since ~1995 that have addressed the ecological sustainability of prawn trawling in areas of the Northern Prawn Fishery. Many of these studies have included areas in the JBG fishing grounds and most have direct relevance to the assessment of impacts of fishing within the JBG sub-fishery.

The earliest research directly assessing ecological sustainability of at-risk species was likely the general descriptions of bycatch resulting from trawl operations undertaken by NT Fisheries in the late 1980s (Ramm et al. 1990; Willing et al. 1992) and, in more detail, as part of the Bycatch Action Plan (BAP) in 1998. The BAP followed implementation of the Northern Prawn Fishery Management Plan in 1995, which had already established strict mechanisms for managing effort levels in the fishery through numbers of trawlers and gear restrictions.

Turtle Excluder Devices (TEDs) were mandatorily implemented on all vessels in the NPF in 2000 after a program of gear trials and assessment of efficacy. As a result, turtle catches were reduced by more than 97% (Brewer et al. 2006) and catches of large sharks and rays reduced by more than 80% (Brewer et al. 2004). There has been a reduction in total bycatch by at least 50% since the BAP was implemented in 1998 (Tuck et al. 2013), due to the combination of TEDs and a number of effort reductions through buy-back and gear unit reduction schemes.

Although TEDs significantly reduced the catches of large bycatch species, they had little (up to 8%) efficacy in reducing small bycatch (Brewer et al. 2004). As a result, Bycatch Reduction Devices (BRDs) became compulsory in 2001; mainly comprising a square mesh panel (90% of operators) or the fisheye design (10% of operators). However, commercial sea trials of the square mesh panel device showed only a small (8%) reduction in small bycatch (Brewer et al. 2004).

A useful timeline of the management measures implemented to address bycatch in the NPF fishery is provided in Tuck et al. (2013), Source: AFMA 2011; Bycatch and Discard Workplan 2011, and is shown here.



Following the early research to address and reduce bycatch in the NPF fishery, an Ecological Risk Assessment (ERA) was undertaken to provide comprehensive assessment of the ecological risks arising from fishing on five ecological components - target species; by-product and by-catch species; threatened, endangered and protected (TEP) species; habitats; and communities (Griffiths et al. 2007).

Seabed habitat within the JBG is broadly described in the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 2006) within the Northwest IMCRA Transition Provincial Bioregion and Bonaparte Gulf meso-scale. However, there has been limited habitat mapping within Joseph Bonaparte Gulf; particularly in the area of the current fishery.

The plenary aim of this desktop study was to determine if there was adequate information currently available, from the sources outlined above, to assess the ecological sustainability of the at-risk species, habitats and ecosystems impacted by the JBG sub-fishery, and if not to make recommendations on research tasks required to make that assessment.

3.3 Need

The Northern Prawn Fishery (NPF) received certification under the Marine Stewardship Council in 2013, becoming the first tropical prawn fishery in the world to receive eco-certification under this stringent process. Certification was conditional upon a number of actions being addressed. Included among the actions was the need to demonstrate, using robust and current information, that prawn trawling in the Joseph Bonaparte Gulf sub-fishery is not having adverse impacts on at-risk species, vulnerable habitats or ecosystems: the key certification conditions.

To maintain certification under the MSC, NPF Industry Pty Ltd was required to undertake a number of actions by 31 September 2013. They included:

- Evaluating existing information to confirm its suitability for understanding key ecosystem elements in the JBG, understanding the nature, distribution and vulnerability of the main habitat types present, and monitoring at-risk species (where identified). Based on this evaluation, identify any data deficiencies and information gaps.
- Implementing a program of activities to address deficiencies/gaps where required; and,
- Using existing and newly-implemented (as required) research and monitoring activities to assess the status of at-risk species, vulnerable habitats and ecosystems in the JBG sub-fishery.

The outcomes of this report will advance these actions. Importantly, failure to do so would jeopardise ongoing certification of the Northern Prawn Fishery.

4 Objectives

1. Determine the feasibility of using and extending the existing observer coverage of the NPF to monitor the at-risk species identified through the ERA process.
2. Assess all available spatially-explicit information on habitats and their proxies (seascapes, bioregions, environmental envelopes, geomorphs etc) and develop a detailed plan to identify the nature, distribution and vulnerability of the main habitat types in the JBG.
3. Assess whether existing information available is sufficient to understand key ecosystem elements (including target species, bycatch species and habitats) in the JBG sub-fishery.

5 Method

5.1 Analysis of JBG “at-risk” species status and monitoring

5.1.1 JBG BYCATCH COMPOSITION

We used information and data from several published FRDC and AFMA reports and peer reviewed articles for this synopsis. Key information on species composition in the JBG sub-fishery was provided in Tonks et al. (2008). Additional distribution data on TEP and at risk species occurring in JBG was provided by the AFMA scientific observer (SO) and NPF crew member observer (CMO) programs, supplementing the assemblage described by Tonks et al. (2008). This benchmark species data-set was then compared with broader species composition data for the entire NPF and the designated “at-risk” and TEP species from several studies addressing the ecological sustainability of the NPF.

Potential “at-risk” species were first identified from the Level 2.5 AFMA ERA for the NPF (Griffiths et al. 2007). This comprehensive assessment covered all sub-fisheries of the NPF; tiger prawn, banana prawn and JBG. As fishing intensity in the tiger and banana prawn fisheries is much higher than in the JBG sub-fishery, this assessment provided a conservative view on which species might be at risk from the impacts of fishing in JBG.

There is little information on the epibenthic species occurring in the JBG sub-fishery to allow for an accurate assessment of the likely impacts of trawling on this assemblage, both through capture and physical damage. A comprehensive study of the impacts of trawling on benthos was undertaken in the Gulf of Carpentaria (GOC) but the outcomes were relevant mainly to the tiger prawn sub-fishery, which operates on the shallow sedimentary shelves and submerged river beds of the south-western GOC (Bustamante et al. 2011). Nonetheless, this study found from conceptual modelling that at the fishing effort levels at the time of the study (2005-2010), the trawling-induced changes were relatively small and with little net variation across the range of performance measures and metrics tested. This was taken as evidence that the changes induced on the benthic ecosystems as a whole were small and minor. Given that effort has declined since this study was completed the outcomes should still hold.

5.1.2 ADEQUACY OF OBSERVER MONITORING

We used information made available from NPF logbook monitoring, AFMA scientific observer and crew member observer programs, as well as that collated in several AFMA and FRDC reports, to assess the likely adequacy of current observer monitoring in the JBG sub-fishery. Our particular focus was on the monitoring of “at-risk” and TEP species. Detailed bycatch species information collected during pre-season and mid-season scientific stock surveys undertaken by CSIRO was not used in this synopsis as the surveys are restricted to the GOC, where the bycatch assemblage differs from the JBG sub-fishery.

5.2 Analysis of JBG Habitats and their vulnerability

There has been no comprehensive mapping of the seabed habitats in the area of the JBG sub-fishery, likely due to the relatively light intensity of fishing effort there in comparison to the GOC. Coarse scale descriptions of benthic habitats of JBG were provided in the Interim Marine and Coastal Regionalisation for Australia (IMCRA, 1998) report and updated to IMCRA version 4.0 in June 2006. Subsequently, Przeslawski et al. (2011) developed a regional habitat map for the Joseph Bonaparte Gulf region. We used information in this report, combined with the VMS spatial coverage, to suggest what broad habitats would be impacted by prawn trawling and their likely vulnerability.

Although there have been several studies on the impacts of prawn trawling on seabed habitats in northern Australia (e.g. Haywood et al. 2005 and Bustamante et al. 2010) and the subsequent recovery of seabed communities (Pitcher et al. 2004) it is difficult to draw conclusions about impacts in JBG from these studies given the inherently different communities in JBG (e.g. depth >40 m, high tidal flow and predominantly off-shore).

5.2.1 SPATIAL AND TEMPORAL PATTERNS OF FISHING IN JBG

The direct and indirect impacts of fishing on at-risk species and seabed habitats could only be determined once the spatial and temporal trends of effort were determined. NPF logbooks provided data at a 6nm by 6nm grid resolution, but finer resolution data was available from the mandatory vessel monitoring system (VMS) implemented in the NPF. The spatial and temporal patterns of fishing in the Joseph Bonaparte Gulf were assessed using VMS data collected by AFMA between 1999 and 2012. These data were assumed as a proxy for seabed habitat impacts by trawl gear.

The VMS data were filtered and interpolated to extract only records that represented trawling, rather than at anchor or travelling, using the methods described in Haywood et al. (2005). The VMS data were then spatially restricted to the area defined as the JBG (AFMA definition; provide a link to the website), and collated in 1nm^2 grids. This information could not be plotted in annual increments due to the ongoing confidentiality agreement pertaining to VMS data namely: data for publication should be aggregated to represent at least 5 or more boats AND 10 or more boat days. Hence, we aggregated the data for two time periods 1999-2005 and 2006-2012 to display the overall spatial distribution of the fleet effort. The cut-off between these time periods was chosen based on the significant effort reduction subsequent to the Commonwealth Structural adjustment in 2006.

The fishing effort data also provided key information on the total number of grids fished and the intensity of fishing in each 1 nm^2 grid (hours.nm^{-2}). The distribution of fishing effort per 1 nm^2 grid was plotted for each year to further refine the analysis of fishing extent and intensity over time.

5.3 Analysis of key elements required to develop a qualitative model of the JBG ecosystem

The ecosystem definition for the JBG encompasses only the available and published information on some of the known elements of the biological, ecological and the physical environmental components of the JBG marine ecosystems. These generically include many elements:

(i) the biotic (e.g. biodiversity, habitats, communities, species, genes),

(ii) the environmental abiotic (e.g. geology, oceanography, atmosphere), and

(iii) their interactions (e.g. food web, biophysical relations, and processes such as production, cycling, linkages).

In this section we have not included the human socioeconomics, indigenous or cultural components that the modern definition of the ecosystem normally embraces (e.g. goods, services, values).

The methodology we have applied is based largely on the use of available literature, bibliographic searches and survey data reviews. The main sources of information are those derived from the biodiversity, fisheries, and geological research conducted in the JBG that include the benthic habitats used by the NPF. We are not providing here the information of the JBG-wide ecosystem, nor the trans-boundaries and interconnected marine or terrestrial ecosystems.

The analyses conducted involved simple qualitative assessments on the elements derived from the above definition of the marine ecosystem (i to iii) and the narrative of the state and quantum of the data, information and knowledge basis for the likely development of ecosystem-based fisheries management. The assessments were tabulated to indicate the level of availability and data, information and knowledge about the fisheries ecosystem of the JBG.

5.4 Statistical analysis of sufficiency of observer data for ecological impact assessment

Assessment of the sustainability of bycatch species is dependent on the species' abundance and distribution within and outside of the fishery. For common, ubiquitous species a statistical analysis of catch trends will invariably be the best and most defensible approach. NPF-wide, Fry et al. (2009) (FRDC Project 2008/826) used a General Linear Model (GLM) to show stable inter-annual trends in catch of the common seasnake species *Hydrophis elegans*, *Lapemis hardwickii* and *Anoxypristis cuspidata* between 2002 and 2009. However, most of the TEP and 'at risk' species were not able to be assessed by the GLM method due to the scarcity of catch records in the time series data.

In FRDC Project 2008/826 it was anticipated that a power analysis would be carried out to assess detectable levels of change in bycatch catches, updating the power calculations of the previous bycatch monitoring FRDC Project 2002/035. However, as stated it was not feasible to carry out a robust statistical analysis of the data for most species. To assess the suitability of current data for a statistical analysis, we used the general recommendation of Brewer et al. (2004, FRDC Project 2002/035) that catch should be collected from a total of 2350 trawls each year as the primary criterion appropriate to detect a decline in TEP and 'at risk' species.

6 Results

6.1 “At-risk” species status and monitoring in JBG

6.1.1 JBG BYCATCH SPECIES COMPOSITION

Species composition of prawn trawl bycatch in the Joseph Bonaparte Gulf was described by Tonks et al. (2008) from 53 commercial trawls over two years. The taxa identified during this research are listed in Appendix 13.3. Other than the exclusion of turtles and large sharks and rays due to the mandatory fitting of TEDs, it is not known if this list of incidental bycatch species was comprehensive and representative of the bycatch to date.

The AFMA scientific observer, Crew member observer, NPF prawn monitoring and other scientific surveys have provided catch data for TEP and ‘at risk’ bycatch species from throughout the NPF since 2002 (Fry et al. 2009). The NPF prawn monitoring surveys are conducted only in the GOC but the remaining programs have included the JBG. Species recorded additional to those from Tonks et al. (2008) are shown in Appendix 13.3.

Effort reduction in the NPF fishery (83 boats at the time of the study by Tonks et al. 2008 cf. 52 boats current) and contraction of the spatial extent of fishing effort since the time of this study (see 6.2.1), would suggest that the recorded species composition in Appendix 13.3 would be representative of current bycatch composition.

Due to the dissimilarity in species composition, Tonks et al. (2008) suggested that the JBG bycatch should be regarded as distinct to the NPF Gulf of Carpentaria (GOC) assemblage. Several JBG species recorded have not been recorded in the GOC: the fish *Polydactylus nigripinnis*, *Setipinna paxtoni*, *Larimichthys pamoides*, *Benthosema pterotum*, *Johnius laevis*, *J.* cf *trawavase*, *Lophichthys boschamai* and the meso-pelagic squid *Abralia amarta*.

6.1.2 NPF COMMERCIAL LOGBOOK MONITORING

Catches in numbers of TEP and ‘at high risk’ bycatch species recorded from NPF commercial logbooks between 1998 and 2012 from the NPF and the JBG sub-fishery only are shown in Appendix 13.5.

A total of 1754 bycatch target specimens were recorded in the JBG sub-fishery since 1998; dominated by sea snakes (Hydrophiidae spp. 1530). Of these specimens, a total of 456 were recorded during the banana prawn fishing season, again dominated by sea snakes (399). However, the banana fishing season was closed in the JBG sub-fishery during 1997-2010. Catches of sea snakes in the JBG sub-fishery were variable over the period monitored but there was no declining catch trend. Effort declined over the same period so it is inferred that total catches of these species declined correspondingly.

The introduction of TEDs substantially reduced catches of turtles. From 1998-2012 a total of 79 marine turtles were recorded in the JBG sub-fishery (56 during the banana fishing season and 23 during the tiger fishing season). However, a total of 60 turtles were recorded in the two years of data collection prior to the introduction of TEDs in 2000, a much greater catch rate than after the introduction of TEDS.

A total of 125 sawfish were recorded in the JBG sub-fishery (1 during the banana fishing season and 124 during the tiger fishing season). Most specimens were unidentified but among them two species were recorded *Pristis zijsron* and *Anoxypristis cuspidata*. There were no declining trends in catches of sawfish for the period monitored; either the unidentified specimens or the recorded species.

6.1.3 NPF CREW MEMBER OBSERVER (CMO) MONITORING

Catches in numbers of TEP and 'at high risk' bycatch species recorded by crew member observers between 2003 and 2012 from the NPF and the JBG sub-fishery only are shown in Appendix 13.6.

A total of 1995 bycatch specimens have been recorded in the JBG sub-fishery since 2003; dominated by the coral prawn *Solenocera australiana* (1632). Note this species was previously listed as 'at high risk' (AFMA 2012), but was subsequently removed from the priority list due to its widespread NPF distribution and consistent significant catches (Fry et al. 2009). Only two TEP specimens (sea snakes) were recorded during the banana fishing seasons in the JBG sub-fishery.

Excluding the coral prawns, from 2003 to 2012 the CMO records were dominated by sea snakes (80%; 292 of 363), followed by sawfish (14%; 51 of 363) (Appendix 13.6). Annually, the sea snakes made up greater than 60% of total catches and there was no declining trend in catch over time. Sawfish catches, although variable between years showed no declining trend.

6.1.4 AFMA SCIENTIFIC OBSERVER (SO) MONITORING

Catches in numbers of TEP and 'at high risk' bycatch species recorded by AFMA scientific observers between 2007 and 2013 from the JBG sub-fishery are shown in Table 1.

A total of 87 TEP and 'at high risk' bycatch specimens have been recorded in the JBG sub-fishery since 2007; dominated by sea snakes (70). Two *Astrotia stokesii* were captured in one trawl in 2010, and two *Disteira major* were captured in one trawl in 2013. Apart from these captures all others were of single specimens per trawl.

During the monitoring period a total of 145 trawls were monitored that had no TEP or 'at high risk' species captures.

Survival rates for the bycatch species were variable. Overall 70% of sea snakes were released alive, and 41% of sawfish were released alive. However, it is not known if these specimens survived post-release.

Table 1 Catch in numbers and survival in percent of TEP and 'at high risk' bycatch species recorded from the AFMA scientific observer program between 2007 and 2013.
Numbers of trawls with no observations are also listed.

Year	CAAB Code	Species Name	Catch	Survival
2010		Nothing was caught/observed	59 (trawls)	
2010	37025001	*Pristis zijsron*	2	50%
2010	37025002	*Anoxypristis cuspidata*	11	45%
2010	39125009	*Astrotia stokesii*	23	48%
2010	39125011	*Disteira major*	8	100%
2010	39125021	*Hydrophis elegans*	13	62%
2010	39125031	*Lapemis hardwickii*	3	100%
2011		Nothing was caught/observed	4 (trawls)	
2011	37025002	*Anoxypristis cuspidata*	3	33%
2012		Nothing was caught/observed	1 (trawls)	
2012	39125021	*Hydrophis elegans*	1	0%
2013		Nothing was caught/observed	81 (trawls)	
2013	37025000	Pristidae - undifferentiated	1	0%
2013	39125000	Hydrophiidae - undifferentiated	1	0%
2013	39125009	*Astrotia stokesii*	1	100%

2013	39125010	*Disteira kingii*	1	100%
2013	39125011	*Disteira major*	10	80%
2013	39125013	*Enhydrina schistosa*	2	100%
2013	39125021	*Hydrophis elegans*	7	86%

6.1.5 PROTECTED (TEP) AND 'AT-RISK' SPECIES STATUS

As per the specific requirements of the EPBC Act, all Commonwealth Fisheries are required to take all reasonable steps to ensure interactions with TEP species are minimised. Theoretically there are 93 TEP species (Appendix 13.4) that occur within the waters of the whole NPF including: 8 elasmobranchs (5 sawfish, 2 speartooth sharks, whale shark), 41 marine reptiles (33 sea snakes, 6 marine turtles, 2 crocodiles) and 44 teleosts (39 pipefish, 5 seahorses). A total of 23 TEP species (five marine turtles, five sawfish and 13 sea snakes) have been recorded by Tonks et al. (2008) or by AFMA and crew member observers from commercial trawls in the JBG (Appendix 13.3).

Marine Turtles

Five species of TEP marine turtle *Caretta caretta* (Loggerhead turtle), *Lepidochelys olivacea* (Olive Ridley turtle), *Chelonia mydas* (Green turtle), *Eretmochelys imbricata* (Hawksbill turtle) and *Natator depressus* (Flatback turtle) have been recorded in waters of the JBG (Appendix 13.3), by the ongoing AFMA and crew member observer programs. A total of 79 turtles were recorded in the JBG sub-fishery by the NPF logbook monitoring program since 1998 and a total of 5 have been recorded by the NPF CMO program since 2003. However, since the introduction of TEDs in 2000 only eleven turtles (two *C. caretta,* one *L. olivacea,* three *C. mydas,* one *N. depressus and* four unidentified turtles) have been recorded in commercial trawls (Appendix 13.5 and 13.6). These species are not listed as priority species for the NPF in the latest Ecological Risk Management (ERM) report (AFMA 2012).

Sea snakes

Thirteen species of TEP sea snake have been recorded in waters of the JBG (Appendix 13.3). These species are recorded by ongoing AFMA and crew member observer programs. TEDs have no significant effect on sea snake escapement and hence catch rates recorded by observers are comparable throughout time. Sea snake catch rates (No.s per km^2) were variable during 1993-2008 but showed no declining trend (Tuck et al. 2013). Zhou et al. (2012) included these species in a SAFE assessment of sea snake sustainability in the NPF under 2004-2006 levels of fishing effort. They concluded that no species of sea snake was at risk of over-fishing or being unsustainable, and commented on the inherent conservative nature of their approach. Given the subsequent decline in fishing effort since the period examined by Zhou et al. (2012), these conclusions should hold. Wassenberg et al. (1994) estimated the survival rate for sea snakes caught incidentally in the NPF at ~60%. In a subsequent study Wassenberg et al. (2001) estimated that 28% of sea snakes landed were already dead and the overall survival rate after release was 51.5%.

All sea snake species occurring in JBG waters also occur throughout the NPF (Tuck et al. 2013).

Elasmobranchs

Five species of TEP sawfish have been recorded in waters of the JBG (Appendix 13.3). Previous studies by Brewer et al. (2004) found that catches of the most common and ubiquitous species found in NPF waters, *Anoxypristis cuspidata*, were reduced by 73% due to the introduction of TEDs. In JBG waters this species is found mainly in inshore waters during both the banana and tiger prawn fishing seasons (Fry et al. 2009).

For sawfishes overall Brewer et al. (2004) found that the reduction in sawfish catches due to TEDs was minimal. Sawfish catch rates (No.s per km^2) showed a generally increasing trend during 1995-2008 (Tuck et al. 2013).

Other TEP elasmobranchs are found in the NPF. One species *U. asperrimus* is a priority species listed in the latest ERM report (AFMA 2012). However, the TEP sting rays *Taeniura meyeni*, *Urogymnus asperrimus* and the wobbegong *Orectolobus ornatus* recorded by the bycatch observer programs have not been recorded in JBG waters (Tuck et al. 2013).

The latest sustainability assessment for fishing effect (SAFE; Zhou 2011) found that no elasmobranch species caught in the NPF had fishing mortality rates greater than their mean maximum sustainable fishing mortality, F_{msm}. This assessment used fishery distribution and effort data from 2007-2009.

Teleosts

The TEP syngnathids (seahorses and pipefish) have only been recorded by the NPF crew member observer program in JBG waters (two specimens in 2009, Appendix 13.6). It is likely prevailing conditions in the JBG are unsuitable for this group; principally high current flow and an absence of seabed structure (either biotic or hard susbtrate), which may affect them due to their limited mobility. Nevertheless, there is a paucity of information on the life history of the group as a result of their cryptic behaviour and small size.

The latest sustainability assessment for fishing effect (SAFE; Zhou 2011) found no teleost species caught in the NPF had fishing mortality rates greater than their mean maximum sustainable fishing mortality F_{msm}. Further, even when the 90%CI of the estimated fishing mortalities were accounted for, no teleost species had a fishing mortality rate greater than its minimum unsustainable fishing mortality (F_{crash}). This latest updated assessment, subsequent to the Level 2 ERA assessment, includes the seven teleosts species found by Tonks et al. (2008) to be unique to the JBG sub-fishery.

Invertebrates

The coral prawn *Solenocera australiana* has been commonly recorded by the bycatch observer programs in JBG waters (Tuck et al. 2013). It also occurs commonly throughout the GOC waters. Although originally listed as high risk from the level 2 ERA (Griffiths et al. 2007), it was subsequently removed from the list of species deemed 'at-risk' due to its widespread distribution and high catch and consistent catch rate (AFMA 2012).

The mantis shrimp *Dictyosquilla tuberculata* was recorded by Tonks et al. (2008) from commercial prawn trawls in JBG waters and 3 specimens were recorded by crew member observers in 2011. The mantis shrimp *Harpiosquilla stephensoni* was also recorded by crew member observers in 2011. Previous monitoring of these species was hampered in part due to the difficulty in reliably identifying them. These species were identified as 'at high risk' from the level 2 ERA (Griffiths et al. 2007). Historical catch rates for these species are largely unknown, again due to the previous difficulty in identifying this group.

D. tuberculata and *H. stephensoni* are two of three species listed as high priority bycatch species for the NPF in the latest ERM report (AFMA 2012).

The squid *Abralia amarta* was recorded by Tonks et al. (2008) in the JBG sub-fishery, but was not recorded from elsewhere in the NPF. The Level 1 or Level 2 ERA analysis (Griffiths et al. 2007) preceded its record and thus it was not assessed. It has not been included in subsequent quantitative assessment. However, it is a meso-pelagic species (http://www.fao.org/docrep/014/i1920e/i1920e05.pdf), reported widely in the Indo-Pacific, and rarely encountered in the JBG fishery. . Species in this genus are typically found in depths of 600 m or so, but ascend to shallower waters (~ 100 m) of a night. Reported from Indonesia, Philippines, Moluccas Islands, the South China Sea (FAO) and additionally, from the Northwest Shelf of Australia (Vic Museum), *A. armata* is thus widespread in the Indo-Pacific but perhaps has little distributional and habitat overlap with the JBG area fished by the NPF. When distribution and habitat are considered, we suggest that the proportion of the squid population that encounters the JBG fishery is very small. Its rarity has made it of interest when assessing fishing impacts. The squid are small (length maximum 13 cm), elongate and with a smooth profile: they would be subject to a low retention rate. Given low encounter and retention rates, it is thus unlikely that the fishery has significant impact on the squid species. Furthermore, monitoring JBG catches for this species would be unlikely to provide any information on species status. Our recommendation is that it should not be a target of the NPF Crew Monitoring or the AFMA Scientific Observer programs.

6.1.6 SCALE OF BYCATCH MONITORING IN THE NPF

Overall effort in the NPF fishery increased rapidly during 1970 to the mid 1980s, but has steadily declined since the peaks (~30000 days and ~7000 days in the tiger and banana sub-fisheries respectively) to less than 5000 days in each of the sub-fisheries (Figure 1).

Remembering that the JBG fishery only began after the peak of the NPF fishery in the early 1980s, the decreasing temporal trend of fishing effort in the JBG sub-fishery (Figure 4) has generally followed that of the whole NPF.

Since implementation of the crew member observer (CMO) program in 2003, the percent coverage of the NPF effort has been variable, declining during 2003-2008 from 10% to 3% of total days fished in the tiger prawn sub-fishery (Figure 2). However, since the record low in 2008 the percent coverage has increased markedly to ~15 % of fishing days monitored in 2012. Due to the difficulty of simultaneously monitoring bycatch and undertaking deck-duties during the banana prawn fishing season, he CMO program has only covered the banana prawn sub-fishery in 2004 (79 days), 2011 (63 days) and 2012 (97 days).

A total of 212 vessel days and 829 trawls have been monitored by the NPF crew member observer program in the JBG sub-fishery during the second season since 2003 (Table 2). The JBG sub-fishery was only monitored during the banana season by the CMO program in 2004 (4 vessel days and 18 trawls). However, the fishery was closed in the banana season during 2007-2010 and since 2010 annual effort in JBG in the Banana Prawn season has been <100 vessel days.

The adequacy of bycatch monitoring is in part determined by the statistical power provided by the observations to detect a certain level of decline (or increase) in abundance. Brewer et al. (2007a) used bycatch data to suggest that a minimum of 2350 trawl samples per year should be monitored to provide sufficient power to detect a decline in abundance of the TEP and 'at risk' species. Current crew member observer effort is very close to this number of samples (Figure 3). However, due to the steady decline in fishing effort, this level represents far greater coverage of the fishery (15% for the tiger prawn fishery) in 2012 compared to a similar number of shots covered in 2004 (with only 9% of days covered). It is perhaps unfortunate that obtaining the key data necessary to determine the status of a species' population is independent of the level of fishing effort impacting on that population.

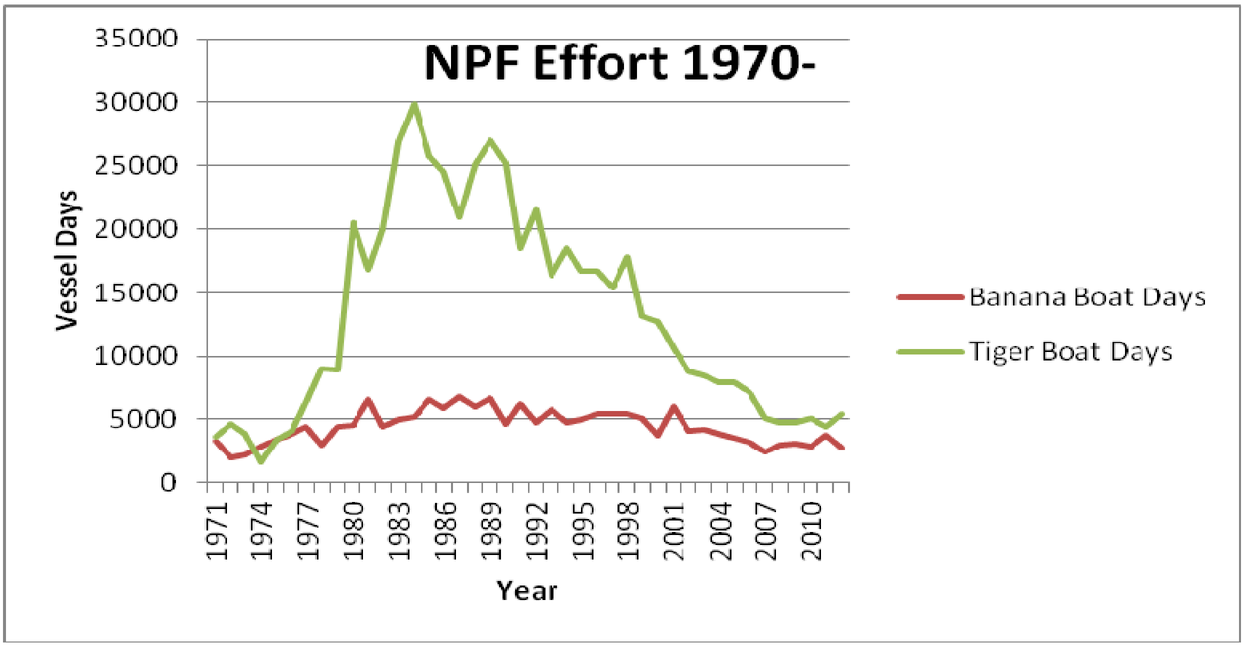


Figure 1 Total fishing effort (vessel days) for the NPF tiger prawn and banana prawn sub-fisheries between 1970 and 2012.

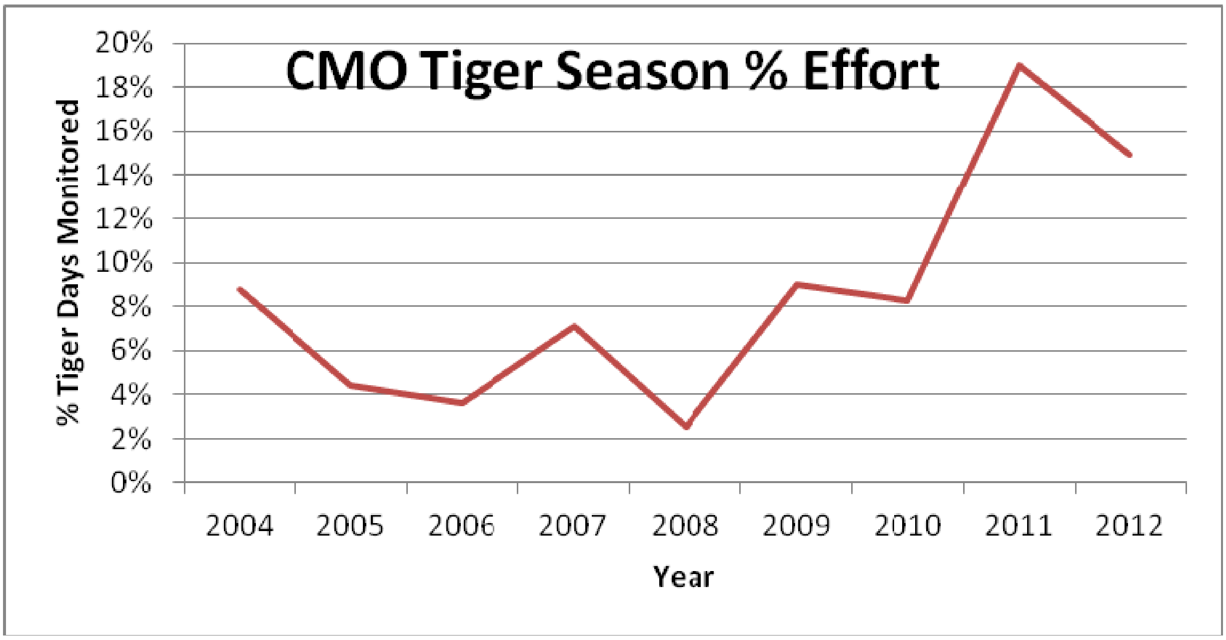


Figure 2 Percentage of fishing days monitored by crew member observers in the NPF tiger prawn sub-fishery between 2003 and 2012.

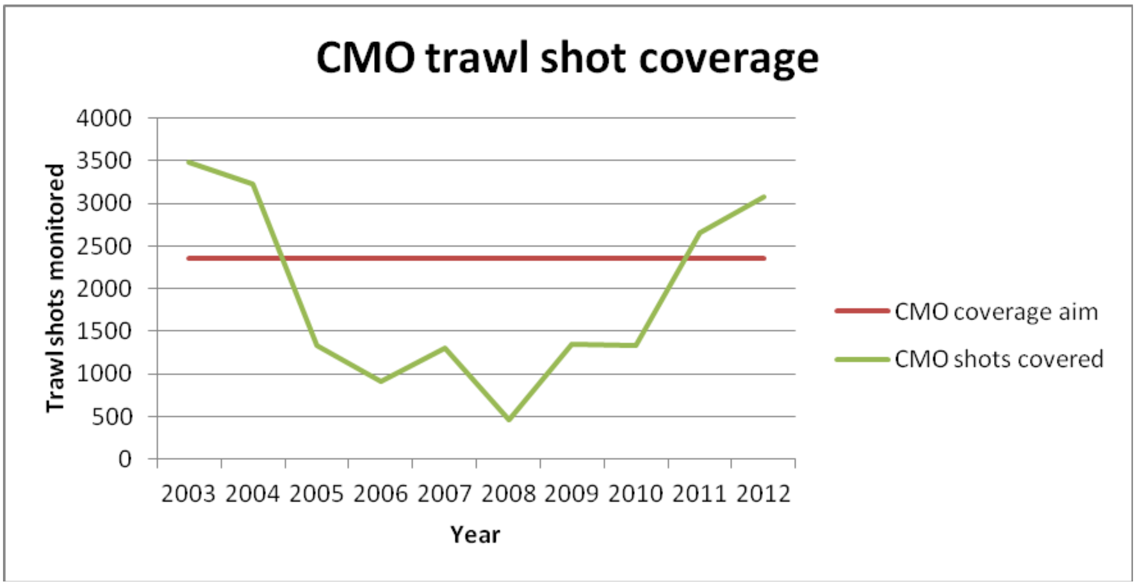


Figure 3 Number of NPF tiger prawn sub-fishery trawl shots monitored by the crew member observer program between 2003 and 2012.
The red line denotes the number of shots suggested by Brewer et al. (2007a) to achieve sufficient power to detect a significant decline in abundance of rare at-risk species.

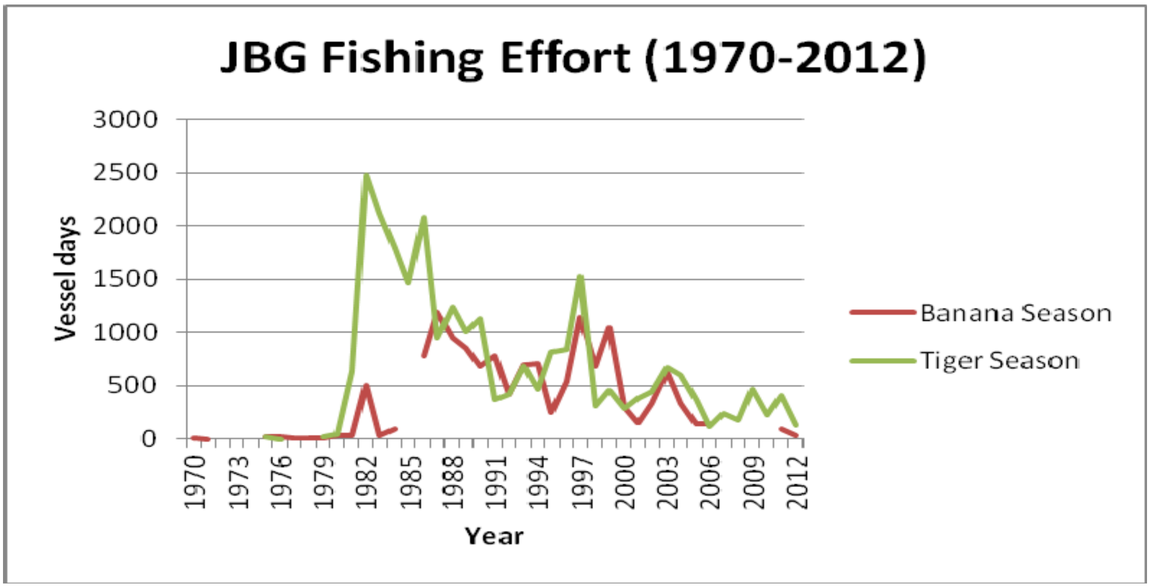


Figure 4 Total fishing effort (vessel days) for the JBG sub-fishery (tiger season and banana season) between 1970 and 2012.
Note the JBG sub-fishery banana season was closed during 2007-2010.

The coverage of the CMO program of the JBG sub-fishery second season has been variable from nil to ~30% of vessel days fished monitored annually. There did not appear to be a close relationship between the number of trawls monitored and the number of TEP and 'at risk' species counted (excluding *Solenocera australiana;* see Appendix 13.6) (Figure 5). However, generally greater numbers of bycatch species were recorded per trawl for most recent years. This was possibly due to maturation of the crew member observer program and increased competence of the observers due to annual training.

Table 2 Number of vessel days and trawls monitored and percent of total fished days for the NPF crew member observer (CMO) program in the JBG sub-fishery between 2003 and 2012.

	CMO Program in JBG sub-fishery		
Year	**Vessel days**	**Trawls monitored**	**% of Vessel Days**
2003	54	228	8.0%
2004	18	83	3.0%
2005	50	198	13.6%
2006	34	109	28.6%
2007	2	4	0.9%
2008			
2009	24	69	5.1%
2010			
2011	30	138	7.4%
2012			
TOTAL	**212**	**829**	

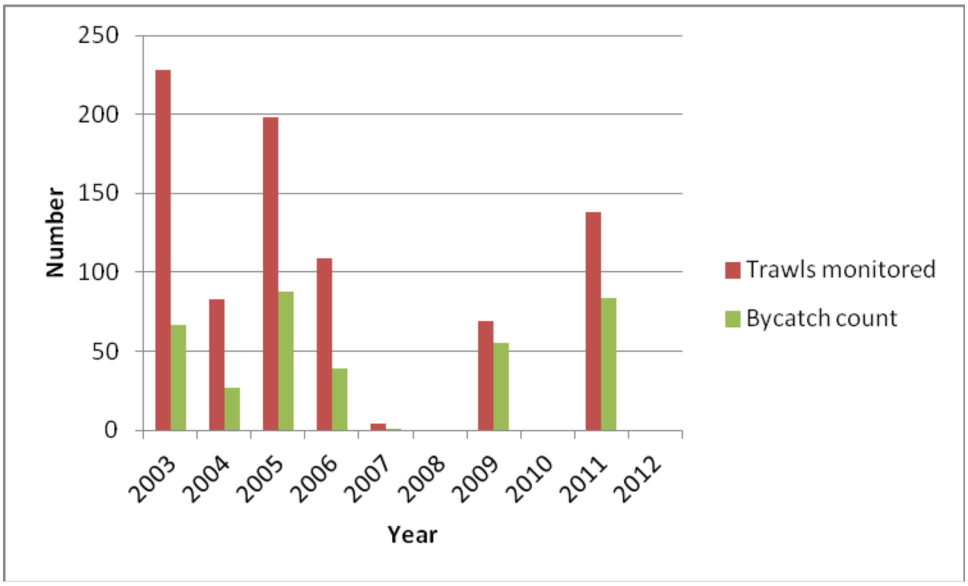


Figure 5 Relationship between the number of trawls monitored and the number of TEP and 'at risk' bycatch species monitored in the JBG sub-fishery during the tiger season.

6.2 Composition of Habitats and their vulnerability in JBG

The latest Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0) provided 41 provincial bioregions characterised by suites of endemic fish, 60 meso-scale regions defined using biological and physical information and 1334 geomorphic units based on geomorphological characteristics. The JBG sub-fishery operates in the Northwest IMCRA Transition provincial bioregion, which extends out to the EEZ.

Although there have been several scientific fishery-related surveys conducted in the Joseph Bonaparte Gulf, none have provided data suitable to precisely map the distribution of seabed habitats exposed to fishing impacts. Kenyon et al. (2004) determined the nursery habitat preferences of *P. indicus* in JBG, with juveniles occurring in the small muddy mangrove lined creeks east of and including Cambridge Gulf. However, no complementary study on the habitat preferences of adult *P. indicus* has been done in the JBG (see Kenyon et al. 2000). This species occurs throughout the Indo-west Pacific and forms the basis of major commercial fisheries in East Africa, India, Malaysia, Thailand and Indonesia (Grey et al. 1983). In Oman waters pre-adult *P. indicus* were found to be concentrated in muddy substrata (Mohan and Siddeek 1996), and in creeks in the Red Sea this species dominated on very fine sediment (Branford 1981). The area of the current JBG sub-fishery (Figure 7) corresponds with modelled peak mud content in the JBG area (Figure D2, Przeslawski et al. 2011). Hence due to the preference of the target species *P. indicus* for habitat comprised of muddy sediment, it is likely that the dominant habitat throughout the fishery for *P. indicus* in JBG is mud.

A generalised habitat map for the Joseph Bonaparte Gulf showing potential distribution of habitats and biological communities is provided in Przeslawski et al. (2011 and shown in Appendix 13.7). Focusing on available biological data from scientific and mining surveys, the study characterised the outer shelf banks mining region and hence most biological information is known for that area. Nevertheless, the broad regional-scale geomorphic features provided useful information on the likely habitats occurring in the area of the JBG sub-fishery.

The model suggests that about 64% of the habitats occurring within the JBG area (Przeslawski et al. 2011) were classified as infaunal plains (inshore flat, soft substrate with occasional rocky outcrops, scattered epifauna, biota dominated by infauna). The remaining offshore habitats tended to be more heterogeneous including sponge gardens and epifaunal terraces. The current (2006-2012) JBG sub-fishery operates in an area bounded to the north by a line between Cape Londonderry, WA and Cape Ford, NT (Figure 7). This entire area is classified as infaunal sediment plains, with adjacent geomorphic features classified as sponge garden to the north-west of the current area fished. The infaunal plain habitat was also characterised by the extremely rare (<0.01%) occurrence of large vulnerable epifauna.

The level 2 ERA analysis (PSA –Productivity Susceptibility Analysis) of the NPF and including the JBG (Griffiths et al. 2007) included 157 habitats classified based on substratum, geomorphology and dominant fauna. Of these 65 were assessed to be at medium risk and the remaining 92 at low risk. This assessment did not explicitly include the JBG; habitats were assessed in terms of risk from fishing strategies associated with the banana prawn and tiger prawn sub-fisheries. Of the medium risk habitats 31 were found on the inner shelf (25-100 m), at depths fished in the JBG sub-fishery. Several of the medium risk habitats comprised hard bottom substrata, with hard and soft corals. The available data suggest hard substrate habitats would not occur in the JBG and thus not be impacted by the JBG fishery.

6.2.1 SPATIAL AND TEMPORAL TRENDS IN FISHING EFFORT IN JBG

The total area of the JBG sub-fishery "box" comprises 16426 x 1 nm^2 grids. A large proportion of the JBG is relatively shallow (< 30 m; Figure 6) and does not seem to be inhabited by the target *P. indicus* (Kenyon et al. 2004). However, the exact extent of the known area of *P. indicus* habitat has not been determined by scientific survey. We used the total JBG area to assess spatial extent of the fishery over time.

Fishing effort between 1999 and 2012 has been concentrated mainly in a central off-shore region and an inshore region on the western margin of the fishery (Figure 7). The spatial extent of fishing decreased after 2005, with contraction of the fishing grounds in the eastern margin. However, a large proportion of the high effort (>50 hr/nm^2) grids were retained post-2005. Importantly, no new areas were fished post-2005 indicating that trawling impacts in the JBG have been consistent spatially and declined in intensity temporally.

Inter-annual spatial trends in fishing effort in the JBG sub-fishery showed a steady decline from ~8% of grids fished in 1999 to ~1.5% of grids fished in 2008, with a smaller peak in 2009 before declining to the 2008 level in 2012 (Figure 8). The trend was similar for fishing intensity within grids with >10 $hours.nm^{-2}$, declining from ~3% to ~0.5%. The consistent decline for high fishing intensity and total spatial effort during 1999-2012 suggest that the fleet did not undertakesearching behaviour for new fishing grounds.

Frequency histograms of fishing effort in the JBG sub-fishery further highlight the decline in fishing intensity after 2005 (Figure 9). In all years most of the fishing effort occurred in grids at <20 $hours.nm^{-2}$. However, the number of grids fished at this low intensity was about four-fold lower in 2012 than 1999.

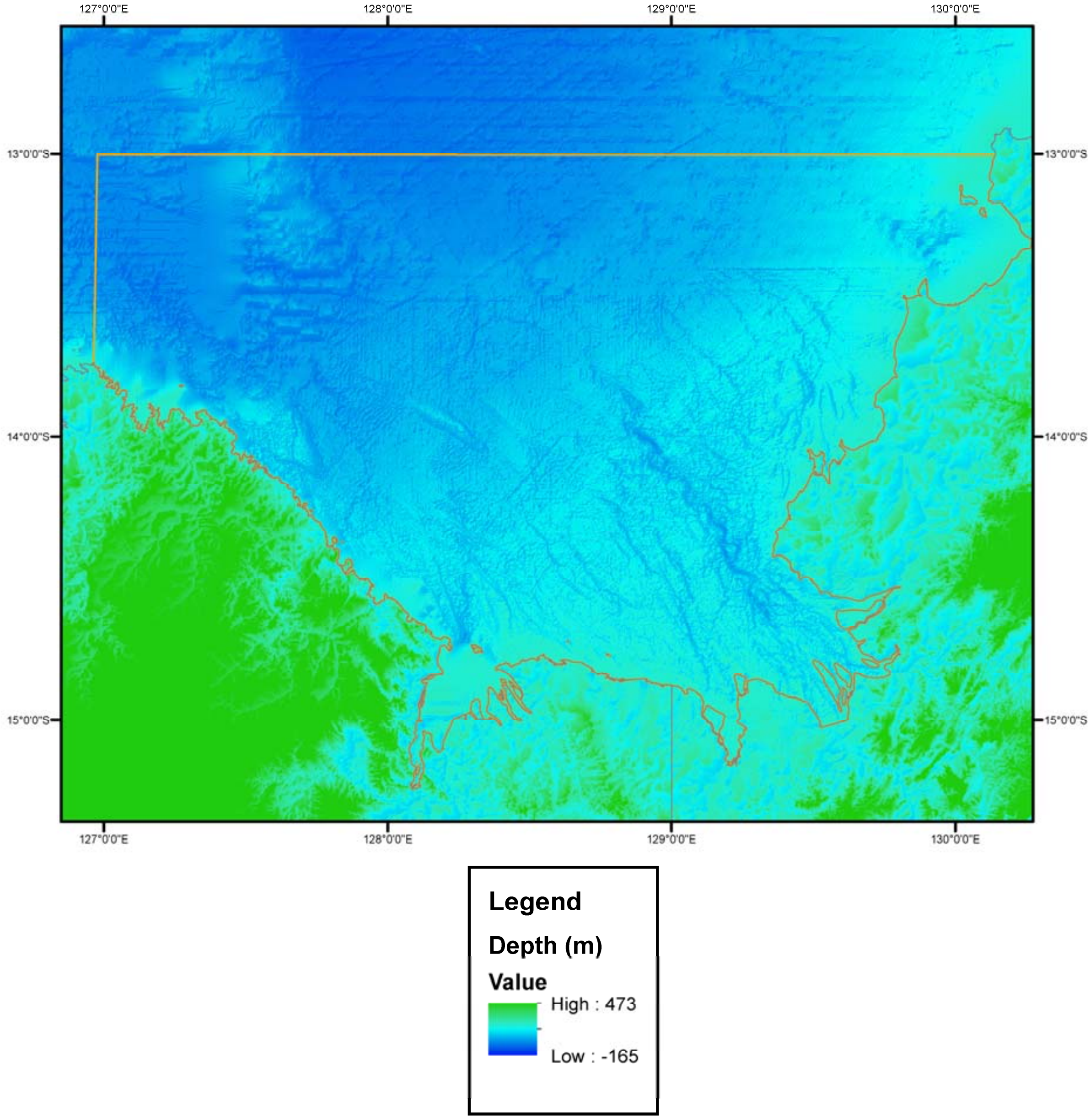


Figure 6 Map of the Joseph Bonaparte Gulf sub-fishery (marked by the brown line) showing general bathymetry in the region. The coastline is shown in orange and the high land is shown in green. The deep blue areas inshore are ancient submerged river beds.

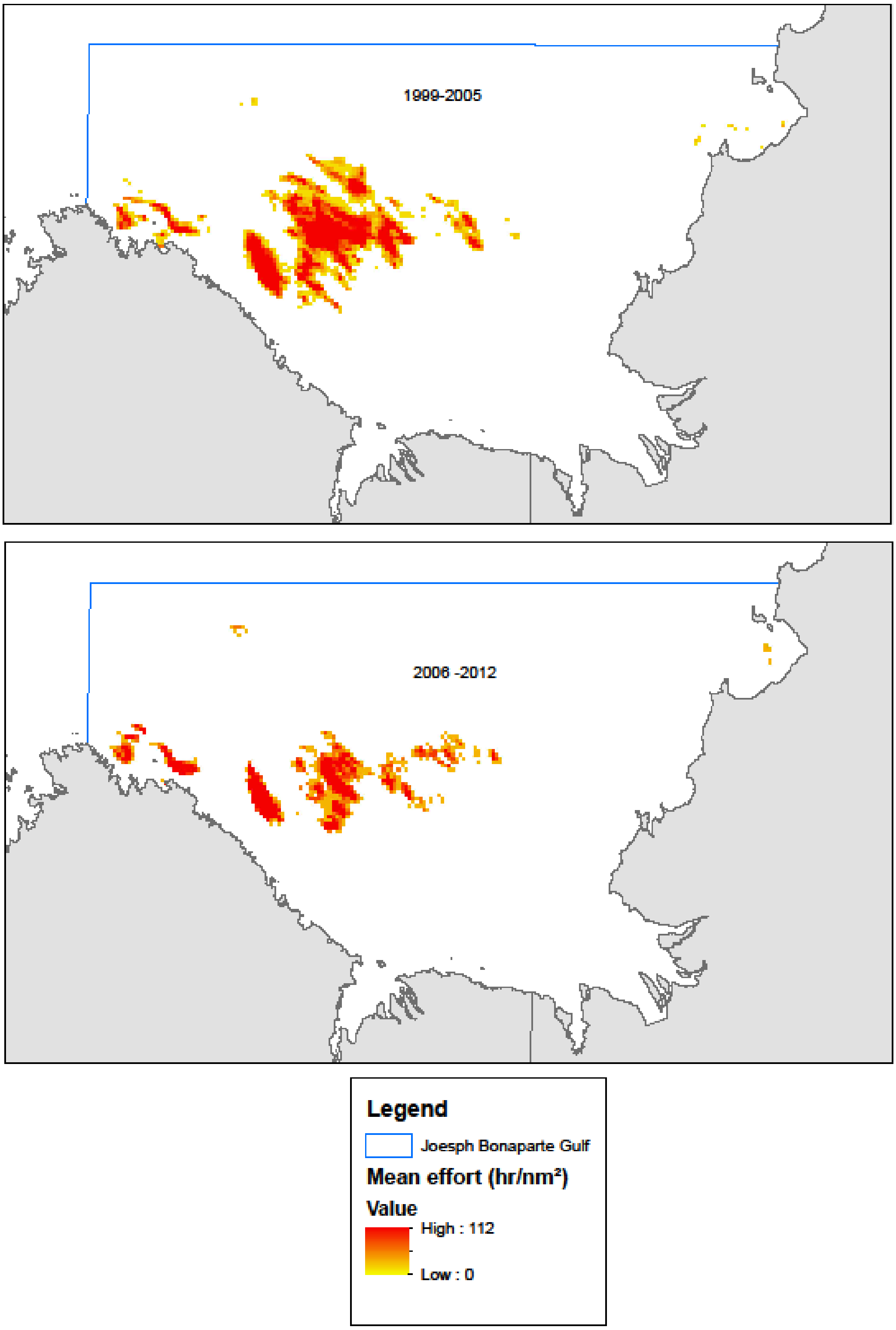


Figure 7 Maps of the Joseph Bonaparte Gulf sub-fishery (boundaries marked in blue) showing mean fishing effort (hours) per nm^2 for the time periods 1999-2005 and 2006-2012.

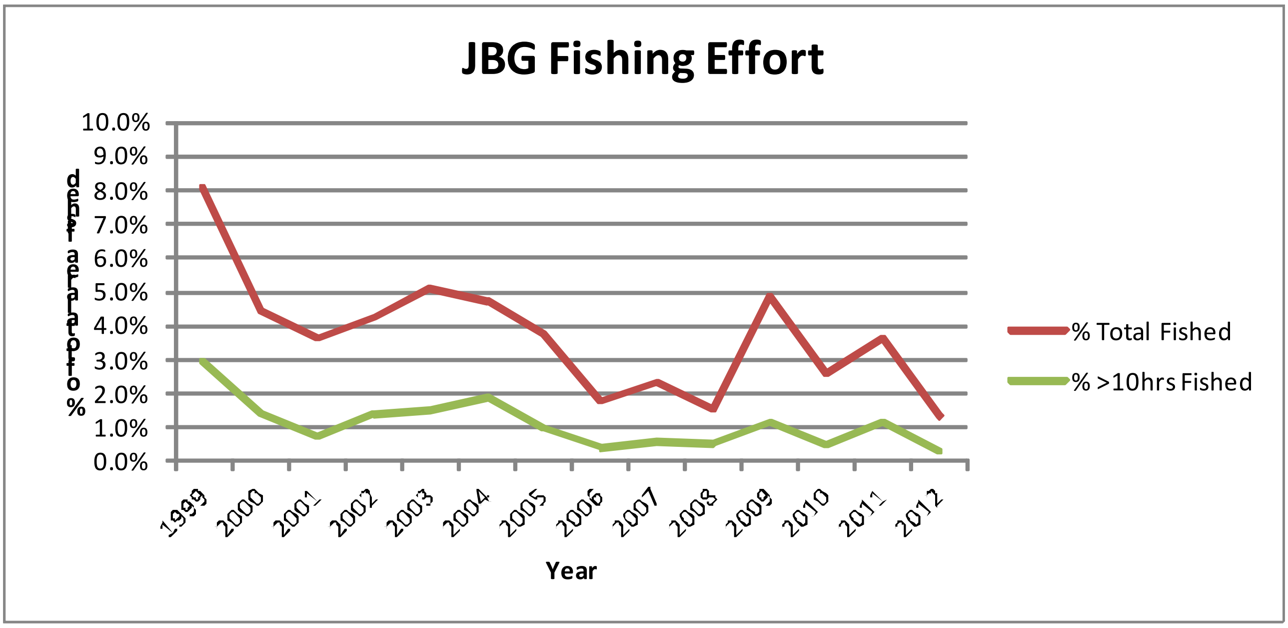


Figure 8 Temporal trends in fishing effort in the JBG sub-fishery during 1999-2012 from VMS data collected by AFMA.

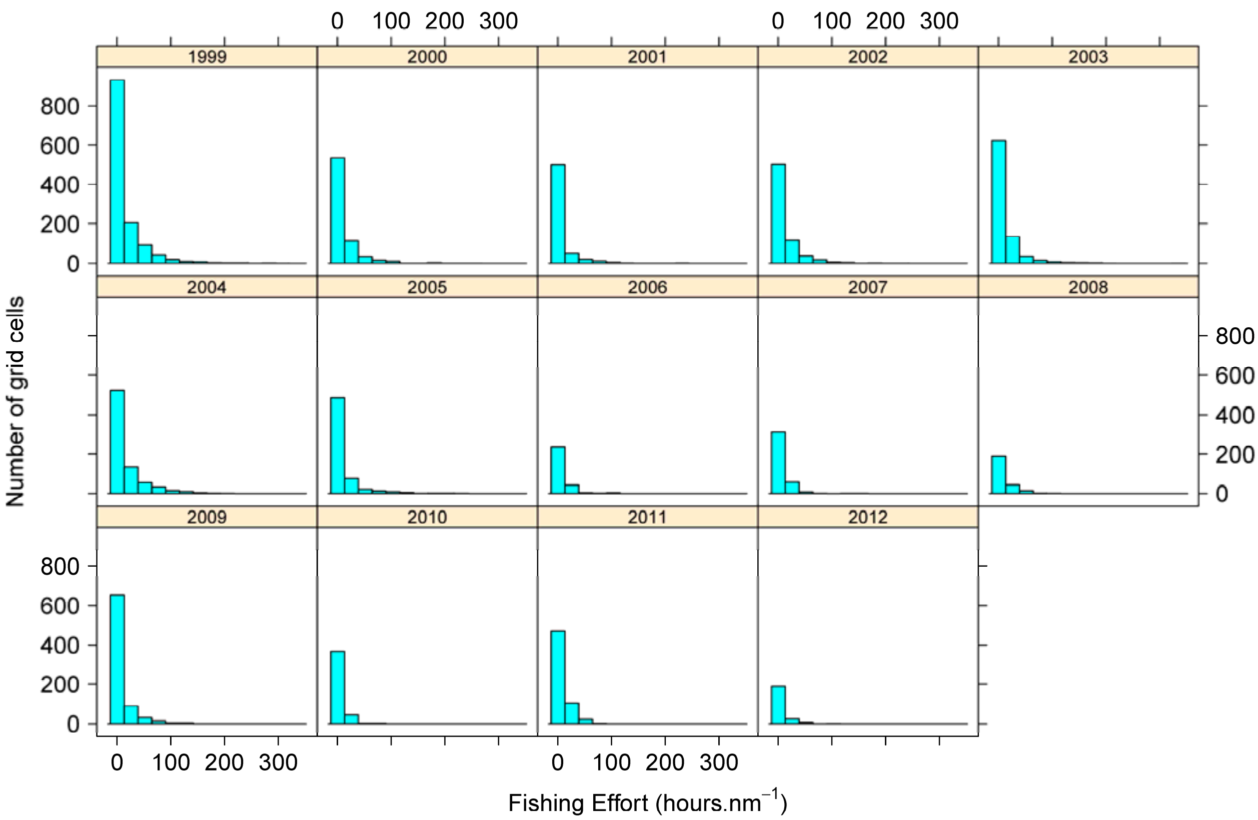


Figure 9 Frequency histograms of fishing effort in the JBG sub-fishery for each year between 1999 and 2012 from VMS data collected by AFMA.

6.3 Sufficiency of available data for qualitatively modelling the JBG ecosystem

The main findings and the areas of data-rich information come largely from the 40+ years of fisheries research associated with and derived from:

- the NT fisheries and NPF management[1] (e.g. Ramm et al. 1990, Loneragan et al. 2002, Tonks et al. 2008)
- the National Marine Bioregionalisation of Australia, and
- associated biodiversity conservation management information base [2] (Australian Government 2013).

The bulk of the field-based data and information is derived from scientific surveys undertaken by the Australian government research agencies Geoscience Australia, CSIRO and AIMS (e.g. Brewer et al. 2007b, Hosack et al. 2012, Nichol et al. 2013).

Qualitative assessments of the state and quantum of data available for modelling the JBG system are provided in Table 3. We emphasise that assessments were tabulated to indicate the level of availability and data, information and knowledge derived of the fisheries ecosystem of the JBG. They do not include the knowledge of nearby or similar ecosystems, such as the Northwest Shelf or Gulf of Carpentaria. This rapid, qualitative assessment approach is focussed on the relative state of ecosystem information and knowledge specifically available for the JBG. It is limited to addressing the benthic aspects relevant and directly related to the extractive fishing in JBG and does not include the coastal, estuarine or offshore regions. Moreover, it does not include the social, cultural or economic dimensions of the ecosystems (values, goods and services, etc.). Scores are based on the knowledge derived from the literature identified and used in this report.

To date, we have found little marine ecosystem, biophysical, or ecological research that has been undertaken by state agencies, or universities. Another potential source of data could be environmental assessments and other components undertaken by the oil-and-gas (O&G) industries and marine mining interests, as part of exploration licensing[3]. The environmental elements of these industry data sources could contribute to the understanding of the JBG marine ecosystem. Such data and information (internal reports, consultancies) are not publically available and, given our limited resources, no searches or reviews of O&G sector information were conducted.

In addition to the fisheries-dependent data, we believe that the critical information required for the development of toolsfor ecosystem-based management for the fished (trawled) benthos of the JBG are:- , (a) a good understanding of the extent and nature of benthic habitats, (b) the biophysical interactions with species affected by fishing, and (c) a good knowledge of the trophic structure and interrelations of the food web.

Benthic Habitats

To our knowledge, there are no JBG-specific benthic data or direct mapping of the benthic habitats of the JBG. The review of Brewer et al. (2007b) provided a generic model and schematic of the likely benthic habitats and ecosystem of the western JBG (Figure 10). Providing more detail, Przeslawski et al. (2011) suggested various conceptual models of the biophysical processes and schematic descriptions of the benthos of the eastern JBG (Figure 13 and Figure 14). These type of descriptions may allow the development of simple qualitative models (as in Hosack et al. 2012), but the data do not allow the development of spatially explicit models.

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[1] See AFMA NPF www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/northern-prawn-fishery/

[2] DSEWPAC www.environment.gov.au/coasts/mbp/imcra/nmb.html

[3] APEAA www.petroleum-acreage.gov.au/release.html

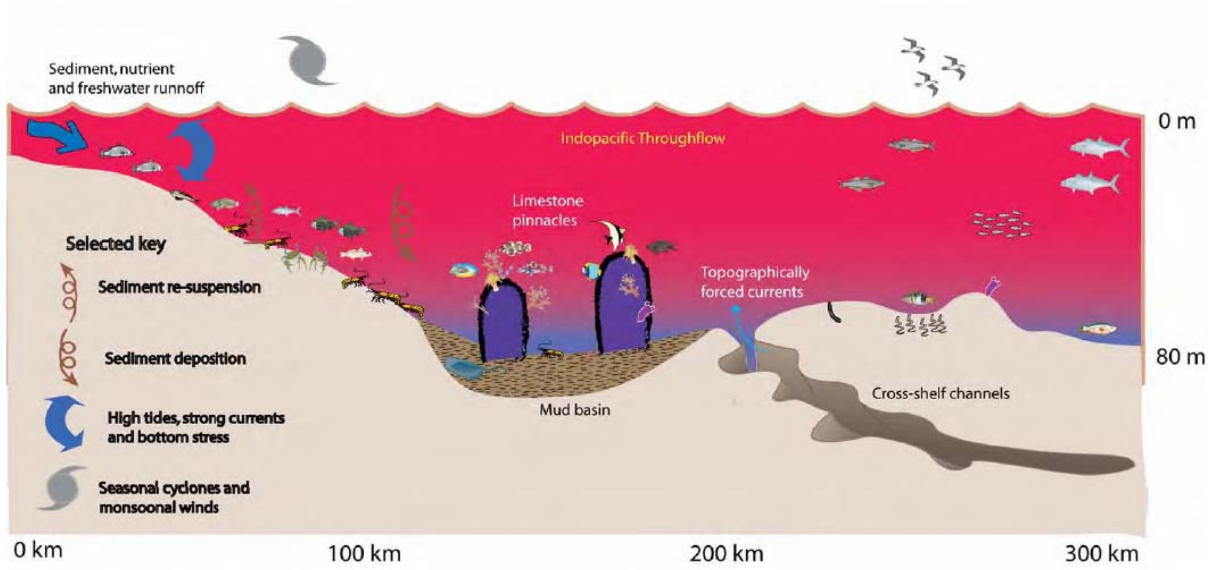

Figure 10. Habitat diagram of the Western Joseph Bonaparte Gulf sub-region showing selected important drivers and features. [From Brewer et al. 2007b]

Limited modelling attempts to define biophysical proxies -or produce numerical products based on extensive analyses of species responses to the physical environment (see NERP North-West Marine Region, NWMR[4] and Ellis et al. 2009a,b). These proxies are intended to predict seabed assemblage patterns of marine fauna, represented as spatial units (in maps, as in Figure 11). In turn, they could be used as benthic habitats (named as "seascapes" and clusters of seabed assemblage patterns, Heap et al. 2009, Ellis et al. 2009a,b, respectively). These habitat proxies have been defined for use in conservation management processes (Australian Government 2013) and they could be used to inform the mapping of a likely benthic ecosystem from a fisheries perspective. Cost-efficient direct habitat mapping and biodiversity sampling need to be conducted to validate the robustness of the predicted habitats proxies and their level of uncertainty.

Using validated benthic maps, in combination with the spatial data of fisheries in the VMS and logbook systems, the impacts of fishing on the benthic ecosystem could be better understood. Then the nature, extent and distribution and levels of impacts of the fishery on the benthic habitats could be known.

Food Webs

The food web of the JBG is probably the least known ecosystem aspect. Brewer et al. (2007b) provided a review with generic and expert opinion-based description of the likely habitats and food webs of the western JBG. This type of conceptual diagram (Figure 12) is too generic for the development of food web models, which require detailed data on the diets of the interacting biota in the benthic JBG food chain.

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[4] NERP www.nerpmarine.edu.au/document/predicted-seabed-assemblage-patterns-marine-fauna-north-west-marine-region-nwmr-product

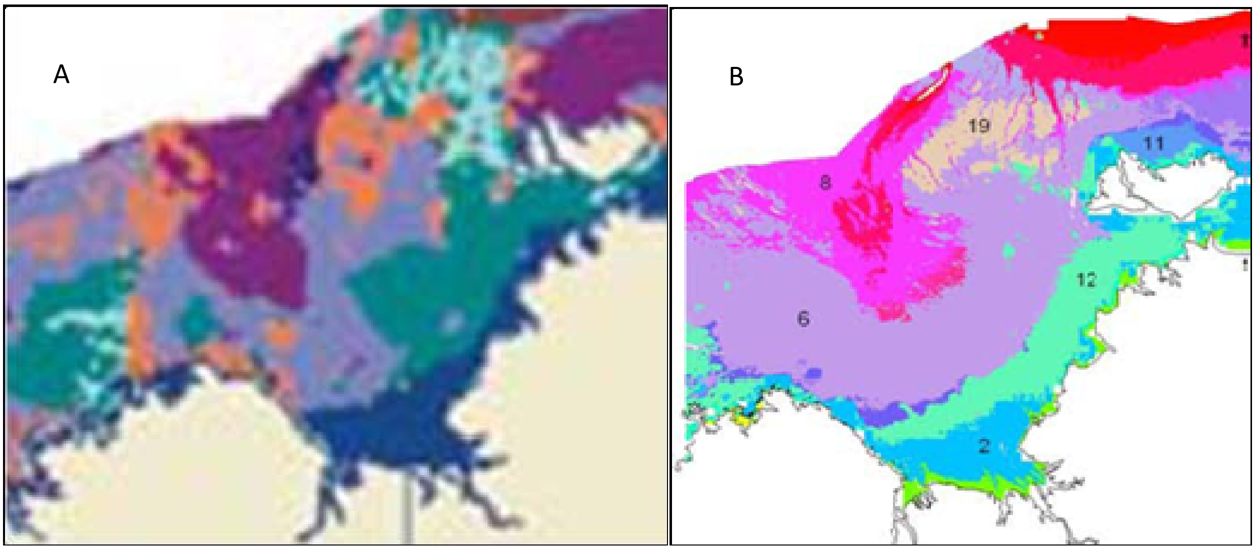

Figure 11. Mapping examples of the existing biophysical proxies for the benthic habitats of the JBG. (A) Seascapes (Heap et al. 2010), (B) clusters of seabed (Ellis et al. 2009a).

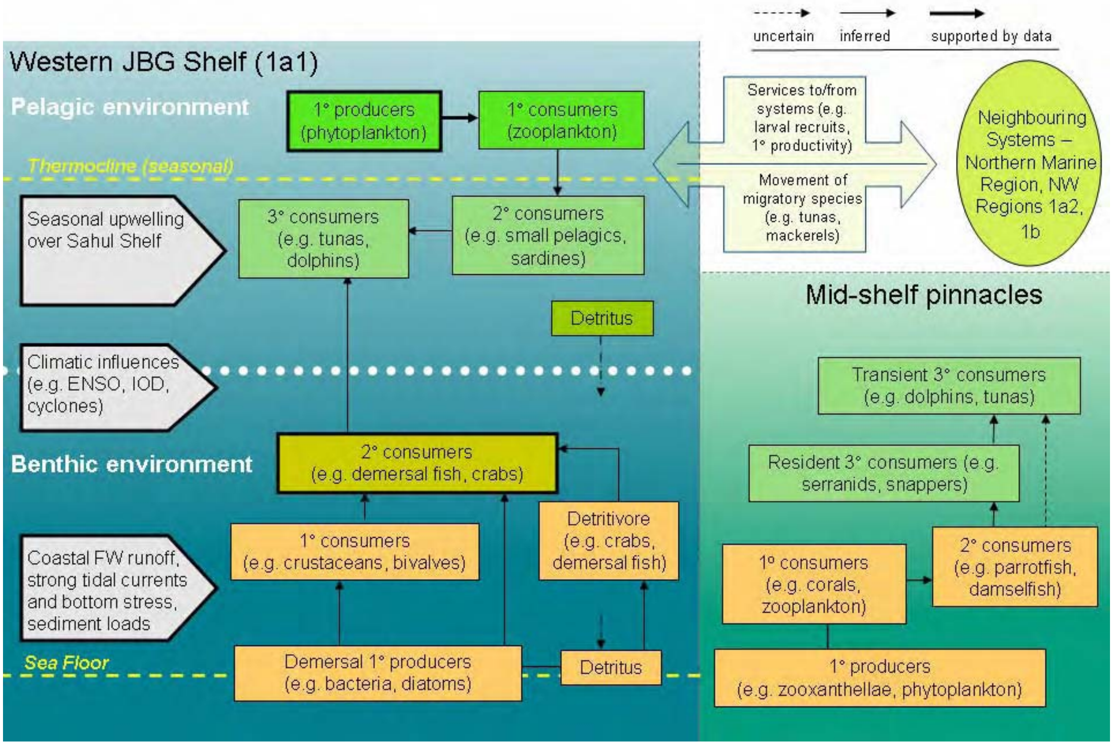

Figure 12. Schematic trophic model of the Western Joseph Bonaparte Gulf subregion. This shows information on the extensive habitat in the coastal and central shelf region (left) and a less extensive but important habitat (right) [From Brewer et al. 2007b].

Thus, to our knowledge there are no dietary studies that have examined the trophic ecology of the species assemblages of the Joseph Bonaparte Gulf. In contrast, there is a considerable body of work on the trophic ecology of teleosts in the Gulf of Carpentaria, particularly those that are known prawn predators (Salini et al. 1994). Further, trophic models have been developed for the Gulf of Carpentaria (Bustamante et al. 2010). However in the Joseph Bonaparte Gulf, the demersal species assemblages are significantly different from other regions in the Northern Prawn Fishery (Ramm et al. 1990, Tonks et al. 2008) so the GOC trophic models can't be adapted. A relatively small number of crustaceans and teleosts dominate the bycatch of the 'red-legged' banana prawn fishery, in this region (Tonks et al. 2008). In terms of relative abundance, the dominant crustaceans are the small portunid crab, *Charybdis callianassa* and the Rough Prawn, *Trachypenaeus gonospinifer*, while the dominant teleosts are the Threadfin Scat, *Rhinoprenes pentanemus*, the Blackfin Threadfin, *Polydactylus nigripinnis*, the Glassy Bombay Duck, *Hapadon translucens*, the Largehead Hairtail, *Trichuriurus lepturus*, the Smooth Jewfish, *Johnius laevis* and several species from the Engraulidae and Clupeidae families (*Setipinna tenuifilis* and *Thryssa setirostris*; and *Pellona ditchela*, respectively).

Qualitative Assessment

Our data assessment (Table 3), it is evident that abiotic and environmental components of the JBG ecosystem are the most information-rich, while the biotic processes and interaction of the ecosystem are the ones with least information and knowledge. The information in the biodiversity element (Table 3) comes from scant fish- and fisheries-focussed surveys (e.g. Sainsbury 1980), or where the overall biodiversity was either not well recorded (high level as in Ramm et al. 1990) or fish-focussed, and consequently, invertebrates, algae, infauna etc., were not recorded at all. Thus, the current biodiversity information comes from the more than 30+ years of fisheries research in the NPF and NT in general. The fisheries focus has, however, provided only low levels of biodiversity data, with few samples other than prawns or fish (e.g. Ramm et al. 1990, Pender et al. 1992). The only modern quantitative biodiversity data has been collected in some local areas of the JBG by Przeslawski et al. (2011) and Nichol et al. (2013).

A relatively high level of abiotic information is provided by remote sensing and model bases used to support the growing regional oceanographic, geological and atmospheric research. This is true for most of Australia, while the direct and in-situ biotic and processes information basis remains low or nil (Table 3). The key missing elements are largely the lack of food web data and direct surveys and measurements of ecosystem processes that drive the dynamics of fisheries production. Without this critical knowledge, it will be hard to build any quantitative ecosystem model. Nevertheless, although the information is fragmented we believe the information is sufficient to begin the process, to develop some analytical qualitative and system models for the JBG fisheries ecosystem (as in Hosack et al. 2012). Such development must include the exploration of the unknown roles of land-sea interaction as well as the environmental forcing derived from climate and ocean variability and change. These we believe will be critical for the future of understanding fisheries production in the JBG.

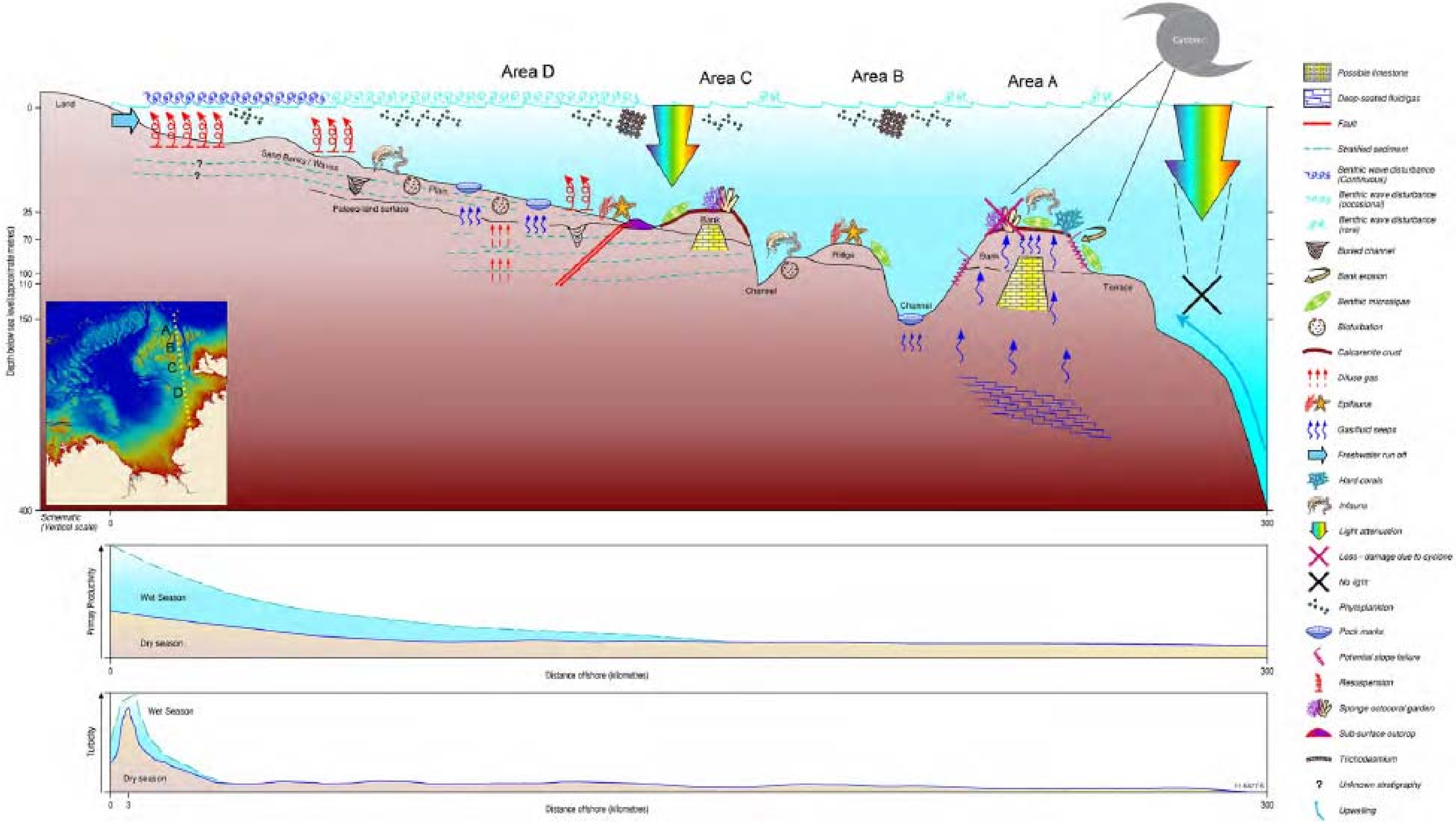

Figure 13. Conceptual model showing the biophysical processes operating in the eastern JBG-TS across the shelf in a S to N transect marked by the inset map. The nearshore environment (S) is shallower, flatter, dominated by soft sediments and associated taxa, with scattered rocky reefs near sand banks (Areas D). Further offshore (N), the environment is deeper, steeper and dotted with palaeoreefs and banks/ridges/terraces separated by valleys (Areas C, B, A). [From Przeslawski et al. 2011]

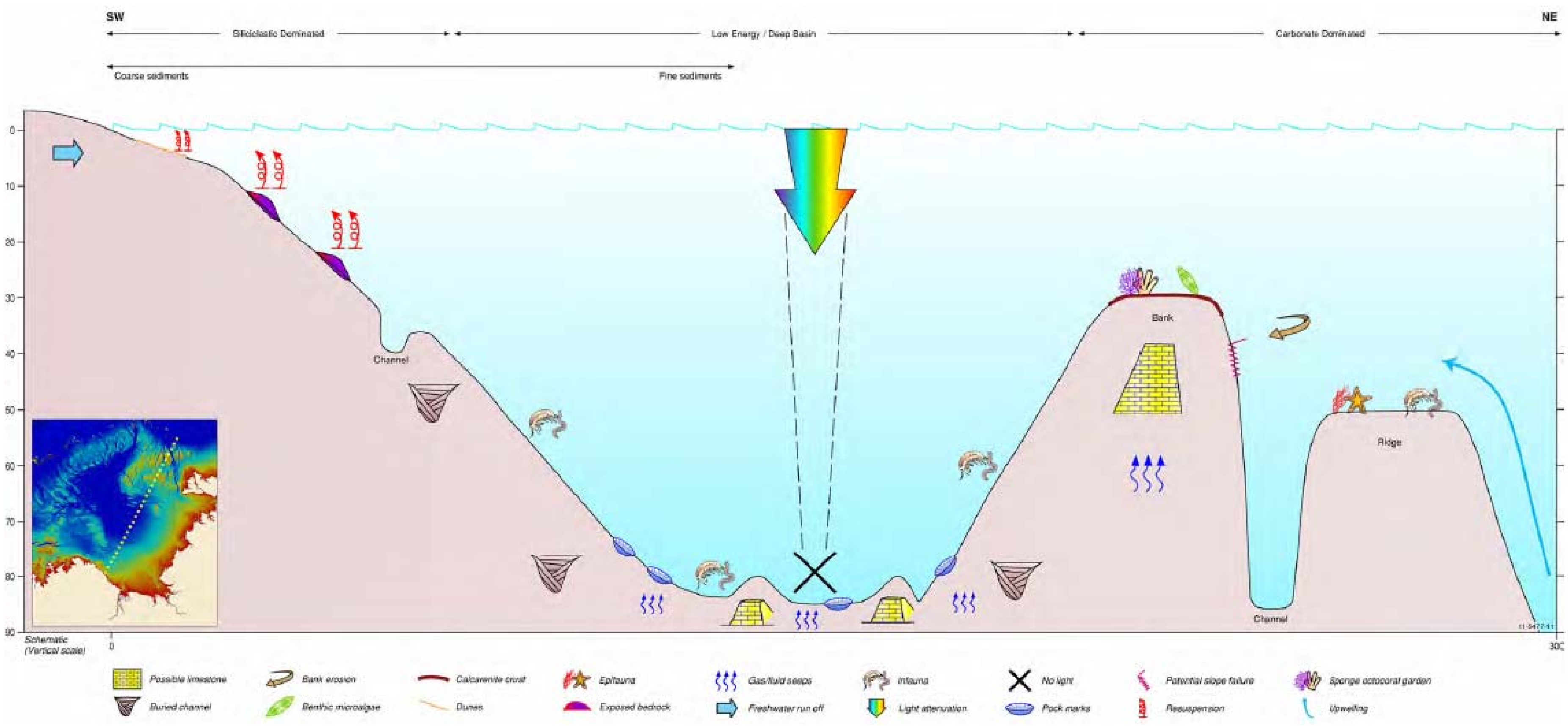

Figure 14. A conceptual model showing the biophysical processes operating in the JBG-TS along the shelf in a SW to NE transect marked by the inset map. The SW shelf adjacent to the basin gently slopes to deeper water and flat soft sediment ecosystem of the basin, interspersed with pockmarks and buried palaeoreefs. To the NE of the basin, the environment is steeper with comparatively complex topography, including banks/ridges/terraces separated by valleys [from Przeslawski et al. 2011].

Table 3. Qualitative assessment of the levels of data and information available for various elements, by each component, of the marine fishery ecosystem of the JBG. Scores range from 0-Nil, 1=Low, 2= Moderate, and 3= High.

	Components						Notes and Comments
	Biotic	**Score**	**Abiotic**	**Score**	**Interactions & Processes**	**Score**	
Elements	*Biodiversity* [1] -Diversity -Biomass -Abundance -Functional -Genetic -Evolution	 1 1 1 1 0 0	*Atmosphere* [2] -Wind -Radiation -Circulation -UV -Pressure -Temperature	 3 3 3 3 3 3	*Food web* [3] -Levels -Dynamics -Energy/biomass flows -Functional groups -Connectedness -Sink/source -Complexity/stability -Apex/keystones	 1 0 0 1 0 0 0 0	1= biodiversity information is mostly on fishes and invertebrates from the bycatch study by Tonks et al. 2008 and the recent GA surveys (Przlawski et al. 2011, Nichols et al. 2013). The little biological sampling is restricted to few groups and in very localized areas of the JBG. 2= The high scores of these elements are given due to the high level of remote sensing and model-based projections (e.g. CSIRO CARS, Ridgway et al. 2002) 3= Trophic levels and functional groups are assigned generically to species aggregated by known groups from elsewhere. None are known directly for the JBG.
	Habitats [4] -Ecological -Geological -Biophysical	 1 3 2	*Bathymetry* [5] *Geology* -Geomorphology -Sediments	3 3 3	*Biological interactions* -Competition, -Mutualism, -Parasitism -Commensalism	 0 0 0 0	4= Habitat proxies are inferred and assigned by modelling biophysical correlates between environmental variables and the existing biological samples (e.g. Heap et al. 2009, Ellis et al. 2009a,b) 5= The high level is due to the use of satellite and geological and geophysical work by the Australian Navy and GA.
	Communities -Dynamics -Succession -Resilience	 0 0 0	*Oceanography* [6] -Temperature (SST) -Salinity -Nutrients -Oxygen -Currents -Acidity/Alkalinity	 3 2 2 2 1 1	*Processes* [7] -Nutrient cycling -Productions (1ry & 2ry) -Energy flows -Decomposition -Biogeochemical cycle	 1 1-0 0 0 0	6= As in note 2 above, the remote sensing and model projections of ocean factors provide some reasonably good levels of data and information. 7= The ocean colour remote sensing is an adequate proxy for primary production, but no data or information on secondary production.
	Species [8] -Metastructure -Populations -Individuals	 0 1-0 1	*Physiographic factors* [9] -Topography -Slope -Mapping & GIS	 3 2 3	*Linkages & exchanges* [10] -Subsidies -Connectivity	 0 0	8= The only population information is around the NPF's target and major byproduct species. Most biological samples represent a few individuals or colonies without enough for information about population levels. 9= Information derived from GIS products based on satellite images, bathymetry and geomorphological work. 10= These elements largely include connections, exchanges and transports of nutrients and materials between juxtaposed and distant terrestrial, coastal and marine ecosystems.

6.4 Sufficiency of observer data for statistical analysis

The bycatch monitoring project (FRDC Project 2002/035) estimated from power calculations that a minimum of ten crew member observers and one AFMA scientific observer were required to collect data from 2350 NPF trawls each year to detect a significant decline in the TEP and 'at risk' bycatch species. This target was subsequently used in the bycatch sustainability project (FRDC Project 2008/826) to assess the sufficiency of catch data. To 2008 there was insufficient catch data to statistically assess the status of the TEP and 'at risk' species as the observer coverage ranged from 450 to 1330 trawls monitored. Nevertheless, the status of three species was assessed using a two factor GLM analysis.

Since 2011 the crew member obsever program on its own has met this target (2350 trawls monitored) due to a concerted effort by industry and scientists to increase coverage across the NPF. An update of the previous GLM analyses is not provided here as it relates to the entire NPF, not the JBG sub-fishery alone.

For the JBG sub-fishery a total of 138 trawls were monitored in 2011 by the NPF crew member observer program and 154 trawls were monitored by the AFMA scientific observer program in 2013. It is obvious that even given that the coverage of these programs appears sufficient, considering fishing effort has been <500 days since 2006, these programs could never yield sufficient data for statistical analysis of catch trends. Further, monitoring in 2011 yielded only 84 TEP and 'at risk' species records (excluding *Solenocera australiana*) and monitoring in 2013 yielded only 23 records. Hampering statistical analysis is also the large number of zero catch records e.g. in 2013 a total of 133 trawls monitored by AFMA observers had zero catches.

In general there is an obvious conflict in assessing bycatch sustainability in the JBG sub-fishery and the NPF in that achieving the goal of reducing bycatch directly through TED and BRD implementation and indirectly through the fishery structural adjustments has ultimately reduced our ability to make statistically robust conclusions about the status of TEP and 'at risk' species. This is particularly the case for the most rarely observed species.

7 Discussion

Tonks et al. (2008) provided a comprehensive assessment of the bycatch assemblage caught incidentally by the JBG fishery. The research showed that due to the dissimilarity in species composition the JBG bycatch assemblage should be regarded as distinct to the NPF Gulf of Carpentaria (GOC) assemblage. Although not addressed by Tonks et al. (2008) it is very likely that the seabed habitats in the JBG also differ significantly from those in the GOC. The combination of subsequent effort reduction in the NPF fishery and contraction of the spatial extent of fishing effort in the JBG since the time of their study strongly suggests that the species composition recorded by Tonks et al. (2008) would be representative of current bycatch composition. Further this study represents a valuable benchmark for future comparisons of bycatch composition.

A total of 23 TEP species have been recorded as incidental bycatch from the JBG sub-fishery including marine turtles, sawfish and sea snakes. The introduction of TEDs in 2000 dramatically reduced the catches of turtles throughout the NPF fishery and they are no longer listed as priority species under ecological risk management. The introduction of TEDs was not as successful in eliminating the remaining species, although the larger elasmobranchs are likely excluded. The NPF wide SAFE assessments for both sea snakes and sawfish showed that none of the species caught were at risk of over-fishing. Further, the AFMA SO program showed that around 70% of sea snakes were returned alive. Hence, overall the TEP bycatch species in the JBG sub-fishery are managed sustainably.

In addition to the listed TEP species two syngnathid species have been recorded as bycatch from the JBG sub-fishery. However, these catches were likely incidental as the strong prevailing tidal currents in the JBG likely exclude most of these species. Further, the NPF wide SAFE assessment of teleosts found no species were at risk from over-fishing. Two mantis shrimps have been recorded as bycatch from the JBG sub-fishery but their identification is difficult and their status across the NPF is under ongoing investigation. The squid *Abralia amarta* has also been recorded as bycatch from the JBG sub-fishery, but the meso-pelagic habitat of this species strongly suggests that only a small fraction of the population would be exposed to trawling.

The combined coverage of the NPF logbook monitoring, AFMA scientific observer and CMO programs in monitoring bycatch of the JBG sub-fishery is likely comprehensive in terms of species recorded and catch rates and would suffice for future abundance trend analysis. However, as stated as an outcome of FRDC Project 2002/035 even this level of monitoring is insufficient for robust statistical analysis of catch trends, particularly for rare species. Ironically bycatch reduction has largely precluded our ability to make statistical conclusions about the status of listed species in the JBG sub-fishery.

Two key components in assessing the ecological sustainability of any fishery are the temporal and spatial trends in fishing effort. In the JBG fishery effort reduced roughly six-fold from 1982 to post-2006 and the number of nm^2 grids fished reduced roughly four fold during 1999 to post-2008. Further, given the structural adjustment to 52 boats across the entire NPF it is likely that these reductions will be persistent.

Although there has been no JBG wide scientific description of seabed habitats the sampling and associated modelling undertaken by Geosciences Australia Przeslawski et al. (2011) provided key information on the likely composition of the habitats impacted by the JBG sub-fishery. Much of the area was classified as infaunal plains composed predominantly of mud. Further, the published habitat preference of *P. indicus* strongly suggests that most of the fishery occurs on flat mud bottoms to take advantage of this species preference. Nevertheless, a more comprehensive understanding of the full range of benthic habitats impacted by the JBG sub-fishery could be provided by opportunistic towed video or grab analysis.

The development of an ecosystem model relevant to the JBG sub-fishery would require the acquisition of detailed seabed habitat data both within and beyond the extent of the fishery, information on the biophysical interactions between species and detailed information on the JBG food web. Future research initiatives should aim to address these current information gaps.

8 Conclusion

Two bycatch species known to occur in the Joseph Bonaparte Gulf sub-fishery *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni* (mantis shrimps) are priority species listed as at ‘high risk’ to the effects of fishing in the NPF (AFMA 2012). These species are monitored as part of the ongoing AFMA scientific observer and NPF crew member observer programs, and the NPF logbook bycatch monitoring program. The squid *Abralia amarta* (found in the JBG sub-fishery) is reported widely in the Indo-Pacific but it seems that it is rarely encountered in the fishery, and so should not be a priority for the monitoring programs. Nevertheless, a “SAFE” analysis (e.g. Zhou 2011) should be an approach to further examine the sustainability of the impact of the fishery on this and other species.

A total of 23 listed threatened endangered or protected (TEP) bycatch species (five marine turtles, five sawfish and 13 sea snakes) are known to occur in the Joseph Bonaparte Gulf sub-fishery. The ecological sustainability of marine turtles has been addressed by the mandatory implementation of turtle exclusion devices (TEDs). The ecological sustainability of the sea snake species was evaluated using the SAFE protocol; logbook effort data for 2004-2006 indicated that current estimated fishing mortality was less than maximum sustainable fishing mortality (F_{msm}) for all seasnake species (Zhou et al. 2012). We suggest that with the reduction in fleet size and effort since 2007, fishing mortality for seasnakes would have further declined. The ecological sustainability of the sawfish species was also addressed using the SAFE protocol and logbook effort data for 2007-2009 (Zhou 2011) which found that current estimated fishing mortality was less than mean unsustainable fishing mortality (F_{crash}) for all sawfish species. Nevertheless, all TEP species continue to be monitored by the ongoing NPF logbook, AFMA SO and NPF CMO programs and their status should be assessed in future under updated levels of fishing effort.

The JBG sub-fishery “box” comprises 16426 one nm^2 grids used to collate the NPF VMS data. The footprint of the fshery has declined over the last decade, both in terms of spatial extent and fishing intensity in fished grids. The percentage of grids fished fell from ~8% in 1999 to ~1.5% in 2012. The percentage of grids fished for >10 hours total fell from ~3% in 1999 to ~0.5% in 2012. The footprint of the fishery has decreased approximately four fold since 1999.

The dominant habitat within the area of the JBG sub-fishery is infaunal sediment plain swept by strong tidal currents with large influxes of suspended sediment (Przeslawski et al. 2001). The habitat is characterised by dominant muddy sand sediments, <1% hard substrata and <1% epifaunal activity. Adjacent geomorphic features to the north-west of the JBG sub-fishery comprised hard substrata and sponge habitats. The fishery was contained within one provincial bioregion (Northwest IMCRA Transition; IMCRA version 4.0) and the Bonaparte Gulf meso-scale bioregion.

The main information available for future modelling of the JBG ecosystem comes from the 30+ years of research conducted into the NPF and NT fisheries, and the National Marine Bioregionalisation of Australia and associated biodiversity conservation management. Most of the field-based data and information came from the scientific surveys by Australian government research agencies such as Geoscience Australia, CSIRO and AIMS. We believe that to develop an approach for ecosystem-based management of the exploited (trawled) benthos of the JBG, the most basic and critical information requirements are; (a) understanding the extent and nature of benthic habitats, (b) understanding the biophysical interactions between species affected by fishing, and (c) understanding the trophic structure of the food web.

To our knowledge, there has been no comprehensive mapping of the benthic habitats of the Joseph Bonaparte Gulf. However, there have been several analytical efforts to define biophysical proxies intended to predict seabed assemblage patterns of marine fauna. The food web of the JBG is probably the least known of the biotic ecosystem aspects. Relevant trophic models have been developed for the Gulf of Carpentaria, but the demersal species assemblages are significantly different in the Joseph Bonaparte Gulf. So adaption of the trophic models is problematic. Nevertheless, the species composition and dominance information is available and could be used to develop a conceptual trophic model. Abiotic information for the JBG is available from remote sensing and models based on increasingly sophisticated oceanographic, geological and atmospheric research. Hence, the key missing ecosystem elements are food web data and direct surveys and measurements of ecosystem processes that drive the dynamics affecting fisheries production. It should be possible to develop a qualitative system model for the JBG fisheries ecosystem. Development of such a model would include determination of the unknown roles of the land-sea interactions as well as the environmental forcing of climate (e.g. cyclones) and ocean variability and change. These, we believe, will be critical to sustaining the continued future of fisheries production in the JBG.

Given the NPF-wide target of 2350 monitored trawls set by the NPF bycatch monitoring project (FRDC Project 2002/035), the current observer programs have achieved adequate coverage at that scale. However at the sub-fishery scale, a total of only 138 trawls were monitored in the JBG in 2011 by the NPF crew member observer program (yielding 84 records of TEP and 'at risk' species) and only 81 trawls were monitored by the AFMA scientific observer program in 2013 (yielding 23 records of TEP and 'at risk' species). These programs are unlikely to yield sufficient data for robust statistical analysis of catch trends. There is an obvious conflict attempting to assess bycatch sustainability using fishery-dependent methods in the JBG sub-fishery and the NPF: achieving the goal of reducing bycatch directly through TED and BRD implementation and indirectly through the fishery structural adjustments ultimately reduces our ability to make statistically robust conclusions about the status of TEP and 'at risk' species. This is particularly the case for rarely observed species.

9 Implications

The principal beneficiaries of this research are industry and management:

1. Northern Prawn Fishery industry who fish the Joseph Bonaparte Gulf sub-fishery
2. The Australian Fisheries Management Authority (AFMA)
3. Consumers who have confidence in the sustainability credentials of the fishery, particularly maintaining Marine Stewardship Council accreditation.

Although no new data were generated by this research, several summaries were provided which will inform future research priorities in monitoring at-risk species, habitats and ecosystem function in the JBG sub-fishery, including:

1. Spatial and temporal distribution of fishing effort in the JBG sub-fishery.
2. Bycatch species caught incidentally and the status of each species against the NPF Ecological Risk Assessment and classified as TEP under the Commonwealth EPBC Act.
3. Description of the ongoing observer monitoring programs operating in the NPF and their adequacy for the JBG sub-fishery.

Additionally, as in any synthesis, the work updated our understanding of the JBG sub-fishery for red-legged banana prawns. The summaries provided a basis for adaption to the remainder of the NPF and similar prawn trawl fisheries elsewhere.

Specifically, the analysis has provided guidance for the design of monitoring in terms of observer days necessary over time to better define the status of the bycatch species of interest.

The research is unlikely to increase the yield of the fishery. However, by providing increased confidence in the sustainability of the JBG sub-fishery, and the NPF as a whole, the research will provide enhanced value of the yield. NPF Industry has identified promotion and market penetration via sustainability as a key opportunity in domestic and international markets.

The project also enhanced collaboration between CSIRO, AFMA and the Northern Prawn Fishery industry.

Direct linkage of this project to other NPF-related research and management was achieved through participation of industry together with scientists who are or have been engaged in other NPF research. Additionally, Ms Jarrett is Executive Officer of the Northern Prawn Resource Assessment Group (NPRAG) and Dr Buckworth and Dr Bustamante are members of the Northern Prawn Resource Assessment Group (NPRAG).Management (AFMA) have been formally informed of project progress via NORMAC and NPRAG, and provision of all milestone reports.

10 Recommendations

Research and other activities that should be undertaken to further develop assessment of the status of the at-risk species, habitats and communities in the JBG sub-fishery include:

Sustainability Assessment for Fishing Effects (SAFE) for the JBG sub-fishery: Previous SAFE assessments have been done at the NPF-wide level to incorporate all sub-fisheries: tiger prawn, banana prawn and JBG. Given the uniqueness of the JBG sub-fishery bycatch, a SAFE assessment should be conducted using all current scientific and crew member observer data. A related key information gap is the catchability coefficient (q) which is often assumed to be 1 (i.e. no escapement or avoidance of the fishing gear) to take a precautionary approach. However, video footage elsewhere in the NPF has shown both avoidance and escapement from prawn trawls, yet in the JBG catchability has not been quantified. This field of research warrants further investigation to improve the precision of SAFE estimates of maximum sustainable fishing mortality and minimum unsustainable fishing mortality.

Quantification of catch trends from scientific observer programs: Key data enabling the assessment of species abundance over time are the catch and effort statistics for both targeted species (prawns and byproduct) and bycatch. However, the introduction of bycatch reduction devices (TEDs and BRDs) has significantly reduced the catches of some groups e.g. large sharks and rays by >85% (Brewer et al. 2004), turtles by >95% (Brewer et al. 2006), small bycatch species by 8% (Brewer et al. 2004). This effectively means that the scientific observer catch data represents only a fraction of the actual interactions that occur each year. Hence, these data are not able to be used to monitor natural fluctuations in populations; e.g. as a result of an environmental disturbance or a human-induced disturbance. Targeted scientific monitoring of escapement by some species (e.g. sawfish, sea snakes) at known locations in the JBG using video footage is warranted to at least confirm the presence of these species.

Habitat mapping in the JBG sub-fishery: Although a fishery-independent habitat mapping exercise is likely not warranted in the JBG given the low intensity of fishing effort there, the opportunistic collection of underwater video footage or grab samples taken over time may provide useful information for subsequent analysis of seabed habitat distribution. This task could be entirely industry-driven or have an initial scientific component to establish a standard protocol. This data could provide useful supplementary sediment and habitat data to help resolve regional habitat mapping in the JBG.

The project provided a synopsis of the current state-of-knowledge on sustainability of the JBG sub-fishery. It uses the most recent available information on bycatch species and habitats impacted by trawling and temporal and spatial changes in the fishery.

The project provided recommendations for future priority research to address key information gaps that precluded a comprehensive analysis of the ecological sustainability of prawn trawling in the JBG sub-fishery.

The combination of these outcomes may provide an improved market penetration benefit to banana prawns caught in the JBG.

11 Extension and Adoption

The outcomes of this project were communicated to the Marine Stewardship Council to address the components required for continued accreditation of the Northern Prawn Fishery and to provide information on key information gaps that might preclude comprehensive assessment of the ecological sustainability of the fishery into the future. This information was provided by both industry and scientific representatives. The synthesis provided in this report has and will continue to guide the MSC accreditation process through annual audits.

The results of this report have been extended to industry through NPF Industry Pty Ltd at the Northern Prawn Fishery Resource Assessment Group (RAG) meetings and outcomes relevant to monitoring of at risk species are being communicated to crew member observers.

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13 Appendices

13.1 Intellectual Property

This project did not generate any new data from field or statistical analyses.

13.2 Staff

Name	Organisation	Funding
Jarrett, Annie	NPFI	In-kind
Barwick, Matt	NPFI	In-kind
Buckworth, Rik	CSIRO Oceans & Atmosphere Flagship	FRDC and in-kind
Dennis, Darren	CSIRO Oceans & Atmosphere Flagship	FRDC
Haywood, Mick	CSIRO Oceans & Atmosphere Flagship	FRDC
Tonks, Mark	CSIRO Oceans & Atmosphere Flagship	FRDC
Fry, Gary	CSIRO Oceans & Atmosphere Flagship	FRDC
Bustamante, Rodrigo	CSIRO Oceans & Atmosphere Flagship	FRDC
Venables, Bill	CSIRO Digital Productivity Flagship	FRDC

13.3 Bycatch species sampled from commercial trawls in Joseph Bonaparte Gulf (from Tonks et al. 2007); or recorded by scientific observers (*). Threatened Endangered Protected (TEP) species identified through the NPF ERA (Griffiths et al. 2007) and priority species identified through the NPF Ecological Risk Management process (AFMA 2012) are shown.

TELEOSTS		**TEP Species (TEP)**	**High Risk Species (HRS 2009 & 2012)**
Family	**Taxa**	**Highest Assessment & Risk Score**	**Highest Assessment & Risk Score**
Antennariidae	*Antennarius hispidus*		
Apistidae	*Apistus carinatus*		
Aploactinidae	*Aploactis aspera*		
Apogonidae	*Apogon poecilopterus*		
Apogonidae	*Apogon fasciatus*		

Apogonidae	*Apogon albimaculosus*		
Apogonidae	*Apogon septemstriatus*		
Apogonidae	*Apogon truncatus*		
Apogonidae	*Siphamia roseigaster*		
Ariidae	*Arius nella*		
Ariidae	*Arius thalassinus*		
Batrachoididae	*Batrachomoeus trispinosus*		
Bothidae	*Arnoglossus waitei*		
Bothidae	*Laeops parviceps*		
Bregmacerotidae	*Bregmaceros mcclellandi*		
Callionymidae	*Repomucenus belcheri*		
Carangidae	*Carangoides malabaricus*		
Carangidae	*Megalaspis cordyla*		
Carangidae	*Parastromateus niger*		
Carangidae	*Caranx bucculentus*		
Carangidae	*Scomberoides tol*		
Carangidae	*Ulua aurochs*		
Carangidae	*Alepes apercna*		
Carangidae	*Carangoides humerosus*		
Carangidae	*Decapterus russelli*		
Carangidae	*Carangoides talamparoides*		
Carangidae	*Caranx kleinii*		
Carangidae	*Pantolabus radiatus*		
Centrolophidae	*Psenopsis humerosa*		
Chaetodontidae	*Chelmon muelleri*		
Champsodontidae	*Champsodon vorax*		
Citharidae	*Brachypleura novaezeelandiae*		
Clupeidae	*Herklotsichthys lippa*		
Clupeidae	*Sardinella albella*		
Clupeidae	*Dussumieria elopsoides*		
Clupeidae	*Ilisha lunula*		
Clupeidae	*Pellona ditchela*		
Congridae	*Lumiconger arafura*		
Congridae	*Uroconger lepturus*		
Cynoglossidae	*Paraplagusia bilineata*		
Cynoglossidae	*Paraplagusia longirostris*		

Cynoglossidae	*Cynoglossus ogilbyi*		
Cynoglossidae	*Paraplagusia sinerama*		
Diodontidae	*Cyclichthys hardenbergi*		
Echeneidae	*Echeneis naucrates*		
Engraulidae	*Setipinna paxtoni*		
Engraulidae	*Setipinna tenuifilis*		
Engraulidae	*Thryssa hamiltonii*		
Engraulidae	*Thryssa setirostris*		
Engraulidae	*Stolephorus* spp.		
Ephippidae	*Zabidius novemaculeatus*		
Gerreidae	*Gerres filamentosus*		
Gerreidae	*Pentaprion longimanus*		
Haemulidae	*Pomadasys maculatus*		
Haemulidae	*Pomadasys kaakan*		
Istiophoridae*	*Istiophorus platypterus**		
Leiognathidae	*Leiognathus ruconius*		
Leiognathidae	*Leiognathus blochii*		
Leiognathidae	*Leiognathus bindus*		
Leiognathidae	*Secutor insidiator*		
Lophichthyidae	*Lophichthys boschmai*		
Lutjanidae	*Lutjanus malabaricus*		
Menidae	*Mene maculata*		
Monacanthidae	*Paramonacanthus filicauda*		
Mugilidae	*Valamugil perusii*		
Mullidae	*Upeneus sulphureus*		
Muraenesocidae	*Muraenesox bagio*		
Myctophidae	*Benthosema pterotum*		
Nemipteridae	*Nemipterus hexodon*		
Nettastomatidae	*Saurenchelys finitimus*		
Ophichthidae	*Muraenichthys* spp.		
Ophidiidae	*Sirembo imberbis*		
Ostraciidae	*Rhynchostracion nasus*		
Paralichthyidae	*Pseudorhombus arsius*		
Percichthyidae	*Synagrops philippinensis*		
Platycephalidae	*Cociella hutchinsi*		
Platycephalidae	*Elates ransonnetii*		

Platycephalidae	*Inegocia harrisii*		
Plotosidae	*Euristhmus nudiceps*		
Plotosidae	*Euristhmus lepturus*		
Polynemidae	*Eleutheronema tetradactylum*		
Polynemidae	*Polydactylus nigripinnis*		
Priacanthidae	*Priacanthus tayenus*		
Psettodidae	*Psettodes erumei*		
Pteroidae	*Pterois russelii*		
Rhinoprenidae	*Rhinoprenes pentanemus*		
Sciaenidae	*Atrobucca brevis*		
Sciaenidae	*Austronibea oedogenys*		
Sciaenidae	*Johnius borneensis*		
Sciaenidae	*Johnius* cf *trewavasae*		
Sciaenidae	*Johnius laevis*		
Sciaenidae	*Larimichthys pamoides*		
Sciaenidae	*Protonibea diacanthus*		
Scombridae	*Rastrelliger kanagurta*		
Serranidae	*Epinephelus sexfasciatus*		
Sphyraenidae	*Sphyraena obtusata*		
Synanceiidae	*Minous versicolor*		
Synodontidae	*Harpadon translucens*		
Synodontidae	*Saurida argentea*		
Synodontidae	*Saurida undosquamis*		
Synodontidae	*Saurida longimanus*		
Terapontidae	*Terapon jarbua*		
Tetrabrachiidae	*Tetrabrachium ocellatum*		
Tetraodontidae	*Lagocephalus lunaris*		
Tetraodontidae	*Lagocephalus spadiceus*		
Tetraodontidae	*Lagocephalus sceleratus*		
Tetraodontidae	*Lagocephalus inermis*		
Tetraodontidae	*Terapon theraps*		
Tetrarogidae	*Cottapistus cottoides*		
Tetrarogidae	*Liocranium praepositum*		
Triacanthidae	*Trixiphichthys weberi*		
Trichiuridae	*Trichiurus lepturus*		
Triglidae	*Lepidotrigla russelli*		

ELASMOBRANCHS			
Carcharhinidae	*Carcharhinus dussumieri*		
Carcharhinidae	*Carcharhinus tilstoni*		
Carcharhinidae	*Rhizoprionodon acutus*		
Dasyatidae	*Dasyatis annotata*		
Dasyatidae	*Himantura toshi*		
Gymnuridae	*Gymnura australis*		
Hemigaleidae	*Hemigaleus australiensis*		
Hemiscyllidae	*Chiloscyllium punctatum*		
Pristidae	*Anoxypristis cuspidate*	TEP (SAFE; Fished less than MSM)	
Pristidae	*Pristis zijsron*	TEP (SAFE; Fished less than MSM)	
Pristidae*	*Pristis microdon**	TEP (SAFE; Fished less than MSM)	
Pristidae*	*Pristis clavata**	TEP (SAFE; Fished less than MSM)	
Pristidae*	*Pristis pectinata**	TEP (SAFE; Fished less than MSM)	
Rhynchobatidae	*Rhyncobatus australiae*		
Sphyrnidae	*Eusphyra blochii*		
SEASNAKES			
Hydrohidae	*Disteira major*	TEP (SAFE; Medium)	
Hydrohidae	*Hydrophis elegans*	TEP (SAFE; Low)	
Hydrohidae	*Lapemis hardwickii*	TEP (SAFE; Medium)	
Hydrohidae*	*Acalyptophis peronii**	TEP (SAFE; Medium)	
Hydrohidae*	*Aipysurus duboisii**	TEP (SAFE; Medium)	
Hydrohidae*	*Aipysurus eydouxii**	TEP (SAFE; Medium)	
Hydrohidae*	*Aipysurus laevis**	TEP (SAFE; Medium)	
Hydrohidae*	*Astrotia stokesii**	TEP (SAFE; Medium)	
Hydrohidae*	*Disteira kingie**	TEP (SAFE; Medium)	
Hydrohidae*	*Enhydrina schistosa**	TEP (SAFE; Low)	
Hydrohidae*	*Hydrophis mcdoweli**	TEP (SAFE; Medium)	
Hydrohidae*	*Hydrophis ornatus**	TEP (SAFE; Fished less than MSM)	
Hydrohidae*	*Hydrophis pacificus**	TEP (SAFE; Fished less	

		than MSM)	
MARINE TURTLES			
Cheloniidae*	*Caretta caretta**	TEP (SAFE; Medium)	
Cheloniidae*	*Lepidochelys olivacea**	TEP (SAFE; Medium)	
Cheloniidae*	*Chelonia mydas **	TEP (SAFE; Medium)	
Cheloniidae*	*Eretmochelys imbricate**	TEP (SAFE; Medium)	
Cheloniidae*	*Natator depressus**	TEP (SAFE; Medium)	
INVERTEBRATES			
Amphinomidae	*Chloeia flava*		
Ascidiidae	Ascidiidae		
Axiidae	*Axiopsis consobrina*		
Class Crinoidea	Crinoidea		
Class Echinoidea	Echinoidea		
Class Ophiuroidea	Ophiuroidea		
Class Scyphozoa	Scyphozoa		
Corystidae	*Jonas leuteanus*		
Crangonidae	*Pontocaris arafurae*		
Diadematidae	*Chaetodiadema granulatum*		
Enoploteuthidae	*Abralia armata*		
Goneplacidae	*Carcinoplax purpurea*		
Holothuridae	Holothuridae		
Loliginidae	*Photololigo spp.*		
Majidae	*Phalangipus australiensis*		
Majidae	*Phalangipus longipes*		
Nephtheidae	Nephtheidae		
Octopodidae	*Octopus spp.*		
Order Hydroida	*Order Hydroida*		
Superfamily Paguroidea	*Paguroidea*		
Palinuridae	*Panulirus polyphagus*		
Pandalidae	*Procletes levicarina*		
Penaeidae	*Atypopenaeus formosus*		
Penaeidae	*Metapenaeopsis spp.*		
Penaeidae	*Metapenaeopsis novaeguineae*		

Penaeidae	*Metapenaeopsis palmensis*		
Penaeidae	*Parapenaeopsis arafurica*		
Penaeidae	*Parapenaeus* spp.		
Penaeidae	*Trachypenaeus anchoralis*		
Penaeidae	*Trachypenaeus curvirostris*		
Penaeidae	*Trachypenaeus gonospinifer*		
Penaeidae	*Trachypenaeus granulosus*		
Pennatulidae	Pennatulidae		
Phylum Porifera	Porifera		
Pilumnidae	*Cryptolutea* sp.		
Pilumnidae	*Glabropilumnus seminudus*		
Pilumnidae	*Harrovia tuberculata*		
Portunidae	*Charybdis callianassa*		
Portunidae	*Charybdis feriata*		
Portunidae	*Charybdis hellerii*		
Portunidae	*Charybdis jaubertensis*		
Portunidae	*Charybdis truncata*		
Portunidae	*Charybdis yaldwyni*		
Portunidae	*Lissocarcinus arkati*		
Portunidae	*Lupocyclus rotundatus*		
Portunidae	*Lupocyclus tugelae*		
Portunidae	*Portunus hastatoides*		
Portunidae	*Portunus gracilimanus*		
Portunidae	*Portunus sanguinolentus*		
Portunidae	*Thalamita sima*		
Sargassaceae	Sargassaceae		
Scyllaridae	*Biarctus sordidus*		
Scyllaridae	*Thenus indicus*		
Sepiidae	*Sepia elliptica*		
Sepiidae	*Sepia papuensis*		
Sepiidae	*Sepia pharaonis*		
Sepiidae	*Sepiella weberi*		
Sepiolidae	*Euprymna cf tasmanica*		
Solenoceridae	*Solenocera australiana*		HRS 2009 (Level 2 PSA: High)
Spenopidae	*Sphenopus marsupialis*		

Squillidae	*Dictyosquilla tuberculata*		HRS 2009 (Level 2 PSA: High)
Squillidae	*Erugosquilla woodmasoni*		
Squillidae	*Harpiosquilla harpax*		
Squillidae*	*Harpiosquilla stephensoni**		HRS 2009 (Level 2 PSA: High)
Squillidae	*Oratosquillina gravieri*		
Squillidae	*Oratosquillina interrupta*		
Stichopodidae	Stichopodidae		
Xanthidae	*Atergatopsis tweediei*		

13.4 Threatened, endangered and protected (TEP) species theoretically occurring in NPF waters (from AFMA, 2012).

TAXONOMIC GROUP	FUNCTIONAL GROUP	SPECIES	COMMON NAME
Chondrichthyan	Speartooth Shark	*Glyphis sp C*	Speartooth Shark
Chondrichthyan	Speartooth Shark	*Glyphis sp. A [in Last & Stevens, 1994]*	Speartooth Shark
Chondrichthyan	Sawfish	*Anoxypristis cuspidata*	Narrow Sawfish
Chondrichthyan	Sawfish	*Pristis clavata*	Dwarf Sawfish
Chondrichthyan	Sawfish	*Pristis microdon*	Freshwater Sawfish
Chondrichthyan	Sawfish	*Pristis pectinata*	Wide Sawfish
Chondrichthyan	Sawfish	*Pristis zijsron*	Green Sawfish
Chondrichthyan	Shark	*Rhincodon typus*	Whale shark
Marine reptile	Sea snake	*Acalyptophis peronii*	Horned Seasnake
Marine reptile	Sea snake	*Aipysurus apraefrontalis*	Short-nosed Seasnake
Marine reptile	Sea snake	*Aipysurus duboisii*	Dubois' Seasnake
Marine reptile	Sea snake	*Aipysurus eydouxii*	Spine-tailed Seasnake
Marine reptile	Sea snake	*Aipysurus foliosquama*	Leaf-scaled Seasnake

Marine reptile	Sea snake	*Aipysurus fuscus*	Dusky Seasnake
Marine reptile	Sea snake	*Aipysurus laevis*	Olive Seasnake, Golden Seasnake
Marine reptile	Sea snake	*Aipysurus tenuis*	Brown-lined Seasnake
Marine reptile	Sea snake	*Astrotia stokesii*	Stokes' seasnake
Marine reptile	Sea snake	*Disteira kingii*	Spectacled seasnake
Marine reptile	Sea snake	*Disteira major*	Olive-headed Seasnake
Marine reptile	Sea snake	*Emydocephalus annulatus*	Turtle-headed Seasnake
Marine reptile	Sea snake	*Enhydrina schistosa*	Beaked Seasnake
Marine reptile	Sea snake	*Ephalophis greyi*	North-western Mangrove Seasnake
Marine reptile	Sea snake	*Hydrelaps darwiniensis*	Black-ringed Seasnake
Marine reptile	Sea snake	*Hydrophis atriceps*	Black-headed seasnake
Marine reptile	Sea snake	*Hydrophis belcheri*	A seasnake
Marine reptile	Sea snake	*Hydrophis caerulescens*	Dwarf seasnake
Marine reptile	Sea snake	*Hydrophis coggeri*	Slender-necked Seasnake
Marine reptile	Sea snake	*Hydrophis czeblukovi*	Fine-spined seasnake
Marine reptile	Sea snake	*Hydrophis elegans*	Elegant seasnake
Marine reptile	Sea snake	*Hydrophis gracilis*	Slender seasnake
Marine reptile	Sea snake	*Hydrophis inornatus*	Plain seasnake
Marine reptile	Sea snake	*Hydrophis mcdowelli*	A seasnake
Marine reptile	Sea snake	*Hydrophis melanosoma*	Black-banded robust seasnake
Marine reptile	Sea snake	*Hydrophis ornatus*	A seasnake
Marine reptile	Sea snake	*Hydrophis pacificus*	Large-headed Seasnake
Marine reptile	Sea snake	*Hydrophis vorisi*	A seasnake

Marine reptile	Sea snake	*Lapemis hardwickii*	Spine-bellied Seasnake
Marine reptile	Sea snake	*Laticauda colubrina*	Banded wide faced Sea krait
Marine reptile	Sea snake	*Laticauda laticaudata*	Large scaled sea krait
Marine reptile	Sea snake	*Parahydrophis mertoni*	Northern mangrove seasnake
Marine reptile	Sea snake	*Pelamis platurus*	Yellow-bellied seasnake
Marine reptile	Marine turtle	*Caretta caretta*	Loggerhead
Marine reptile	Marine turtle	*Chelonia mydas*	Green turtle
Marine reptile	Marine turtle	*Dermochelys coriacea*	Leathery turtle
Marine reptile	Marine turtle	*Lepidochelys olivacea*	Olive Ridley turtle
Marine reptile	Marine turtle	*Natator depressus*	Flatback turtle
Marine reptile	Marine turtle	*Eretmochelys imbricata*	Hawksbill turtle
Marine reptile	Crocodile	*Crocodylus johnstoni*	Freshwater crocodile
Marine reptile	Crocodile	*Crocodylus porosus*	Saltwater crocodile
Teleost	Pipefish	*Acentronura breviperula*	Hairy Pygmy Pipehorse
Teleost	Pipefish	*Bhanotia fasciolata*	Corrugated Pipefish, Barbed Pipefish
Teleost	Pipefish	*Campichthys tricarinatus*	Three-keel Pipefish
Teleost	Pipefish	*Choeroichthys brachysoma*	Pacific Short-bodied Pipefish, Short-bodied pipefish
Teleost	Pipefish	*Choeroichthys suillus*	Pig-snouted Pipefish
Teleost	Pipefish	*Corythoichthys amplexus*	Fijian Banded Pipefish, Brown-banded Pipefish
Teleost	Pipefish	*Corythoichthys conspicillatus*	Yellow-banded Pipefish, Network Pipefish
Teleost	Pipefish	*Corythoichthys haematopterus*	A pipefish
Teleost	Pipefish	*Corythoichthys intestinalis*	Australian Messmate Pipefish, Banded Pipefish

Teleost	Pipefish	*Corythoichthys ocellatus*	Orange-spotted Pipefish, Ocellated Pipefish
Teleost	Pipefish	*Corythoichthys schultzi*	Schultz's Pipefish
Teleost	Pipefish	*Cosmocampus banneri*	Roughridge Pipefish
Teleost	Pipefish	*Cosmocampus maxweberi*	A pipefish
Teleost	Pipefish	*Doryrhamphus janssi*	Cleaner Pipefish, Janss' Pipefish
Teleost	Pipefish	*Doryrhamphus melanopleura*	Bluestripe Pipefish
Teleost	Pipefish	*Dunckerocampus dactyliophorus*	Ringed Pipefish
Teleost	Pipefish	*Festucalex cinctus*	Girdled Pipefish
Teleost	Pipefish	*Filicampus tigris*	Tiger Pipefish
Teleost	Pipefish	*Halicampus brocki*	Brock's Pipefish
Teleost	Pipefish	*Halicampus dunckeri*	Red-hair Pipefish, Duncker's Pipefish
Teleost	Pipefish	*Halicampus grayi*	Mud Pipefish, Gray's Pipefish
Teleost	Pipefish	*Halicampus macrorhynchus*	A pipefish
Teleost	Pipefish	*Halicampus spinirostris*	Spiny-snout Pipefish
Teleost	Pipefish	*Haliichthys taeniophorus*	Ribboned Seadragon, Ribboned Pipefish
Teleost	Pipefish	*Hippichthys cyanospilos*	Blue-speckled Pipefish, Blue-spotted Pipefish
Teleost	Pipefish	*Hippichthys heptagonus*	Madura Pipefish
Teleost	Pipefish	*Hippichthys parvicarinatus*	Short-keeled Pipefish
Teleost	Pipefish	*Hippichthys penicillus*	Beady Pipefish, Steep-nosed Pipefish
Teleost	Pipefish	*Hippichthys spicifer*	A pipefish
Teleost	Pipefish	*Hippocampus zebra*	A pipefish
Teleost	Pipefish	*Micrognathus micronotopterus*	Tidepool Pipefish
Teleost	Pipefish	*Micrognathus pygmaeus*	A pipefish

Teleost	Pipefish	*Microphis brachyurus*	A pipefish
Teleost	Pipefish	*Solegnathus guentheri*	Indonesian Pipefish, Gunther's Pipehorse
Teleost	Pipefish	*Solegnathus sp. 1 [in Kuiter, 2000]*	Pipehorse
Teleost	Pipefish	*Solenostomus cyanopterus*	Blue-finned Ghost Pipefish, Robust Ghost
Teleost	Pipefish	*Syngnathoides biaculeatus*	Double-ended Pipehorse, Alligator Pipefish
Teleost	Pipefish	*Trachyrhamphus bicoarctatus*	Bend Stick Pipefish, Short-tailed Pipefish
Teleost	Pipefish	*Trachyrhamphus longirostris*	Long-nosed Pipefish, Straight Stick Pipefish
Teleost	Seahorse	*Hippocampus angustus*	Western Spiny Seahorse
Teleost	Seahorse	*Hippocampus jugumus*	Spiny Seahorse
Teleost	Seahorse	*Hippocampus planifrons*	Flat-face Seahorse
Teleost	Seahorse	*Hippocampus spinosissimus*	Hedgehog Seahorse
Teleost	Seahorse	*Hippocampus taeniopterus*	Spotted Seahorse, Yellow Seahorse

13.5 Catch in numbers of TEP and 'at high risk' bycatch species recorded from the NPF Logbook Program between 1998 and 2011. Figures in brackets are catches from the JBG sub-fishery.

		Total NPF Logbook TEP & At-risk species catch										
		Tiger Prawn Fishery Season										
SP_CODE	NAME	1998	1999	2000	2003	2005	2006	2007	2008	2009	2010	2011
28714011	*Solenocera australiana*											
28051000	Squillidae											
28051030	*Dictyosquilla tuberculata*											
28051039	*Harpiosquilla stephensoni*											
37025000	Pristidae							44 (11)	174 (18)	153 (10)	131 (13)	174 (33)
37025001	*Pristis zijsron*							17 (1)		57 (17)	28 (4)	54 (2)
37025002	*Anoxypristis cuspidata*							59 (2)	90	10	38 (11)	59 (2)
37025003	*Pristis microdon*							1			5	
37025004	*Pristis clavata*										2	
37035027	*Urogymnus asperrimus*											
37035017	*Taeniura meyeni*											
37282000	Syngnathidae				25		38	1726	36	3	18	5
37444005	*Istiophorus platypterus*							1 (1)				
37282101	*Trachyrhamphus longirostris*											
39020000	Cheloniidae	66 (2)	67 (1)	2	4		8	6	14	28 (2)	3	7 (1)
39020001	*Caretta caretta*	39	55 (2)	1		1		1	2			7
39020002	*Chelonia mydas*	108	120	8	8	16 (1)	5	2		7	7	26
39020003	*Eretmochelys imbricata*	26	16	2		1	4		2	1		
39020004	*Lepidochelys olivacea*	227 (8)	190	14 (1)	2	2	4	6	3	1	6	8
39020005	*Natator depressus*	253 (2)	189 (3)	3	6	5	10	10	5	2	5	4
39021001	*Dermochelys coriacea*	17	2	1					6			
39125000	Hydrophiidae sp				6230 (201)		7695 (16)	6689 (335)	4526 (86)	5965 (187)	5766 (116)	4231 (190)

40040000	Diomedeidae - undifferentiated						10					
40128031	*Sterna nilotica*						5					
40128901	*Sterna* spp.								1			
41116000	Delphinidae - undifferentiated						1	1				
41131002	*Arctocephalus gazella*											1
		Banana Prawn Fishery Season										
SPECIES_CODE	NAME	1998	1999	2000	2003	2005	2006	2007	2008	2009	2010	2011
28714011	*Solenocera australiana*											
28051000	Squillidae											
28051030	*Dictyosquilla tuberculata*											
28051039	*Harpiosquilla stephensoni*											
37025000	Pristidae							109	140	158	155	128 (1)
37025001	*Pristis zijsron*							4	10	25	18	15
37025002	*Anoxypristis cuspidata*							76	44	6	4	41
37025003	*Pristis microdon*							1				
37025004	*Pristis clavata*							1				
37035027	*Urogymnus asperrimus*											
37035017	*Taeniura meyeni*											
37282000	Syngnathidae				1		4	21	2	5		1
37444005	*Istiophorus platypterus*											
37282101	*Trachyrhamphus longirostris*											
39020000	Cheloniidae	49 (9)	44 (9)	6	1		2	25	4	8	1	
39020001	*Caretta caretta*	15 (1)	3	5		1	2					
39020002	*Chelonia mydas*	60 (5)	30 (3)	9	2 (1)	2	5	5			4	1
39020003	*Eretmochelys imbricata*	15 (1)	9				2					
39020004	*Lepidochelys olivacea*	88 (7)	72 (13)	9	1	1	1					
39020005	*Natator depressus*	97	86 (6)	8	3 (1)		2		3		1	
39021001	*Dermochelys coriacea*											
39125000	Hydrophiidae sp				1545 (239)		1894 (139)	892	1452	1383	1724	1132 (21)
40040000	Diomedeidae - undifferentiated											
40128031	*Sterna nilotica*											

40128901	*Sterna* spp.											
41116000	Delphinidae - undifferentiated									1		
41131002	*Arctocephalus gazella*											

13.6 Catch in numbers of TEP and 'at high risk' bycatch species recorded from the NPF Crew Member Observer (CMO) Program between 2003 and 2012. Figures in brackets are catches from the JBG sub-fishery.

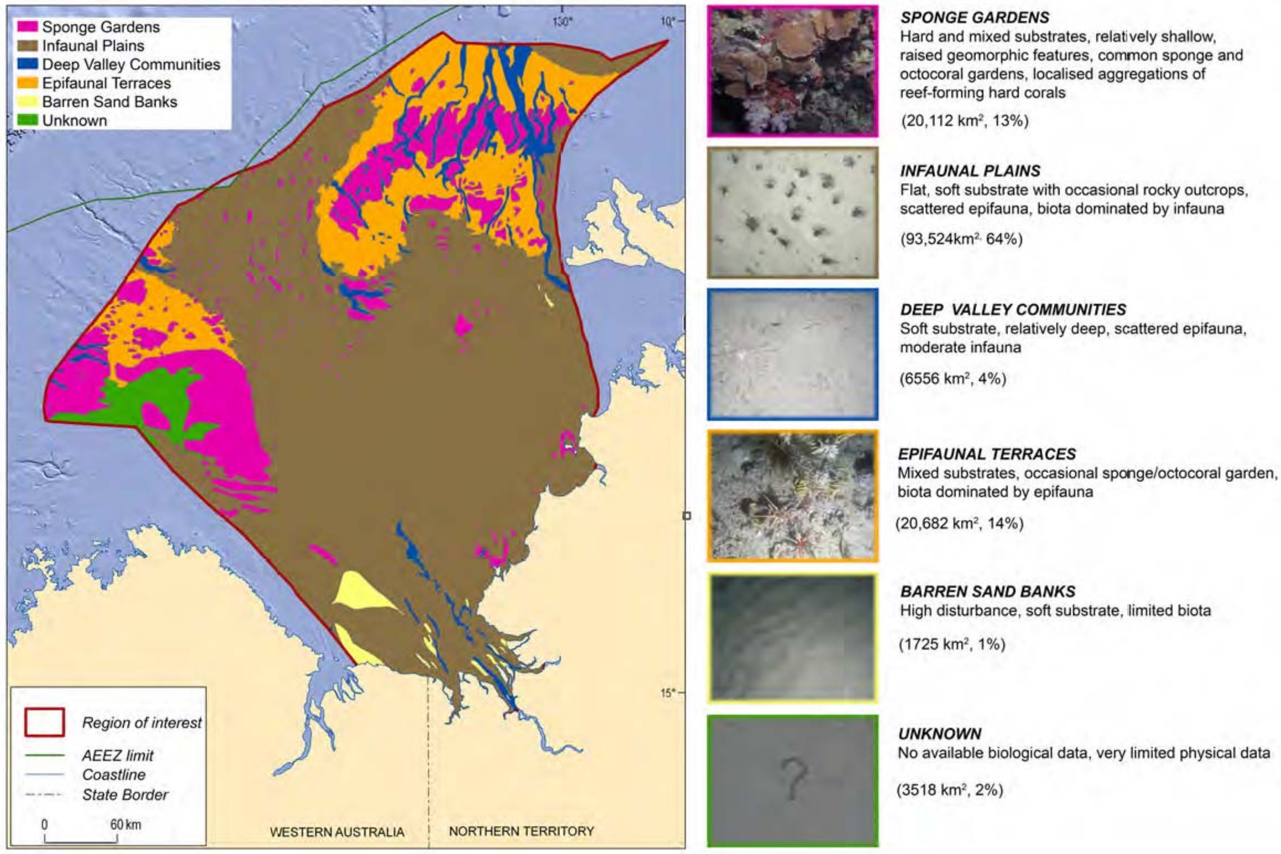
		NPF Crew Member Observer (CMO) TEP and 'at risk' species catch									
		Tiger Prawn Fishery Season									
SPECIES_CODE	NAME	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
28714011	*Solenocera australiana*	290 (259)						4	381	6262 (1373)	7989
28051000	Squillidae							27	101	122	13
28051030	*Dictyosquilla tuberculata*							4	210	886 (3)	2348
28051039	*Harpiosquilla stephensoni*								137	39 (10)	23
37025000	Pristidae	41	5		13 (4)	15	9	74 (12)	16	40	16
37025001	*Pristis zijsron*	1	1					1	1	7 (3)	3
37025002	*Anoxypristis cuspidata*	63 (4)	52 (8)	2	28 (6)	6	6	3 (1)	4	65 (13)	43
37025003	*Pristis microdon*							1			
37025004	*Pristis clavata*	1									1
37035027	*Urogymnus asperrimus*							7			
37035017	*Taeniura meyeni*		2					3	3	1	2
37282000	Syngnathidae				7	15	11	39 (2)	47	77	103
37444005	*Istiophorus platypterus*										
37282101	*Trachyrhamphus longirostris*		1			13	4				
39020000	Cheloniidae	6			5	9	1	41 (1)	4	10	18

39020001	*Caretta caretta*	1	2 (1)			1			4	2 (1)	
39020002	*Chelonia mydas*					1				13 (1)	3
39020003	*Eretmochelys imbricata*	1				1	1				1
39020004	*Lepidochelys olivacea*	2 (1)	2			1	1	1	2	4	3
39020005	*Natator depressus*	1	4		2	2	2	1		19	10
39021001	*Dermochelys coriacea*										
39125000	Hydrophiidae sp	816 (19)	319 (5)	138	87 (13)	220 (1)	65	664 (39)	461	1273 (53)	1305
39125001	*Acalyptophis peronii*	40	11	3 (1)	5	11					
39125003	*Aipysurus duboisii*			5 (1)	2	15					
39125004	*Aipysurus eydouxii*	72 (1)	73	36 (2)	7	17	2				
39125007	*Aipysurus laevis*	128	53	40 (6)	35	25	1				
39125009	*Astrotia stokesii*	142	88 (1)	73 (12)	24 (1)	34					
39125010	*Disteira kingii*	7	3	2 (1)							
39125011	*Disteira major*	330 (15)	154 (4)	98 (24)	37 (8)	38	2				
39125021	*Hydrophis elegans*	337 (20)	332 (6)	177 (23)	134 (2)	93	14				
39125025	*Hydrophis mcdowelli*	2	4	3							
39125028	*Hydrophis ornatus*	67	37	29 (7)	13	14	3				
39125029	*Hydrophis pacificus*	53	41	18 (4)	5	4					
39125031	*Lapemis hardwickii*	207 (7)	128 (2)	32 (7)	32 (5)	18	6				
39125033	*Pelamis platurus*			1							
40040000	Diomedeidae - undifferentiated										
40128031	*Sterna nilotica*										
40128901	*Sterna* spp.										
41116000	Delphinidae - undifferentiated										
41131002	*Arctocephalus gazella*										
		Banana Prawn Fishery Season									
SPECIES_CODE	NAME	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
28714011	*Solenocera australiana*		10								508
28051000	Squillidae										178
28051030	*Dictyosquilla tuberculata*									16	14
28051039	*Harpiosquilla stephensoni*									3	26

37025000	Pristidae		5							4	5
37025001	*Pristis zijsron*										4
37025002	*Anoxypristis cuspidata*		9							2	20
37025003	*Pristis microdon*		1							1	
37025004	*Pristis clavata*										
37035027	*Urogymnus asperrimus*										
37035017	*Taeniura meyeni*										
37282000	Syngnathidae									1	16
37444005	*Istiophorus platypterus*										
37282101	*Trachyrhamphus longirostris*										
39020000	Cheloniidae									7	2
39020001	*Caretta caretta*										
39020002	*Chelonia mydas*		1								1
39020003	*Eretmochelys imbricata*										
39020004	*Lepidochelys olivacea*										1
39020005	*Natator depressus*										
39021001	*Dermochelys coriacea*										
39125000	Hydrophiidae sp		85(2)							8	76
39125001	*Acalyptophis peronii*		1								
39125003	*Aipysurus duboisii*										
39125004	*Aipysurus eydouxii*										
39125007	*Aipysurus laevis*		2								
39125009	*Astrotia stokesii*		3								
39125010	*Disteira kingii*										
39125011	*Disteira major*		20								
39125021	*Hydrophis elegans*		24								
39125025	*Hydrophis mcdowelli*										
39125028	*Hydrophis ornatus*		1								
39125029	*Hydrophis pacificus*										
39125031	*Lapemis hardwickii*		41								
39125033	*Pelamis platurus*										

40040000	Diomedeidae - undifferentiated										
40128031	*Sterna nilotica*										
40128901	*Sterna* spp.										
41116000	Delphinidae - undifferentiated										
41131002	*Arctocephalus gazella*										

13.7 Generalised habitat map showing potential distribution of habitats and biological communities in Joseph Bonaparte Gulf (Figure 4.1 in Przeslawski et al. 2011).



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