Collation and Analysis of Oceanographic Datasets for National Marine Bioregionalisation

The Northern Large Marine Domain

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CSIRO Marine Research

Collation and Analysis of Oceanographic Datasets for National Marine Bioregionalisation: The Northern Large Marine Domain.

A report to the Australian Government, National Oceans Office.

May 2005

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1. Summary

This report is a supplement to the main report on *Collation and Analysis of Oceanographic Datasets for National Marine Bioregionalisation*. It provides additional detail on oceanographic datasets from the Northern Large Marine Domain (NLMD) encompassing Torres Strait, the Gulf of Carpentaria, the southern Arafura Sea, Joseph Bonaparte Gulf, and the southern Timor Sea. This region consists almost entirely of shallow shelf seas and experiences a pronounced seasonal climate with wet monsoon conditions over the warmer months and dry south-easterly trade winds over the cooler months.

The NLMD is relatively remote and there are only a relatively small number of oceanographic datasets available that are relevant to bioregionalisation. The spatial coverage of these datasets is particularly poor outside of the Gulf of Carpentaria. Key datasets include the CSIRO Atlas of Regional Seas (mapped temperature, salinity, dissolved oxygen and nutrients); outputs from hydrodynamic models of the region (tides and circulation patterns); satellite derived estimates of phytoplankton related characteristics (incident light, chlorophyll, and primary productivity); and zooplankton sampled from the Gulf of Carpentaria (zooplankton biomass and prawn larvae abundance).

The report also includes a more detailed case study of datasets from Albatross Bay in the northeast Gulf of Carpentaria. In addition to the biological datasets listed previously, this analysis includes *in situ* chlorophyll and primary production measurements, and copepod abundance estimates.

2. Project Objectives

This project aims to collate and analyse relevant oceanographic datasets as specified by the National Oceans Office to provide information on pelagic oceanographic characteristics in Australia's marine jurisdiction, and to provide expert advice on the use of this information in defining and describing bioregions in the development of the National Marine Bioregionalisation.

The oceanographic information will contribute to the definition and description of marine bioregions at two scales – a broad national scale and a more detailed scale in the northern region. This supplementary report aims to describe specific oceanographic information relevant to defining finer-scale bioregions for the NLMD. These outputs are similar to the national outputs (Hayes et al. 2005) but include finer scale detail and some additional datasets not available at the national scale.

3. Background

National Marine Bioregionalisation will provide the spatial framework for the National Oceans Office regional marine planning process. The development of bioregions has been a multi- phase process, beginning with the identification of seven Large Marine Domains around Australia (Lyne et al. 1998). Further refinements have been developed for both benthic and pelagic environments, with this report contributing to the latter.

The main components of the pelagic bioregionalisation work were:

i. *National Oceanographic Description and Information Review for National Marine Bioregionalisation* describing major oceanographic features and identifying key datasets for bioregionalisation (Condie et al. 2003).

ii. *Collation and Analysis of Oceanographic Datasets for National Marine Bioregionalisation*, providing data at both a broad national scale (Hayes et al. 2005) and at a more detailed scale for the NLMD. This supplementary report provides the NLMD focus.

iii. *Pelagic regionalisation* defining a set of bioregions based on the collated oceanographic datasets that will form the National Marine Bioregionalisation for the Australian Marine Jurisdiction (Lyne and Hayes 2005).

4. Data Storage and Metadata

The oceanographic data collation relied entirely on existing datasets. Some of these existed only in paper cruise reports and had to be manually entered, while others required transcribing from old formats. However, most of the datasets were in a readily accessible format and these have been archived as collected from the various contributors. This data is termed 'Base-data' and is stored on Neptune (http://neptune.oceans.gov.au), which is the Nation Oceans Office's dedicated area on the CSIRO Marine Research Data Centre Web Server. The only exception is when the file size exceeds 100 megabytes, in which case the relevant metadata record direct users to the data off-line. The offline data is currently being stored on LTO-2 tapes in 'tar' format and housed by CSIRO Marine Research.

The Base-data remains the property of the original custodians and is generally not public. However, a range of derived datasets, GIS layers, and maps have been created from the Base-data and are publicly web accessible though the Neptune metadata link (http://neptune.oceans.gov.au). Details of the approaches used to derive these products and a full products list are documented in the main report (Hayes et al. 2005). Products for the NLMD are listed in the Appendix.

5 Setting for the Northern Large Marine Domain

The Northern Large Marine Domain extends from Cape Talbot in northeastern Western Australia to Cape York in Queensland (Figure 1). It encompasses Torres Strait, the Gulf of Carpentaria, the southern Arafura Sea, Joseph Bonaparte Gulf, and the southern Timor Sea, covering a total area of 1,081,620 km^2. Nearly all of this area lies over the continental shelf.

A tern photographed by Southern Surveyor crew in the Gulf of Carpentaria in March 2005. ©CSIRO

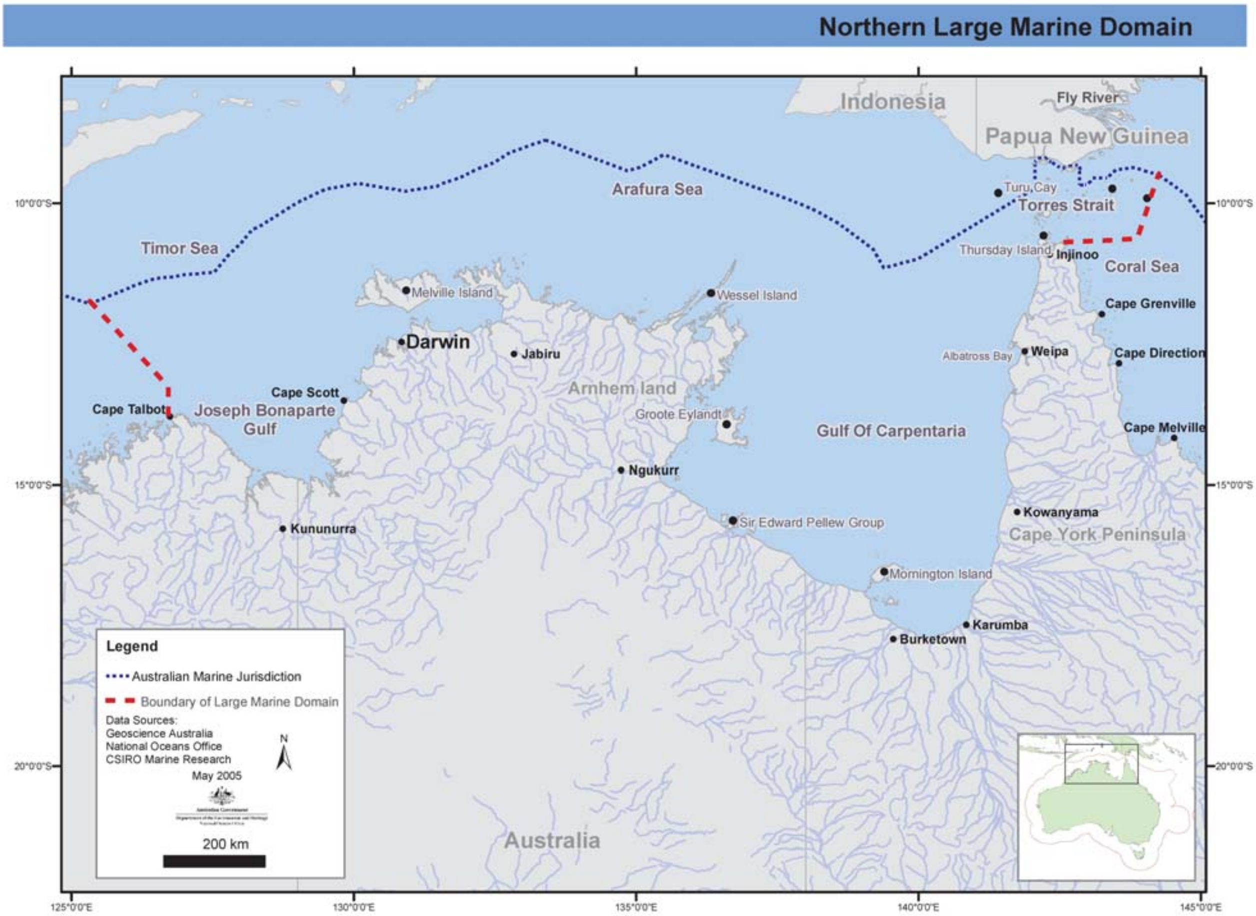


Figure 1 Map of northern Australia with the Northern Large Marine Domain (NLMD) delineated by red dashed lines.

5.1 Geomorphology

The NLMD is dominated by a shallow shelf and large basins in the Gulf of Carpentaria and Arafura Sea (Figures 2 and 3). The Gulf of Carpentaria is a relic lake (6000 YBP) and today forms a shallow (< 70 m) semi-enclosed sea bordered to the east by Torres Strait (< 20 m) and to the west by a sill extending from the Wessel Islands to Papua New Guinea (< 50 m). These constrictions limit water exchange between the Gulf of Carpentaria and the neighbouring Coral and Arafura Seas (Forbes 1984). Joseph Bonaparte Gulf is also relatively shallow (< 100 m), but is open to the Timor Sea where the depth increases dramatically into the Timor Trench (Figure 2). Many other smaller-scale geomorphic features have been identified across the NLMD, with tidal sand banks and subtidal dunes particularly common around the major island groups (Figure 3). A full description of the geomorphic features of the region is available at http://www.oceans.gov.au/pdf/National_Bathymetry_Report.pdf.

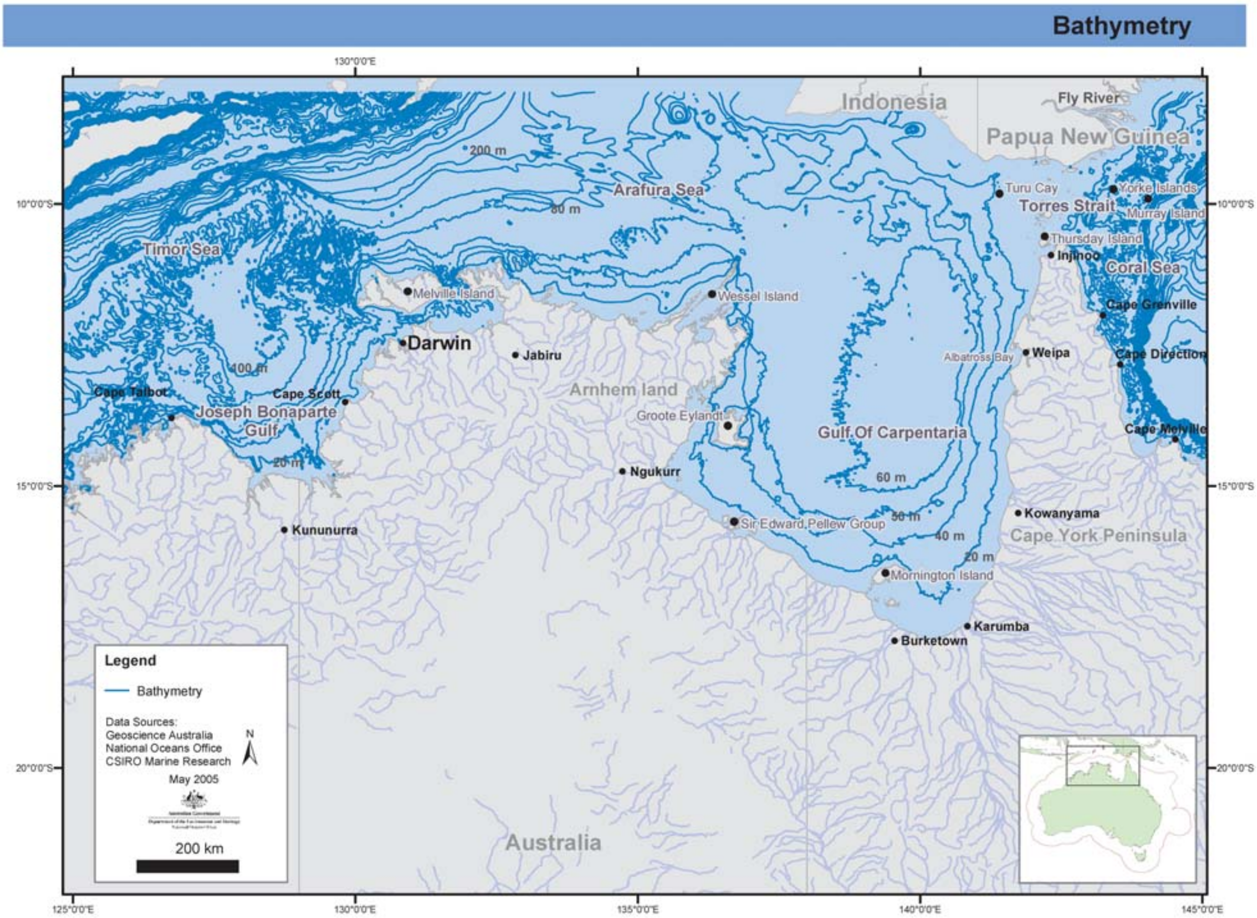


Figure 2. Bathymetry contours from the National 250m Bathymetry Grid (Geoscience Australia)

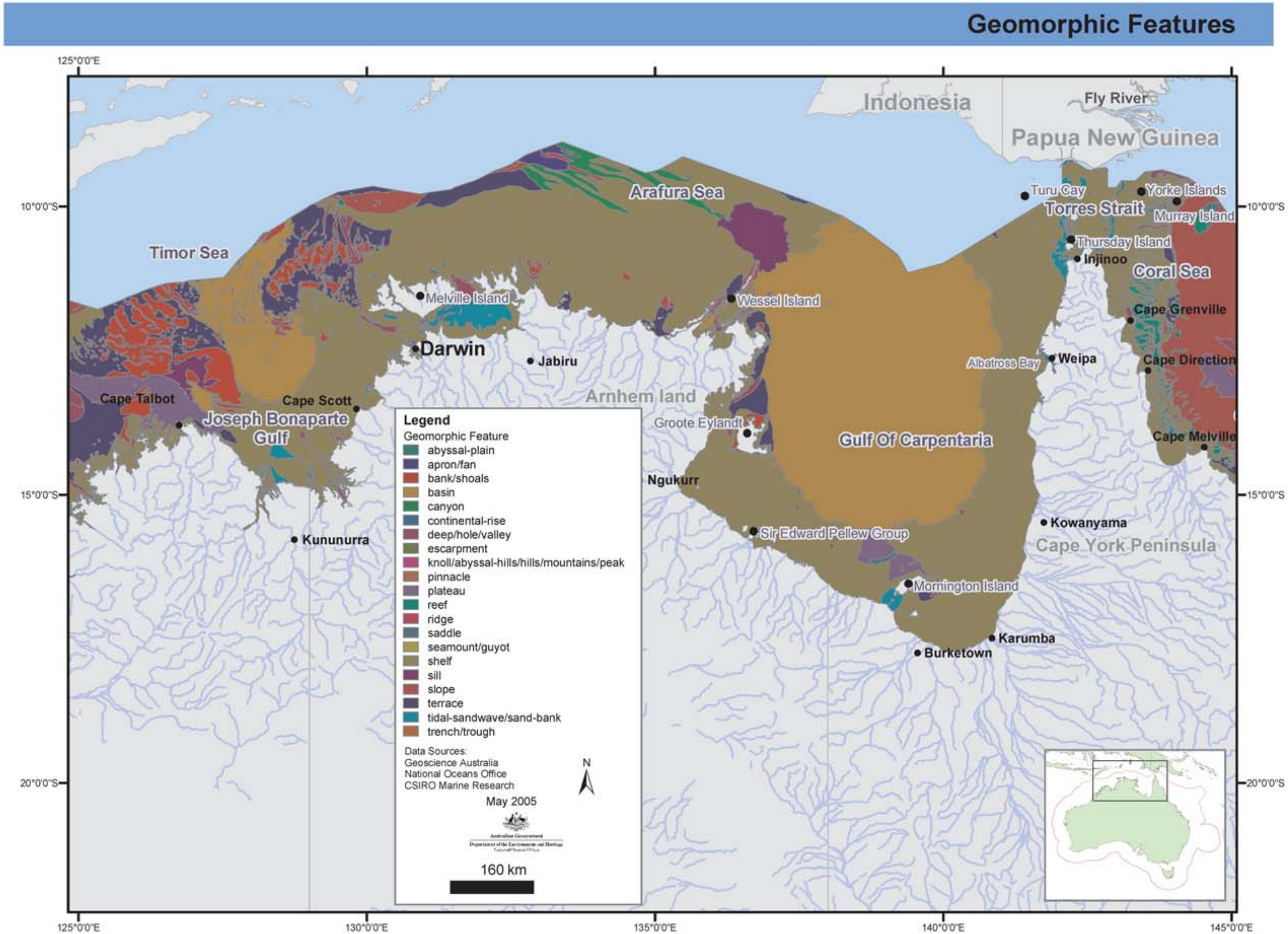


Figure 3 Geomorphic Features of the Northern Large Marine Domain (Harris et al. 2005).

5.2 Climatic conditions

The climate over the NLMD is dominated by the Australian summer monsoon, characterised by seasonal reversal of the prevailing winds. During the months from October to March the winds are predominantly from the north or northwest and quite variable in intensity. From April to September, stronger and more consistent trade-winds arrive from the southeast (Figure 4). Rainfall is also highly seasonal, with 80% of tropical Australia's annual mean precipitation falling from December to March (Bureau of Meteorology 1988, Figure 5). In addition to this strong seasonal signal, there is considerable variability in the timing and duration of the monsoon (Holland 1986). For example, there is evidence that El Nino delays the monsoon and reduces rainfall, although these influences are largely restricted to spring-time (e.g. Godfred-Spenning and Reason 2002).

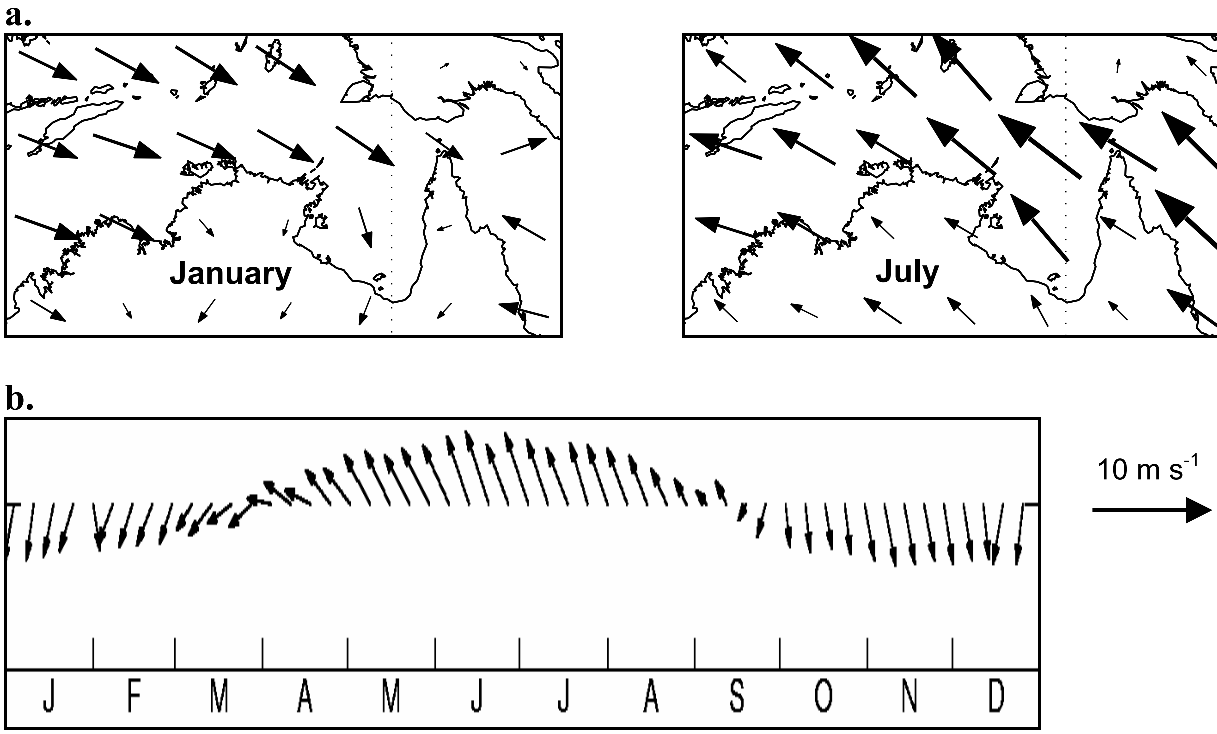


Figure 4 Seasonal wind vectors at a height of 10 m above sea-level: (a) Across the NLMD during the wet season (January) and dry season (July); (b) At one location in the Gulf of Carpentaria (138.8°E, 16.2°S). The seasonal vectors were derived by averaging the NCEP-NCAR Reanalysis winds (Kalnay et al. 1996) over the years 1982 to 1997.

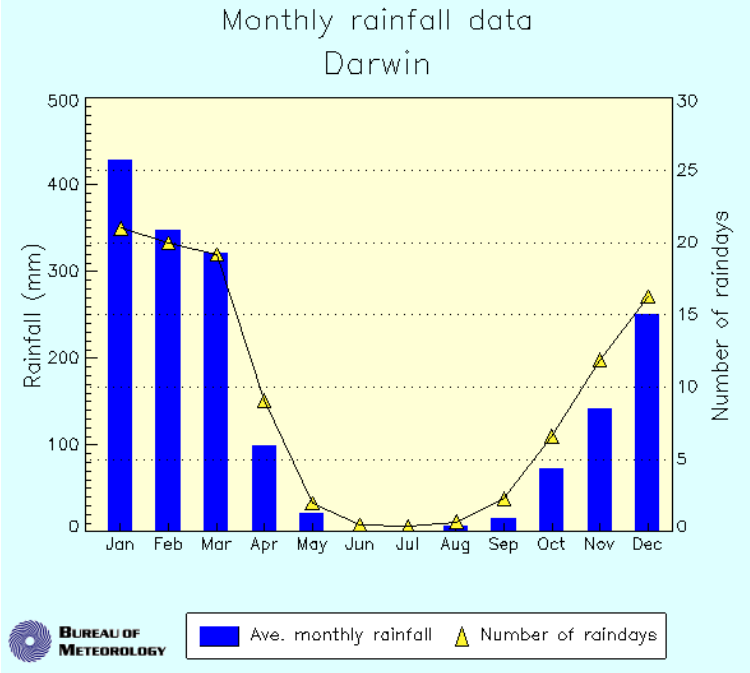


Figure 5 Darwin monthly rainfall and number of raindays (wet season = October to April) (reproduced with permission from the Bureau of Meteorology http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/map_script_new.cg).

6. Water Properties: CARS

Descriptions of the hydrographic water properties in the NLMD are based on the CSIRO Atlas of Regional Seas (CARS). This product is a set of seasonal maps of ocean properties including temperature, salinity, dissolved oxygen, nitrate, phosphate and silicate (Dunn & Ridgway 2002; Ridgway et al. 2002, Condie and Dunn 2005). It was produced using a weighted least squares (Loess) mapping of all available hydrographic data, sourced from the World Ocean Atlas 98, CSIRO Marine Research and NIWA archives. Stringent quality control procedures were used to reject corrupted data, duplicated data, and data which departed excessively from a first pass mapping. In the case of temperature and salinity, data which departed excessively from known temperature-salinity trends was also rejected.

Individual casts (Figure 6) were interpolated vertically onto standard depth levels, before being horizontally interpolated onto a uniform 0.1° grid using a locally-weighted least squares, or "loess", filter. This involved projecting the data onto quadratic functions of latitude and longitude while simultaneously fitting annual and semi-annual harmonics by weighted least squares. A significant advantage of the simultaneous fitting of temporal and spatial functions is that seasonal biases in sampling are less likely to introduce biased mean fields or aliased spatial structure.

The mapping was designed to retain much of the structure resolved by the underlying data by allowing the smoothness scale to vary with data density. A minimum smoothness radius of 200 km was used to ensure that small-scale eddy fluctuations were appropriately smoothed in regions where data was abundant. Distortion of fields by clusters of high data density was avoided by thinning these clusters to a set of monthly averages of the data. This process preserved the seasonal information, while allowing a spatially representative sample to be included in the mapping. Special schemes were also developed to reduce smearing of the tracer structure across land barriers such as islands and capes (Dunn and Ridgway 2002).

The spatial and seasonal distribution of individual casts provides a useful indication of the uncertainties in the mappings associated with low data density (Figure 6). However, even in regions of adequate data density, there may be additional uncertainty in the seasonal patterns due to high levels of interannual variability, or small-scale variability arising from unresolved ocean processes (such as mesoscale eddies and internal waves), or errors associated with the data collection methods. The root-mean-square (rms) of residuals between the mapped fields and original data can be used as a relative measure of these errors (Ridgway et al. 2002, Condie and Dunn 2005).

Sample reference maps from CARS will be presented below with a brief interpretive description of each field.

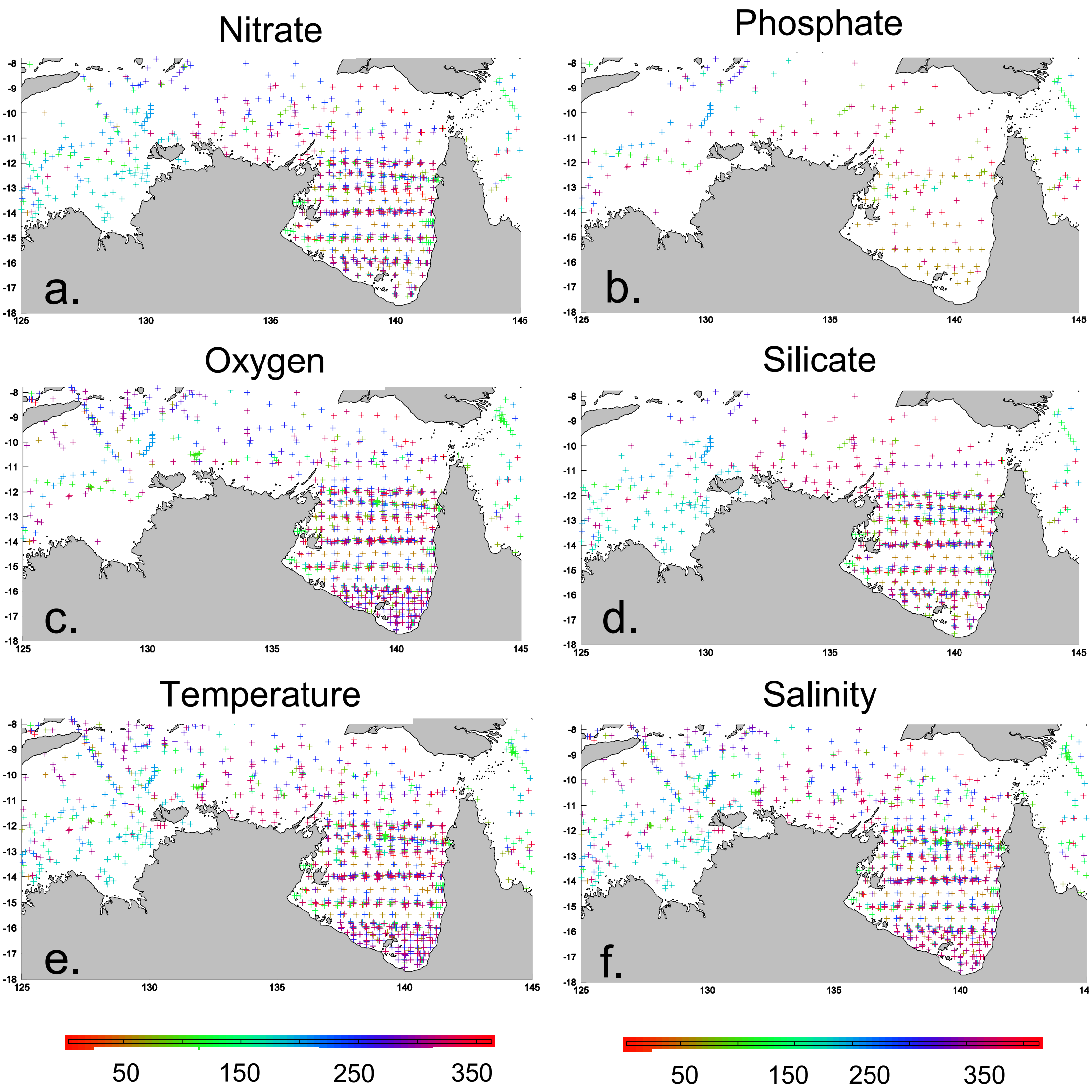


Figure 6. CSIRO Atlas of Regional Seas (CARS) spatial and temporal (colour coded for day of year) coverage of individual casts: (a) Nitrate; (b) Phosphate; (c) Oxygen; (d) Silicate; (e) Temperature; and (f) Salinity.

6.1 Temperature

During the summer wet season (November through March) tidal mixing ensures that water properties in shallow regions, such as Torres Strait, coastal Gulf of Carpentaria (to the 20 m depth contour) and Joseph Bonaparte Gulf, remain vertically uniform. However, thermal stratification develops in the central Gulf of Carpentaria and deeper regions of the Arafura and Timor Seas as solar heating warms a thin surface layer (< 30 m deep, Condie et al. 2003). Both CARS and remotely sensed sea-surface temperature indicate that near-surface temperatures are uniformly high (28 - 31°C) across the NLMD, with slightly cooler waters evident in the northeast around Torres Strait (Figures 7a and 8a).

During the winter dry season, temperatures are typically 5°C lower than summer and tend to be vertically uniform across most of the NLMD due to strong vertical mixing by tides, trade winds, and surface cooling. Cool anomalies across the shallow southern end of the Gulf of Carpentaria are likely to be associated with heat loss to the atmosphere over winter (Figures 7b and 8b).

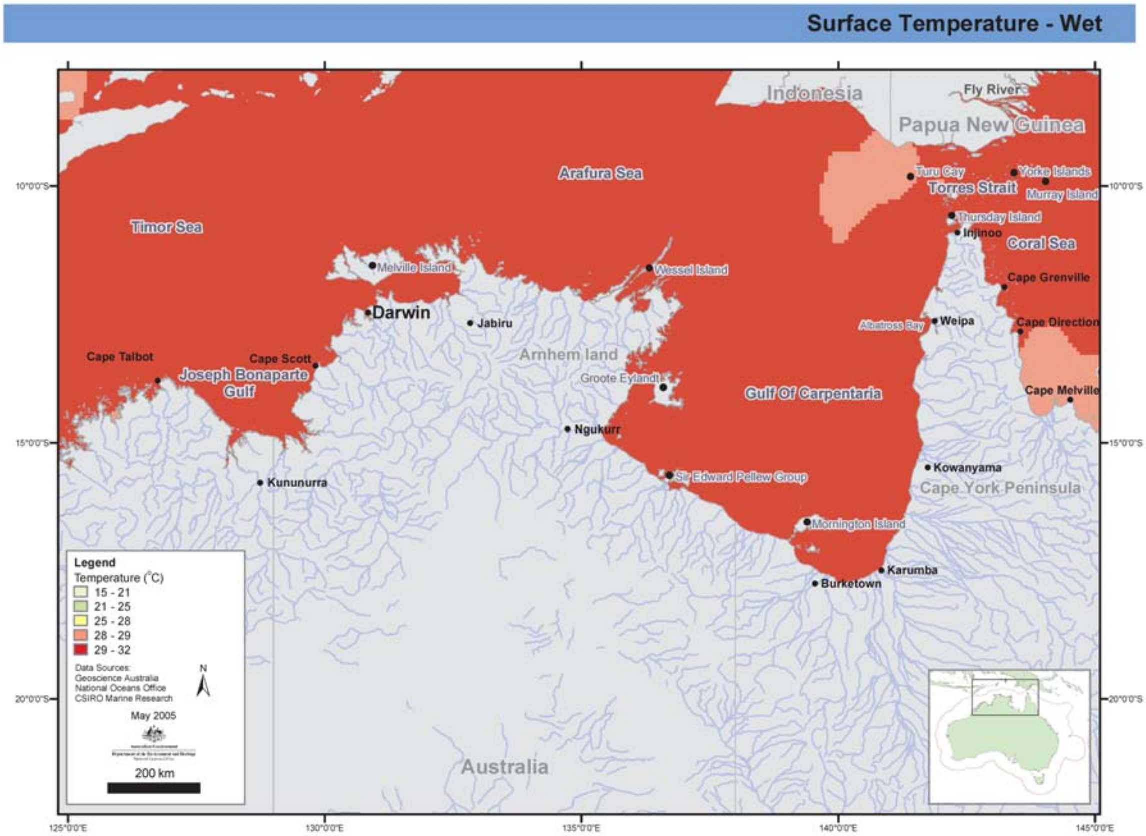
6.2 Salinity

Salinities in the NLMD are influenced by high evaporation rates and substantial precipitation and freshwater river inflow during the wet season. The net effect of the riverine inputs is low salinity anomalies on the eastern and western sides of the Gulf of Carpentaria (Figure 9). However, evaporation dominates in the southern Gulf of Carpentaria and Joseph Bonaparte Gulf, resulting in anomalously high salinity. The salinity of offshore waters in the western Arafura and Timor seas are likely to be significantly influenced by low salinity Indonesian Throughflow waters travelling west.

6.3 Dissolved oxygen

The dissolved oxygen distribution near the surface remains near equilibrium with the atmosphere. The oxygen levels are therefore mainly a function of temperature and the highest oxygen in the NLMD occurs in the relatively cool waters of the southern Gulf of Carpentaria (Figure 10). However, the temperature differences are relatively small and oxygen patterns may also be influenced by ocean transport patterns and vertical mixing with deeper waters depleted in oxygen.

a.



b.

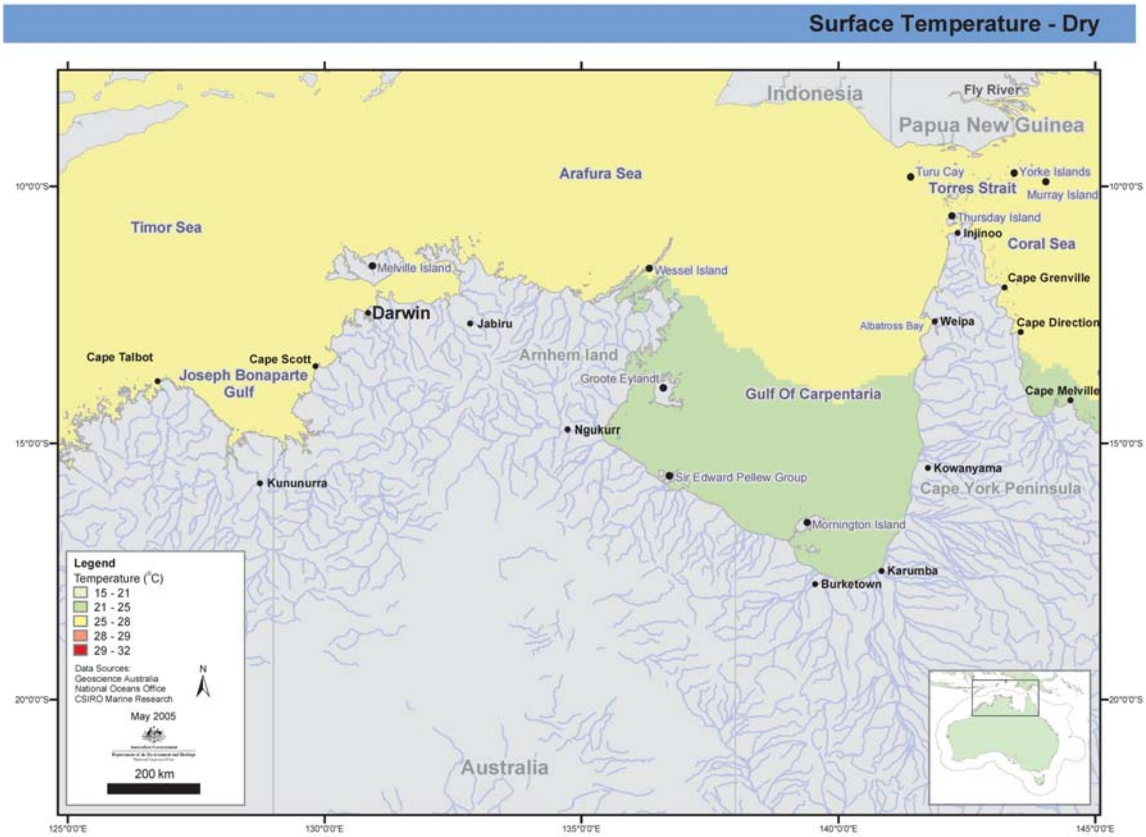


Figure 7. Near-surface water temperature from CARS: (a) Wet season (January); (b) Dry season (July).

a.

b.

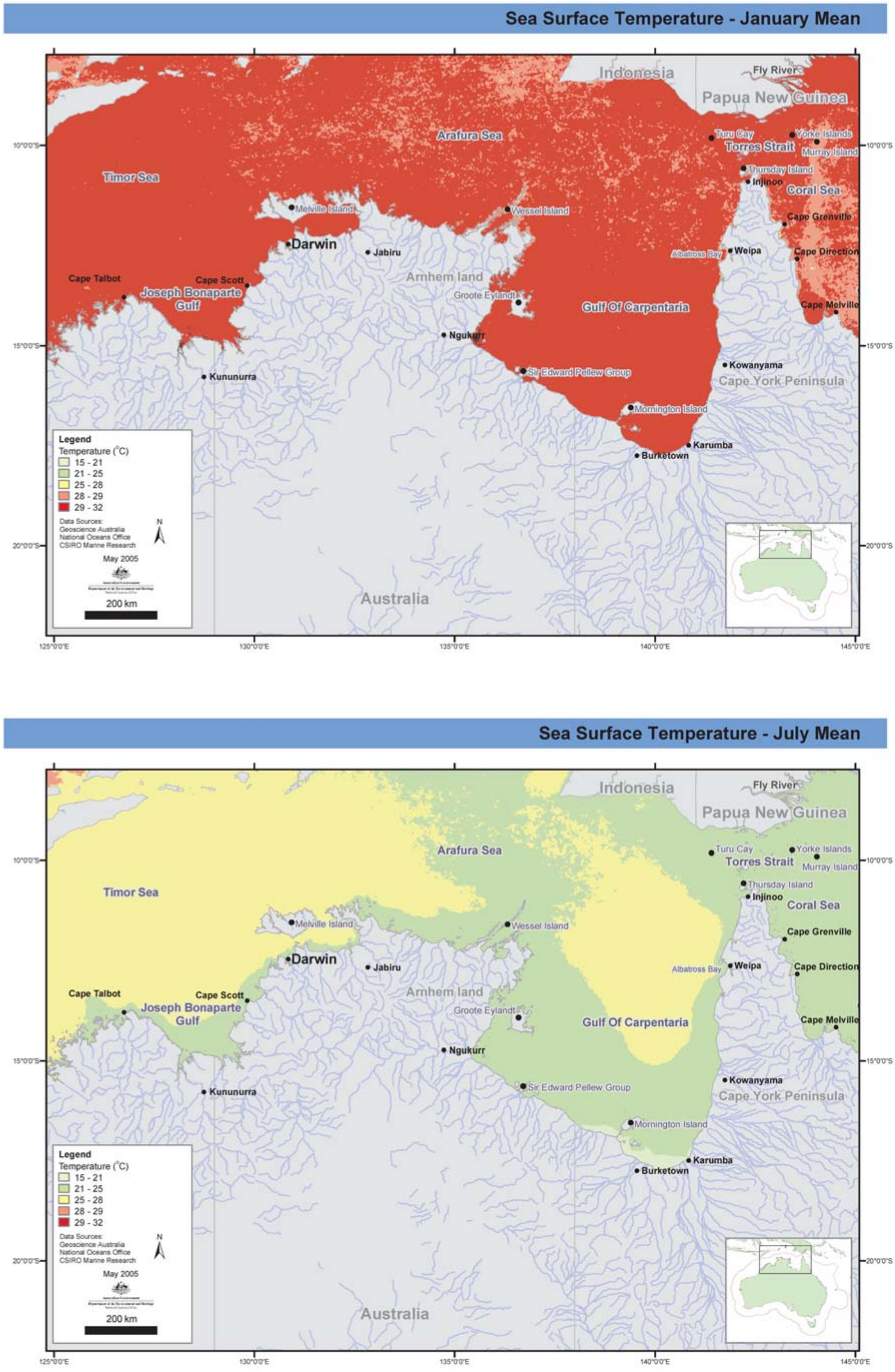


Figure 8. Satellite derived monthly mean sea surface temperature: (a) Wet season (January); (b) Dry season (July).

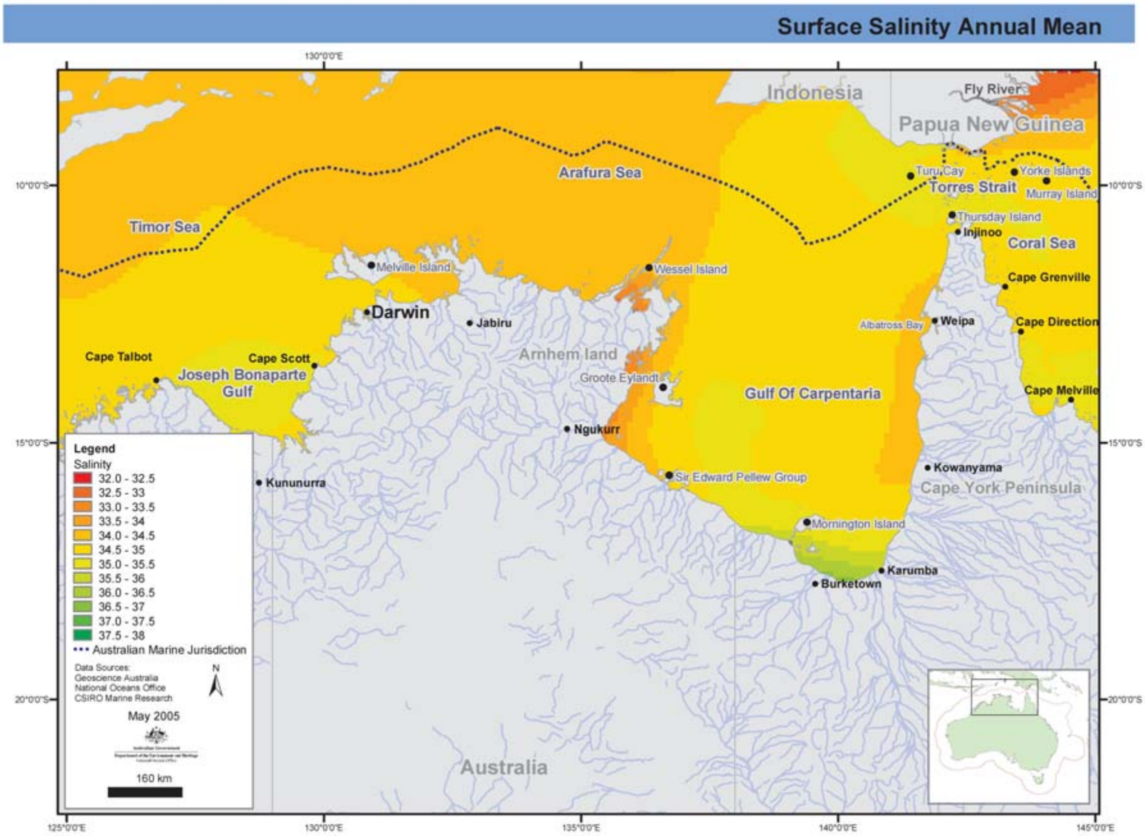


Figure 9. Annual mean near-surface salinity from CARS.

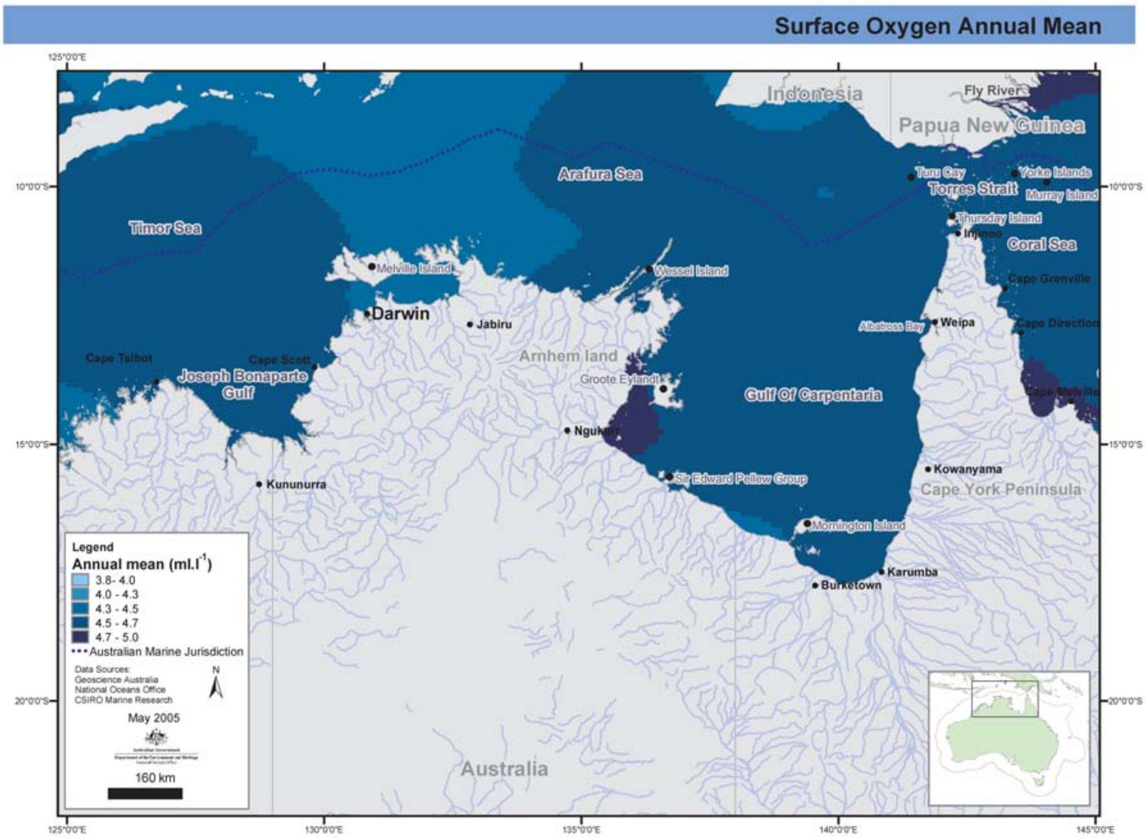


Figure 10. Annual mean near-surface dissolved oxygen from CARS.

6.4 Nutrients

Nutrients tend to be low in the surface waters of the NLMD, reflecting the rapid consumption by phytoplankton that is typical of most tropical systems. This is particularly true of nitrate in the Gulf of Carpentaria (< 0.1 μM, Figure 11). While levels in the Joseph Bonaparte Gulf appear to be significantly higher, sampling of nutrients in this area is extremely sparse (Figure 6). Phosphate levels are also relatively low throughout the NLMD (< 0.1 μM) with higher values only encountered to the north in Indonesian waters (Figure 12). Silicate distributions tend to reflect localised riverine inputs, particularly around the Gulf of Carpentaria and the Fly River in southern Papua New Guinea, where values commonly exceed 5 μM (Figure 13). Values in the central Gulf of Carpentaria, and the western Arafura and Timor Seas are lower, but still significant.

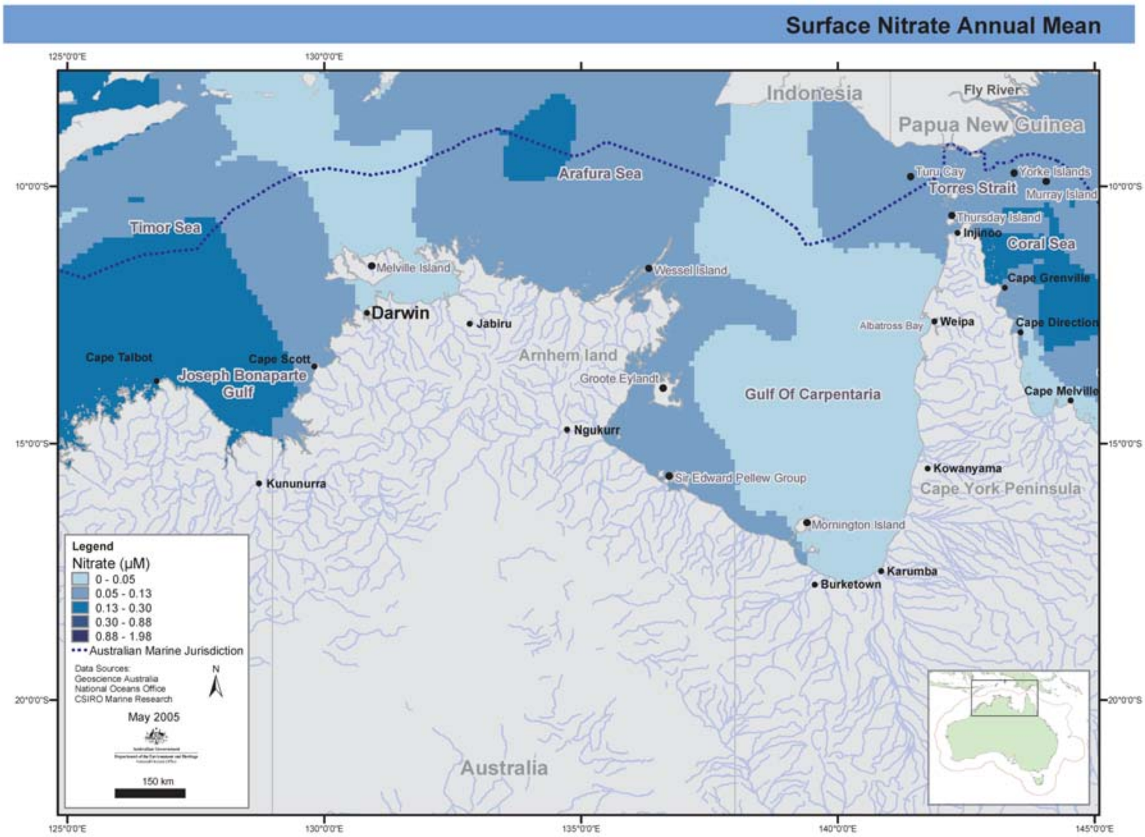


Figure 11. Annual mean near-surface dissolved nitrate from CARS.

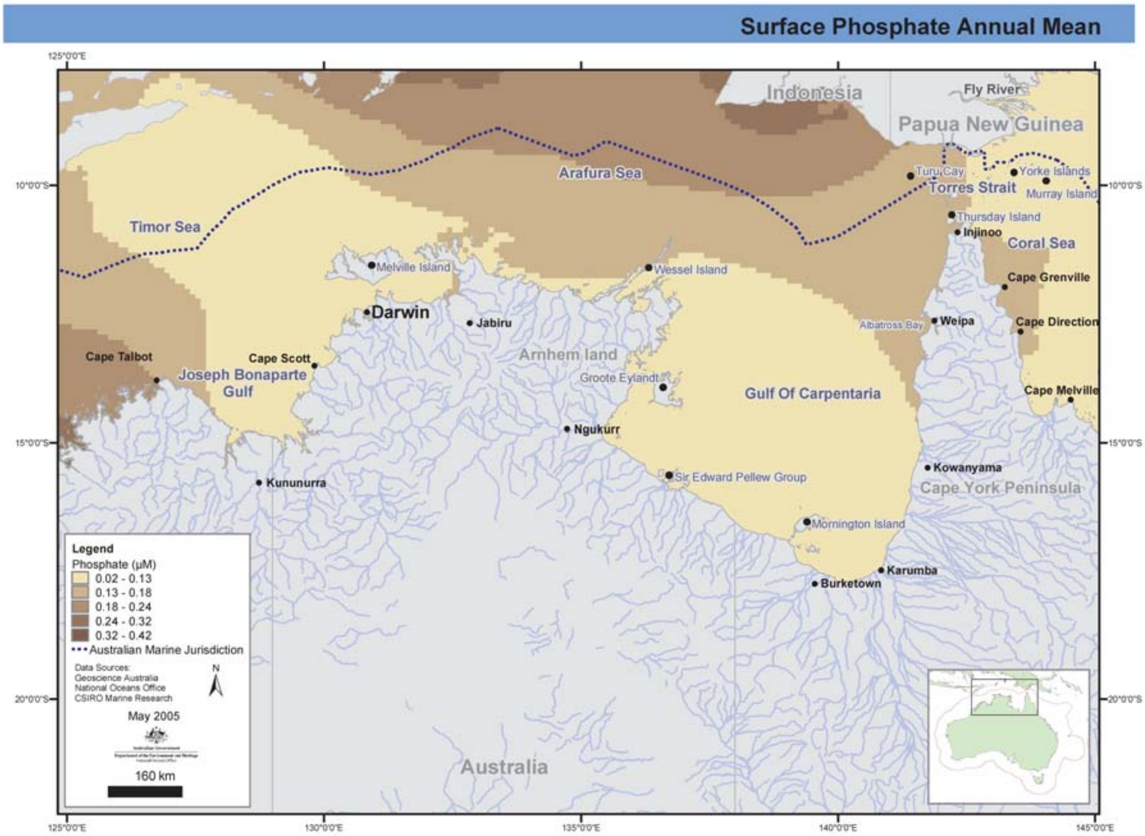


Figure 12. Annual mean near-surface dissolved phosphate from CARS.

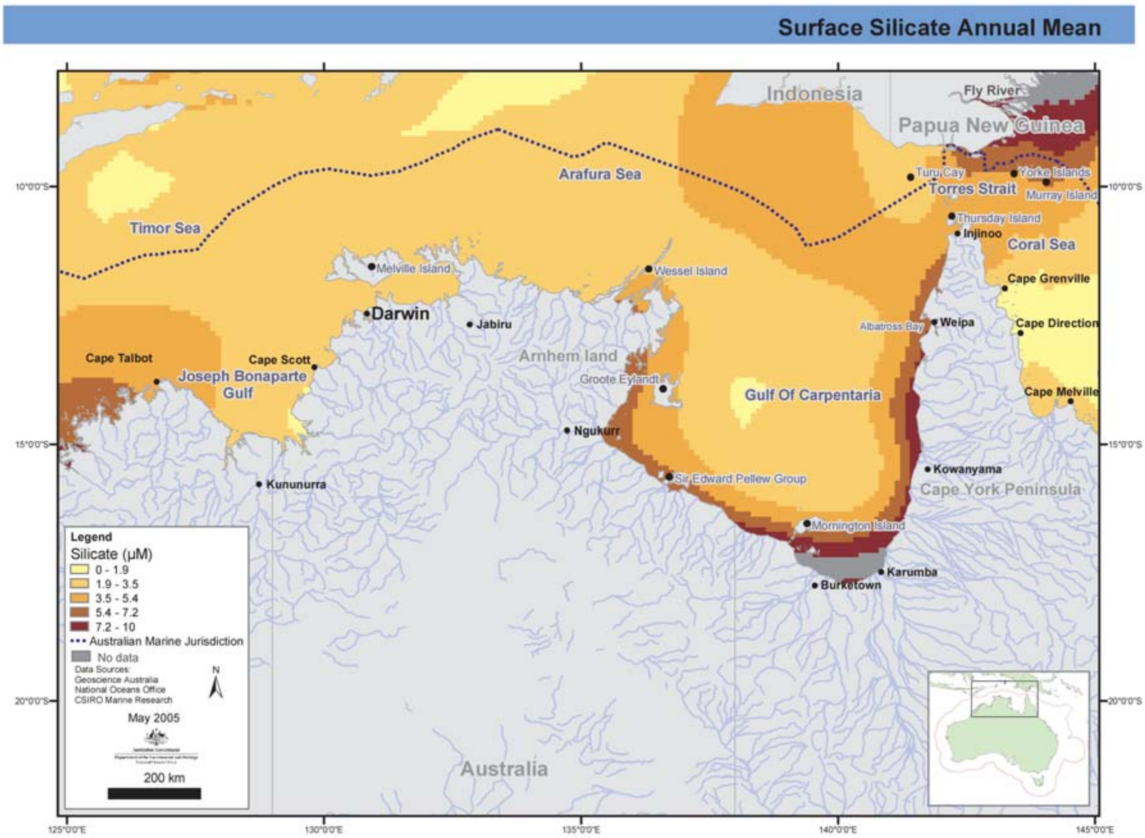


Figure 13. Annual mean near-surface dissolved silicate from CARS.

7. Tides and circulation: model results

Information on tidal currents and general circulation patterns in the NLMD are based on results from a recently developed three-dimensional hydrodynamic model of the region (excluding eastern Torres Strait). This model includes realistic seasonal wind, wave, tidal, and temperature and salinity forcing (from CARS). While further validation is required, it has been shown to reproduce observed tides very satisfactorily (Hill et al. 2002). The model has been run over a period of one year to provide comprehensive information on daily to seasonal variability.

7.1 Tides

The oceanographic environment of the NLMD is dominated by diurnal and semi-diurnal tides, with the Joseph Bonaparte region featuring some of the largest tidal energies observed anywhere in the world. Tidal sealevel ranges exceed 7 m along the western side of Joseph Bonaparte Gulf during the spring tide, falling to less than 2 m in the central and western Gulf of Carpentaria (Figure 14). Geographical features, such as Melville Island, Wessel Island, Mornington Island, and Torres Strait appear to provide major barriers to the propagation of tidal energy.

The strength of the tidal currents generally follow similar patterns to tidal sealevel, with localised enhancement around headlands and bathymetric constrictions. These features are captured by the bottom stress distributions, which show large areas of high stress in Joseph-Bonaparte Gulf and around Melville Island (Figure 15). More localized high stress zones are also evident around the Wessel Islands, west of Groote Eylandt, Mornington Island, and Torres Strait. Peak model currents in excess of 1.5 m s^{-1} occur in Joseph Bonaparte Gulf and values around 0.5 m s^{-1} are commonplace throughout the NLMD. While not included in the model domain, currents in excess of 2 m s^{-1} have been observed in Torres Strait.

7.2 Seasonal circulation patterns

While tides dominate any instantaneous snapshot of currents in the NLMD, lower frequency flows are largely responsible for the longer-term transport patterns (days to months). The model results suggest that this component varies seasonally in response to changing wind patterns and larger-scale influences such as the Indonesian Throughflow (Figure 16).

During the summer monsoon, a large clockwise gyre develops in the Gulf of Carpentaria with broad-scale drift in the east and south (~ 2 cm s^{-1}) balanced by more concentrated return flow in the west and north (~ 8 cm s^{-1}). Mean flows are relatively weak in Joseph Bonaparte Gulf and off Arnhem Land, while there is a more significant northeastward flow in the Timor Sea (Figure 16a) consistent with available field observations (Cresswell 1993). The model results suggest that largest mean currents in the NLMD are eastward through the Clarence Strait (south of Melville Island), with magnitudes approaching 50 cm s^{-1} under monsoon winds and 30 cm s^{-1} under opposing southeast trade winds.

Under the stronger southwest trade-winds, flow in the Gulf of Carpentaria breaks into multiple clockwise and anti-clockwise eddies, with typical diameters of 200 km and speeds in the northeast approaching 30 cm s^{-1} (Figure 16b). These conditions also drive a substantial westward flow off Arnhem Land (~ 15 cm s^{-1}) and through the Timor Sea (Cresswell 1993), with a small part this transport diverting southwest through Joseph Bonaparte Gulf.

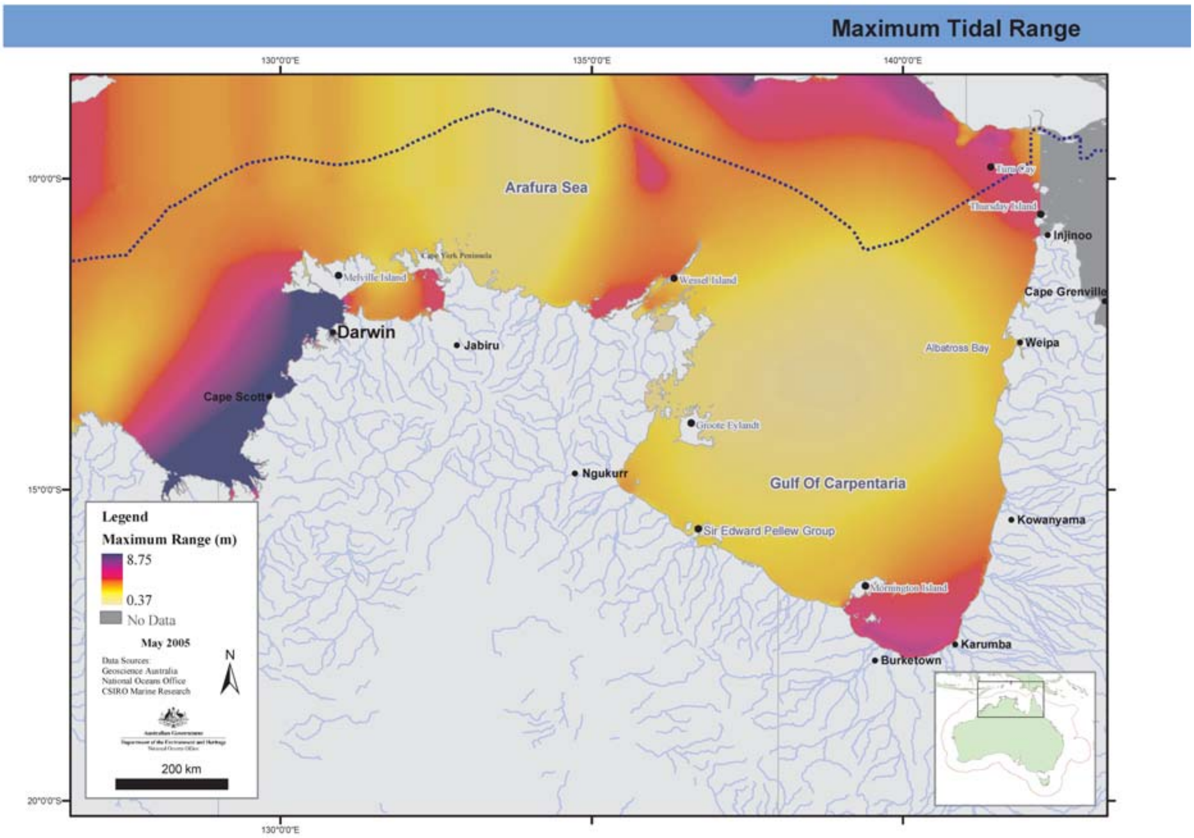


Figure 14. Maximum tidal sea level range as estimated by a hydrodynamic model of the region.

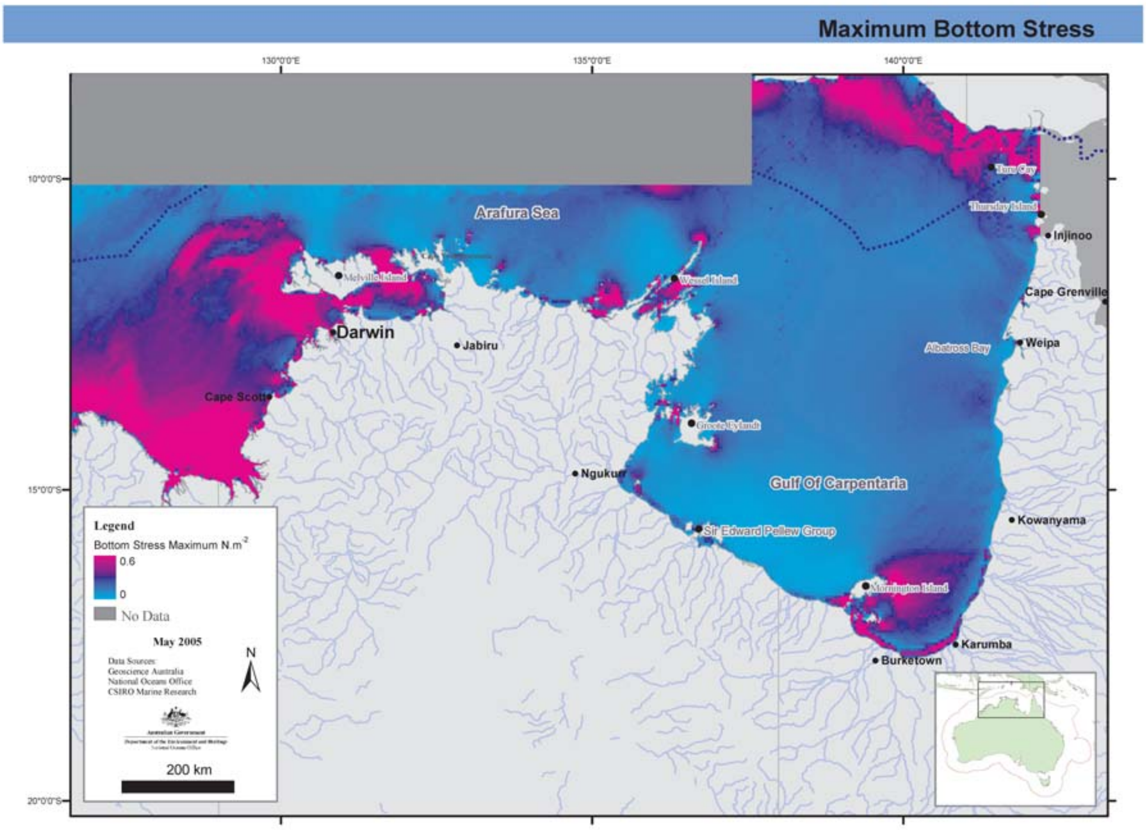
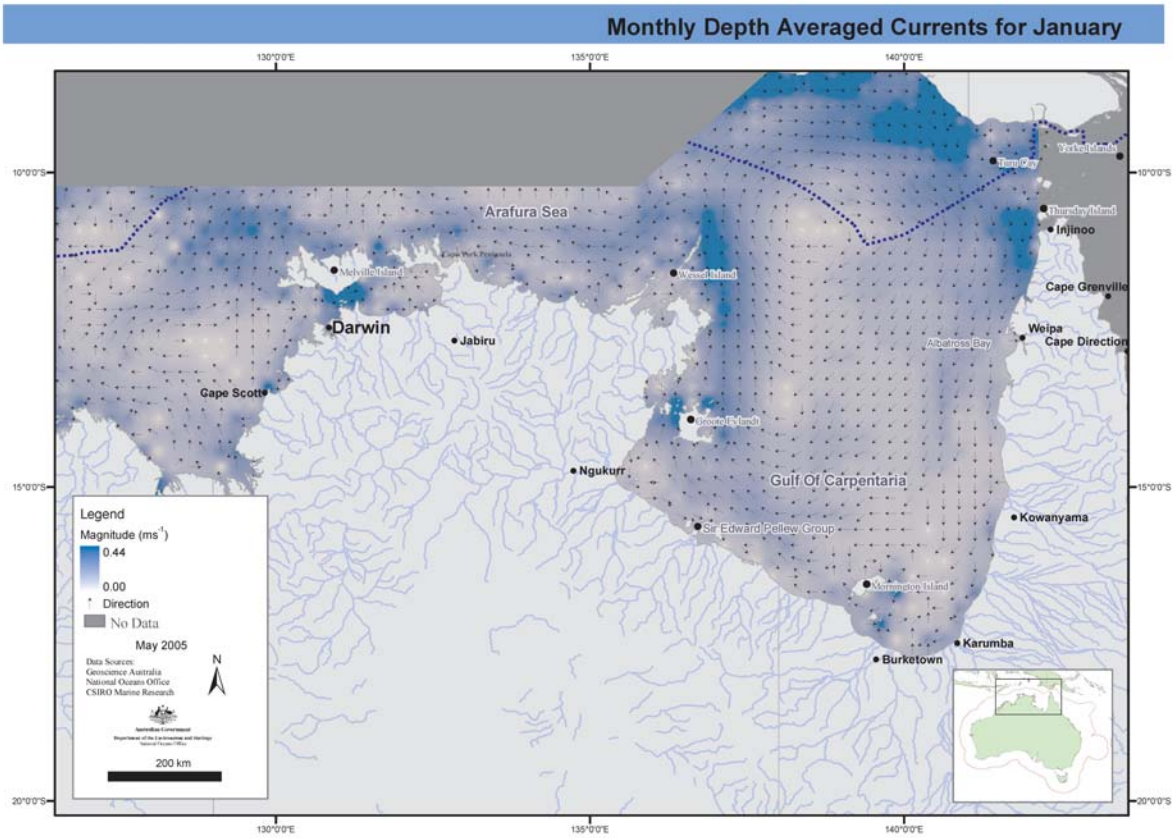


Figure 15. Maximum bottom stress as estimated by a hydrodynamic model of the region.

a.



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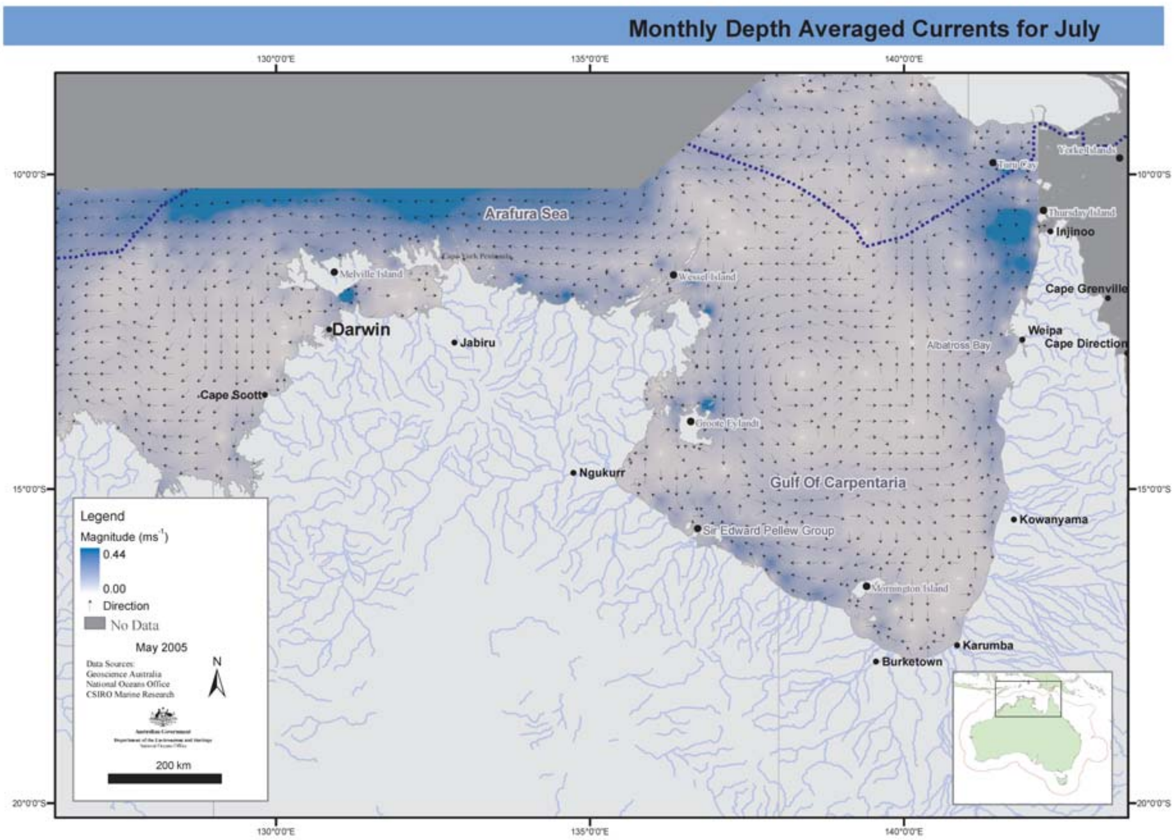


Figure 16 Monthly mean depth-averaged currents: (a) Wet Season (January); (b) Dry Season (July).

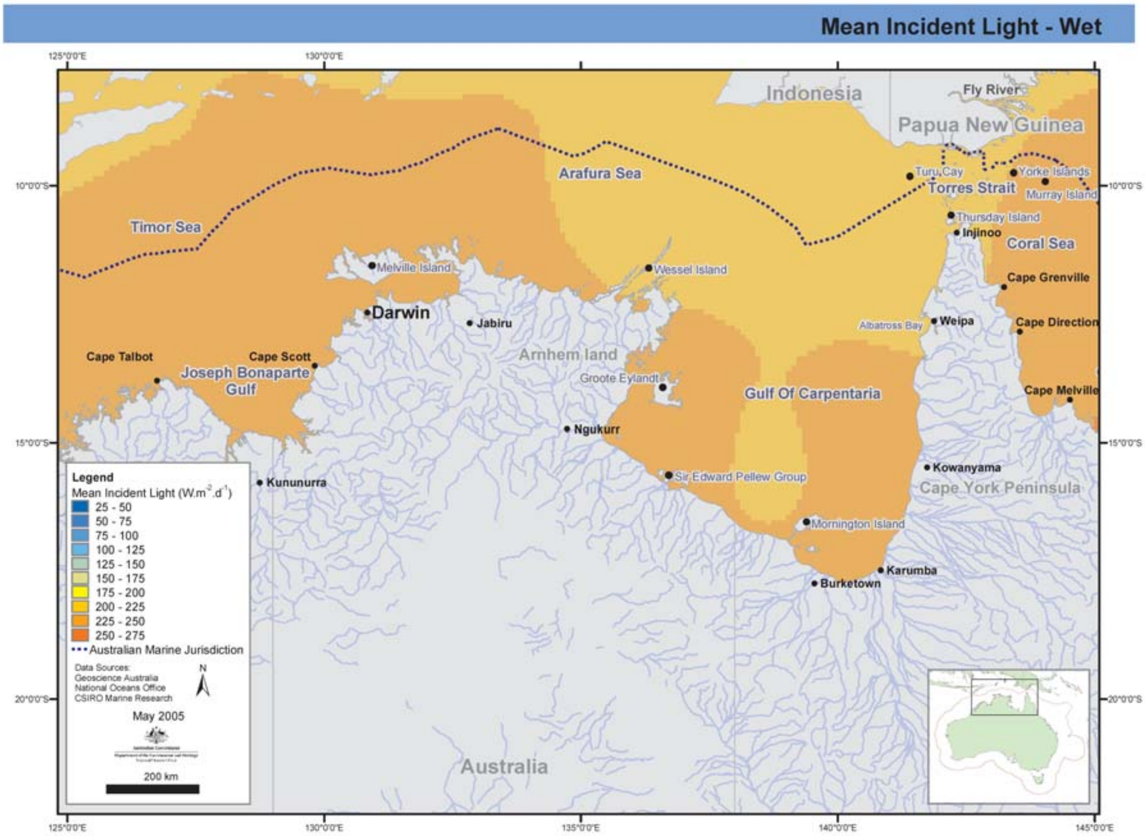
8. Phytoplankton related characteristics

8.1 Photosynthetically active radiation (PAR)

Photosynthetically active radiation (PAR) is defined as the light energy required for photosynthesis, and is restricted to wavelengths between 400 and 700 nm. Surface irradiance as a function of time of day was calculated for clear-sky irradiance following Kirk (1983), and the effects of cloud cover were incorporated by adjusting the theoretical clear-sky irradiance to match the monthly mean irradiance estimates for the station latitude and longitude produced by Bishop and Rossow (1991). Following Bishop and Rossow (1991), PAR was calculated as 50% of the surface irradiance. The amount of PAR on a square metre of ocean surface is determined by the elevation of the sun above the horizon, cloud cover, and atmospheric transmittance of light from the sun. The elevation of the sun varies with latitude and month and is greatest in December, and least in June. Day length plus sun altitude, determine the daily amount of PAR per unit area, and the amount of PAR available for photosynthesis and primary production at depth. In the water, the amount of PAR available for photosynthesis is determined by the absorbance of PAR by pure water, and the absorbance and backscatter of light by phytoplankton, detritus and suspended sediments in the water. Due to absorbance, the wavelength of PAR changes with increasing depth, with most of the energy being confined to the 450-500 nm range in clear ocean waters at 100m.

Day lengths in the Large Northern Marine Domain do not vary greatly between seasons, with the longest day length at 10°S (12.45 hours) occurring in January, and the shortest at 20°S (11 hours) in July. There will be some reduction in PAR superimposed on these latitudinal patterns due to seasonal changes in cloud cover, particularly during the wet season. During the wet season, light intensities are in the range of 225 to 250 Watts m^{-2} d^{-1}, some 25 Watts m^{-2} d^{-1} higher than during the winter, in spite of the impact of clouds during the wet season (Figure 17). This difference is due to the higher sun angle, and longer day length seen during January compared July. There is some evidence for slightly higher irradiances to be found west of about 135°E, and the region south of PNG shows slightly lower total irradiances in both seasons compared to the rest of the Gulf of Carpentaria or the Arafura Sea, probably related to differences in cloud cover, although there is no ground-truth data to confirm this speculation. These differences are not large, and probably do not impact substantially on any changes in primary production that may occur in different seasons in the Gulf of Carpentaria or the Arafura Sea region.

a.



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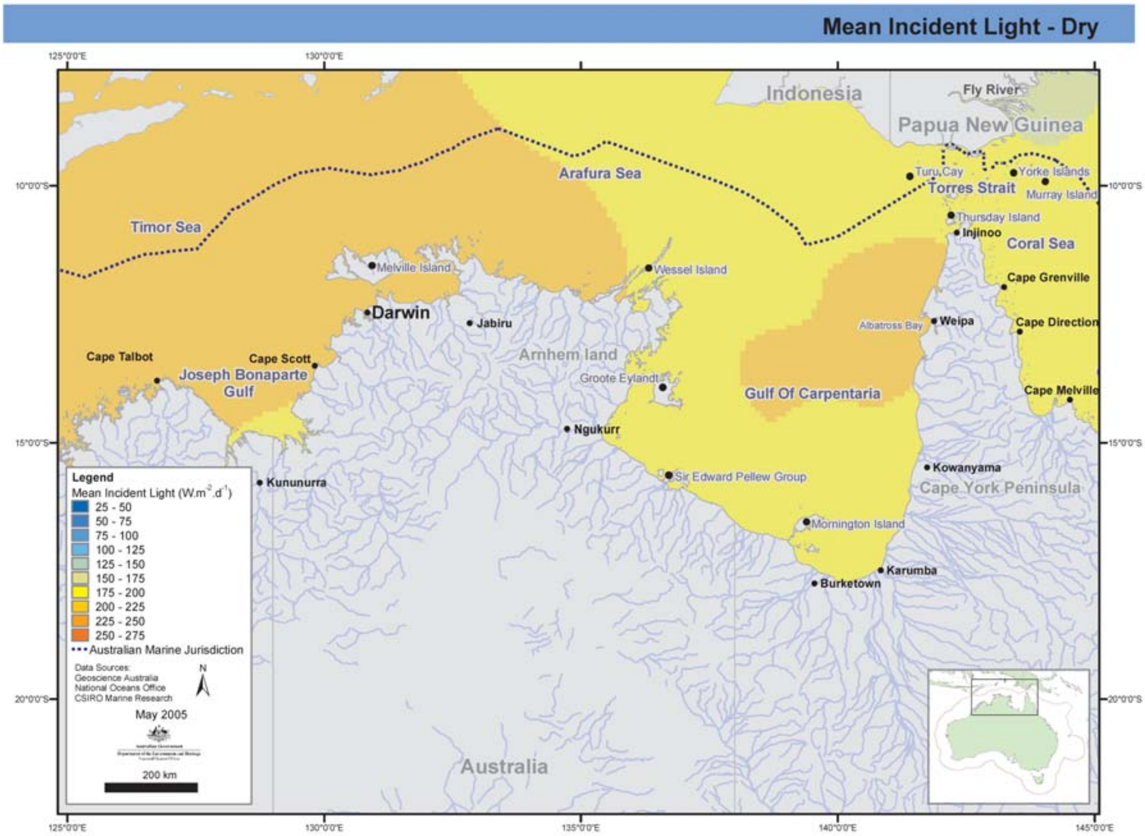


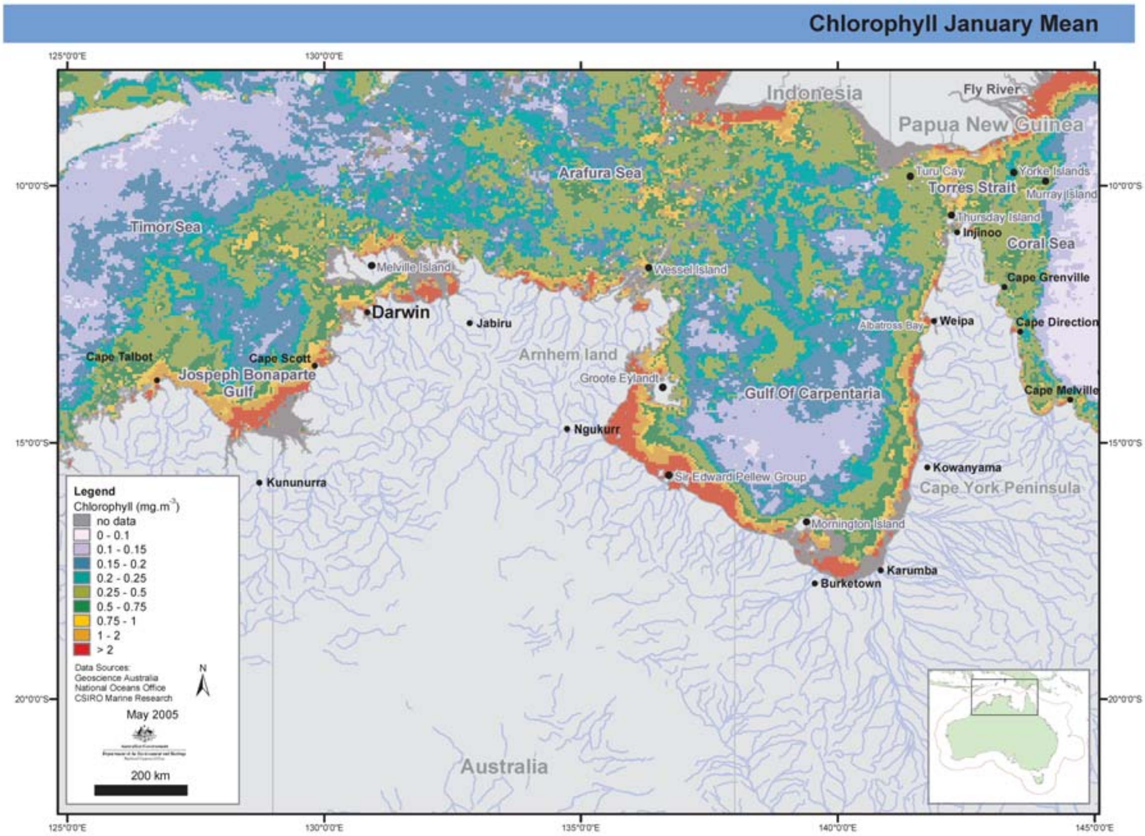
Figure 17. Incident light: (a) Wet season; (b) Dry season

8.2 Chlorophyll distributions

Near-surface chlorophyll patterns have been estimated from MODIS ocean colour satellite data based on 4.5km resolution monthly means processed to Level 3 (Figure 18). During the wet season monthly mean surface chlorophyll is typically around 0.25 mg m^{-3}, although values range from 0.1 mg m^{-3} in the Timor Sea and southern central Gulf of Carpentaria to more than 2.0 mg m^{-3} in parts of the coastal zone (Figure 18a). Values in the coastal zone may be over-estimated due to coloured dissolved organic matter (CDOM) carried by the rivers. Interference from large quantities of suspended sediments and particulate materials brought in by rivers may lead to over- or under-estimates, and there may be further contamination of the satellite signal by bottom reflectance. MODIS satellite chlorophyll values in waters less than 20m deep therefore need to be interpreted with caution. However, these higher chlorophylls do compare favourably with wet season measurement in Albatross Bay on the northeast side of the Gulf of Carpentaria (2.0 to 2.5 mg mL^{-3} in Figure 26). Burford and Rothlisberg (1999) have also shown that a wet season deep chlorophyll maximum is often present in the central Gulf of Carpentaria, suggesting that satellite chlorophyll estimates may not be good predictor of total water column chlorophyll in this region.

Spatial trends are similar during the dry season (Figure 18b), but values are typically 0.25 to 0.5 mg m^{-3} higher than during the wet season (with the same caveats about high apparent chlorophylls in inshore waters). Another significant difference, at least in the Gulf of Carpentaria, is that the water column is well mixed during the dry season and chlorophyll concentrations are uniform throughout the water column (Burford and Rothlisberg 1999). This implies higher standing stocks of chlorophyll, and higher primary production during the dry season.

a.



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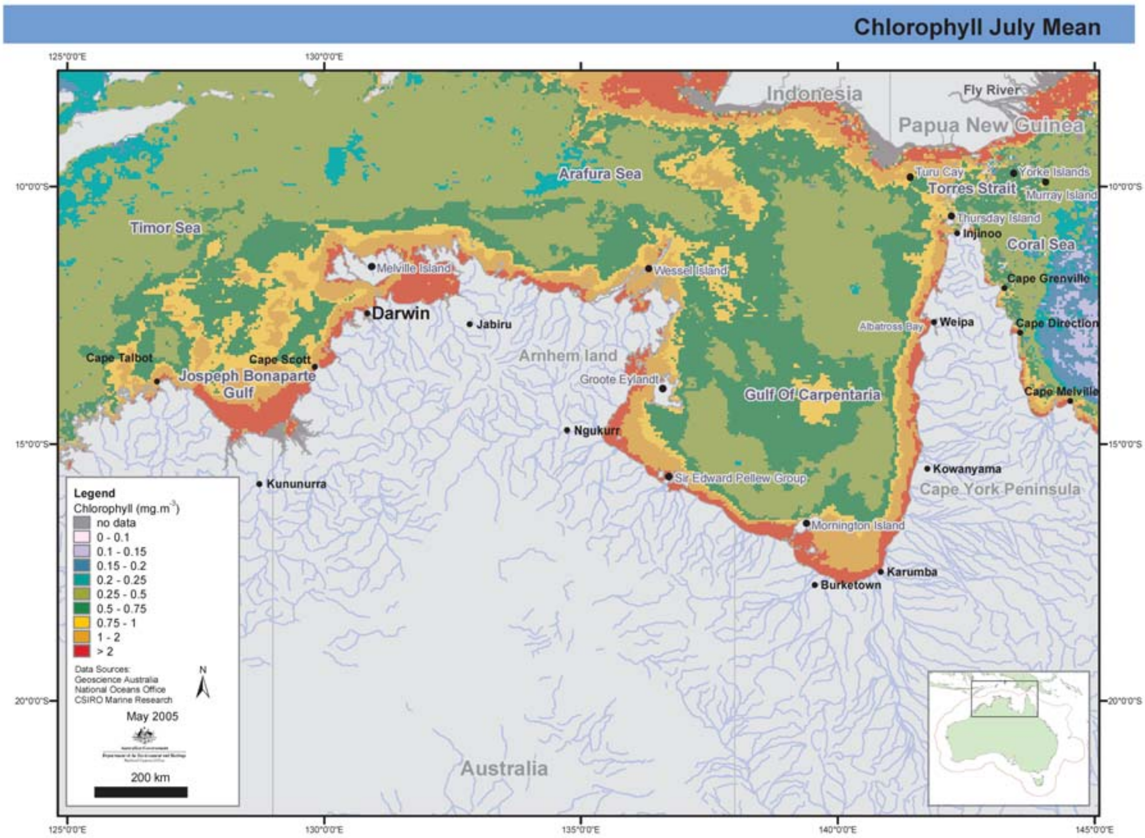


Figure 18. MODIS remotely sensed monthly mean chlorophyll: (a) January; (b) July. MODIS satellite chlorophyll values in waters less than 20m deep need to be interpreted with caution because of interference from coloured dissolved organic matter, particulate matter and suspended sediments brought into the near-shore regions by river inflow.

8.3 Primary Production

Primary Production may be estimated from the satellite chlorophyll measurements, although there is significant uncertainty in these estimates unless adequate *in situ* data is available for calibration. While *in situ* data is available from the Gulf of Carpentaria (Table 1; data from Burford and Rothlisberg, 1999), there is little available for other parts of the NLMD. As noted above, MODIS satellite chlorophyll values in waters less than 20m deep need to be interpreted with caution: the primary production estimates resulting from, and that rely on, these chlorophyll estimates must also be interpreted with caution.

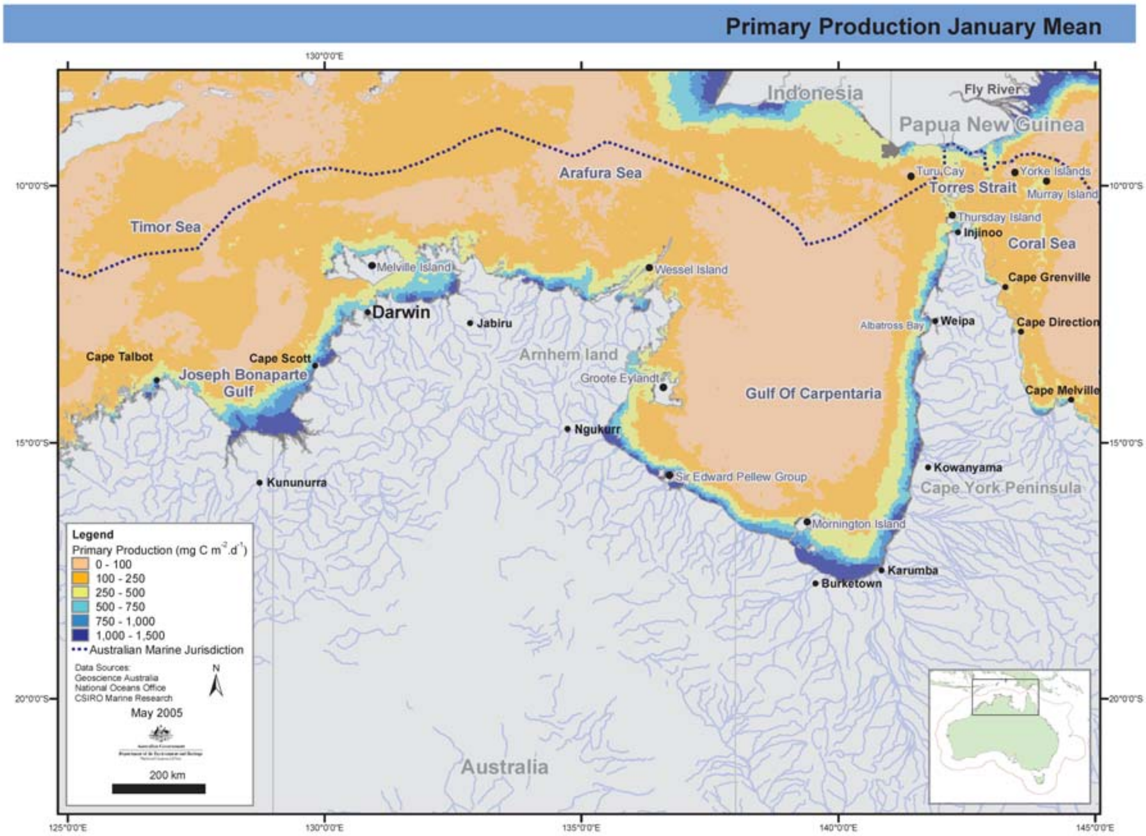
During the wet season, the estimated depth-integrated primary production is low in the central Gulf of Carpentaria (0 to 100 mg C m^{-2} d^{-1}) grading up to 1500 mg C m^{-2} d^{-1} in the coastal zone. The near-shore estimates agree reasonably well with *in situ* values of 950 mg C m^{-2} d^{-1} (Table 1; data from Burford and Rothlisberg 1999). However, further offshore, the measured rate of 995 mg C m^{-2} d^{-1} was largely associated with a deep chlorophyll maximum and therefore not captured by ocean colour satellites.

During the dry season, mean productivities estimated from satellites are a little higher (100 to 250 mg C m^{-2} d^{-1}) than in summer because of the higher chlorophyll concentrations. However, these estimates are still less than half the measured *in situ* rate of 557 mg C m^{-2} d^{-1} (Table 1; data from Burford and Rothlisberg 1999).

Table 1. *In situ* measurements of chlorophyll-*a* concentration and primary productivity in the wet and dry season at both coastal and offshore stations in the Gulf of Carpentaria (data from Burford and Rothlisberg 1999). In each case, n represents the number of samples.

	Wet season	**Dry Season**
Coastal		
Water column	Well mixed	Well mixed
Integrated production	950 mg C m^{-2} d^{-1} (n=5)	740 mg C m^{-2} d^{-1} (n=3)
Chlorophyll concentration	14.3 mg C m^{-2} (n=5)	12.2 mg C m^{-2} (n=3)
Offshore		
Water column	Stratified	Well mixed
Integrated production	995 mg C m^{-2} d^{-1} (n=7)	557 mg C m^{-2} d^{-1} (n=3)
Chlorophyll concentration	16.8 mg C m^{-2} (n=7)	32.9 mg C m^{-2} (n=3)

a.



b.

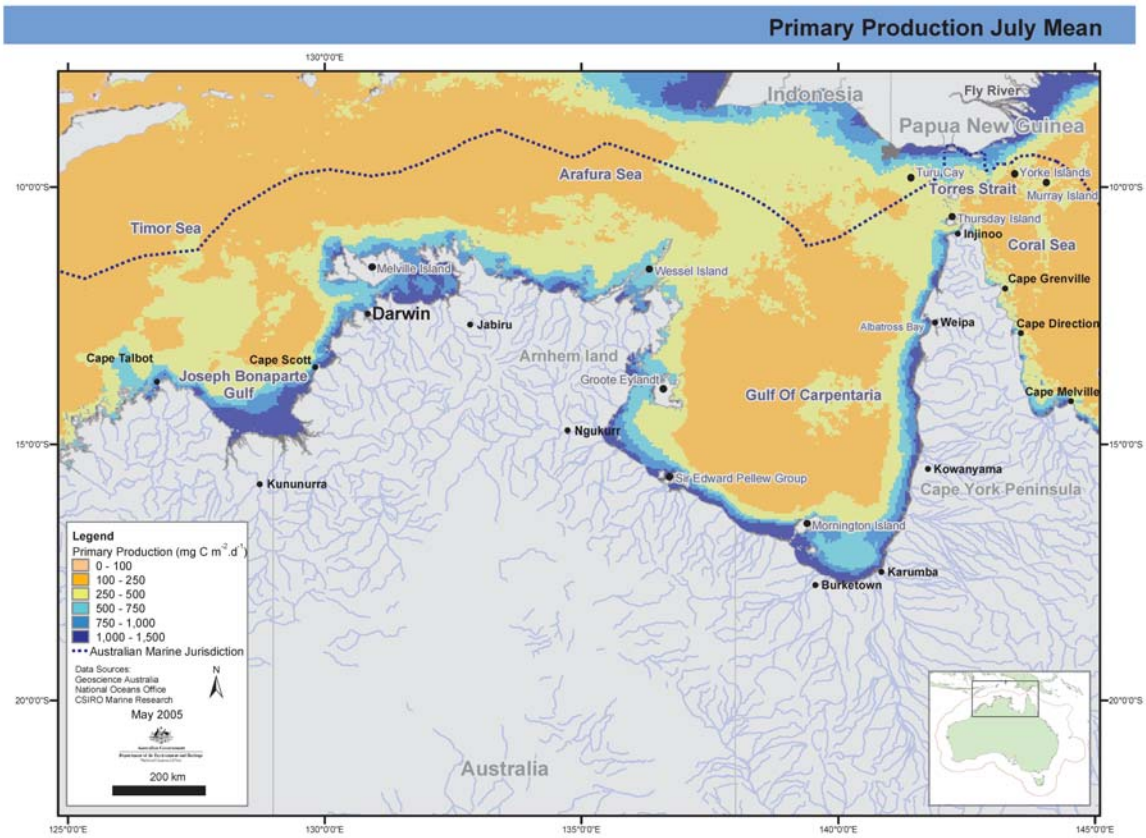


Figure 19. MODIS Mean near-surface primary productivity: (a) Wet season (January); (b) Dry season (July). In waters less than 20m deep, primary production estimates based on MODIS satellite chlorophyll values need to be interpreted with caution because of interference from coloured dissolved organic matter, particulate matter and suspended sediments brought into the near-shore regions by river inflow.

9. Zooplankton

Fish sampling from the RV *Southern Surveyor* in the Gulf of Carpentaria, March 2005 ©CSIRO

Available information on zooplankton is limited to the Gulf of Carpentaria. Descriptions are based on results from 10 voyages undertaken over a 20 month period from August 1975 to May 1977 (Rothlisberg and Jackson 1982). Samples were taken over a station array covering most of the Gulf (Figure 20). Paired bongo nets (0.5 m by 0.5 m mouth openings with 142 µm and 500 µm meshes) were deployed simultaneously by lowering them to the bottom and towing from bottom to top in a stepped oblique profile. A time-depth recorder was fitted to the net to measure the depth of the tow. The net mouth was fitted with a calibrated flowmeter to calculate density and then standardised to the number per unit area by multiplying by the sample depth (Kramer *et al*. 1972).

All samples were preserved in formaldehyde and divided using a Folsom plankton splitter (McEwen *et al*. 1954), with half of the sample committed to destructive biomass estimation. These samples were oven dried to 70°C for 1 - 2 days before being weighed to the nearest 0.01 g.

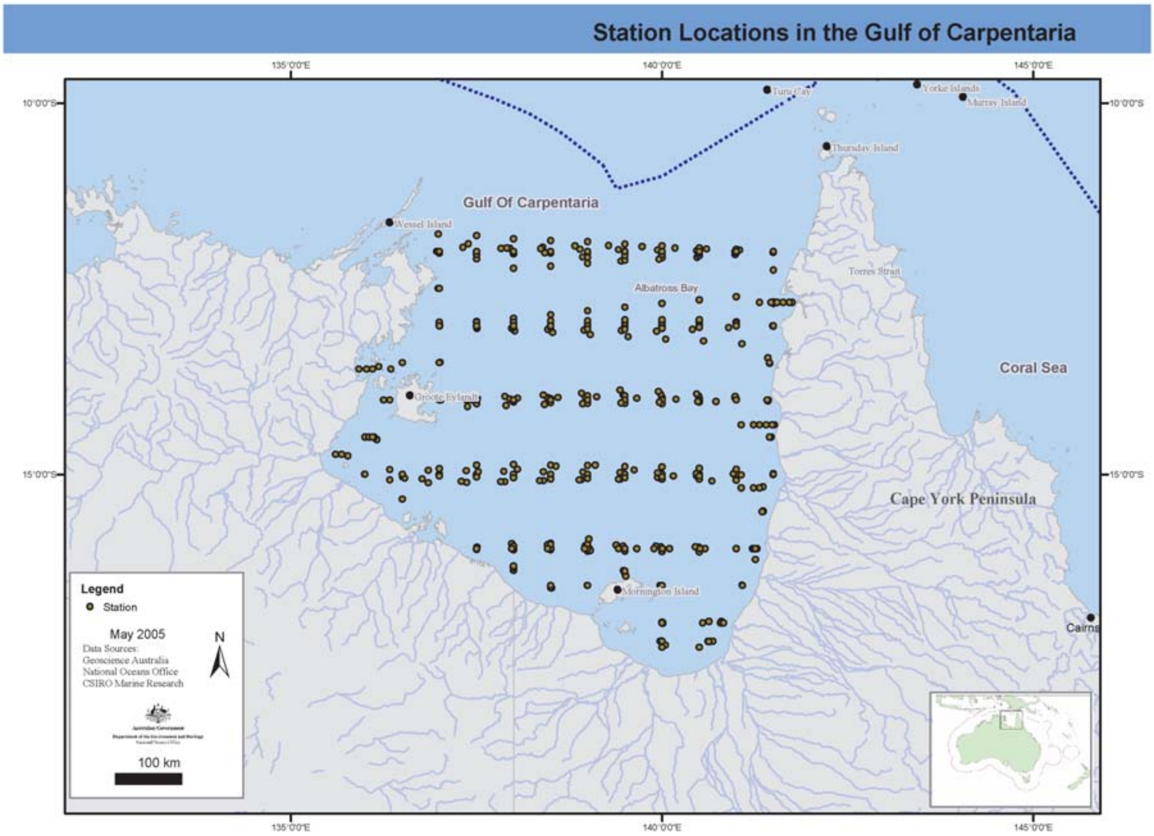


Figure 20. Gulf of Carpentaria sampling array for zooplankton and larval penaeid prawns Data collected from 15 cruises (9 in the dry season and 7 in the wet season) over 3 years (1975-1978).

9.1 Zooplankton total biomass

The mean zooplankton biomass from the fine 142 µm mesh net after averaging over all 10 cruises was found to be 1.88 g (dry weight) m^{-2} (Rothlisberg and Jackson 1982). For Australian waters this is a very high value and compares with abundances found in seasonal upwelling areas south of Java and off the North West Shelf of Australia. During the wet season, the highest biomasses were measured on the eastern side of the Gulf, peaking in the southeast, and in the northwest around Cape Arnhem (Figure 21a). During the dry season, biomass was generally low in the south and high in the deeper offshore waters of the northeast Gulf (Figure 21b). Peak biomasses exceeded 8 g m^{-2} in both seasons.

9.2 Prawn larval density

In tropical Australia there are a suite of genera in the prawn family Penaeidae: *Penaeus*, *Metapenaeus, Metapenaeopsis, Parapenaeopsis, Atypopenaeus,* and *Trachypenaeus*, all of which are common across the entire Indo-west Pacific (Racek and Dall 1965). However, there are also a number of species that are endemic to Australia, such as *Penaeus esculentus* and *Metapenaeus endeavouri* (Rothlisberg and Jackson 1987, 1994, Rothlisberg *et al*. 1983, 1985, 1987).

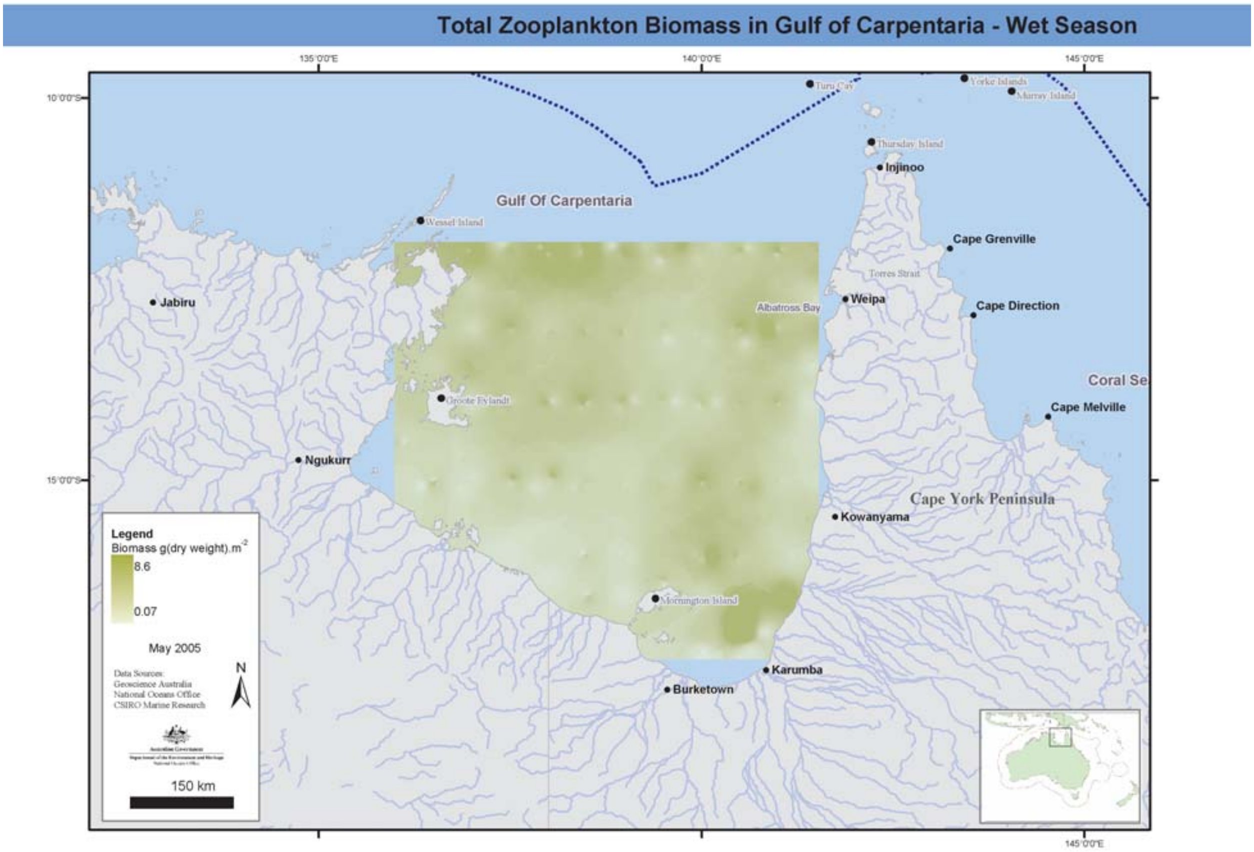
Adult tiger prawn

Penaeid larval abundances in excess of 300 m^{-2} have been measured during both the wet and dry seasons (Figure 22). The highest abundances during the wet season are largely coastal with hot spots in the northeast off Weipa, in the southeast north of Karumba, in the southwest offshore of the Sir Edward Pellew Group (Vanderlins), and in the northwest around Cape Arnhem (Figure 22a). During the dry season, the Weipa hotspot persists, while others were found north of Groote Eylandt and in the northern central Gulf (Figure 22b).

The vast majority of the larvae are from small non-commercial species such as *Metapenaeopsis* spp., *Parapenaeopsis* spp., *Trachypenaeus* spp., *Atypopenaeus* spp., and non-commercial species of *Metapenaeus* such as *M. eboracensis* and *M. insolitus* (Jackson *et al*.1989). Larval abundances of commercial species, such as *Penaeus* spp. and *Metapenaeus* spp., are much lower with peaks in the range 30 to 75 m^{-2} (Figure 23). They are also highly localised, with wet season hotspots north of the Vanderlins and off Weipa (Figure 23a) and dry season hotspots north of Groote Eylandt (18 to 33 m^{-2}), off Weipa (33 to 50 m^{-2}), and south of Mornington Island (50 to 75 m^{-2}) (Figure 23b).

Commercially important species of penaeid prawns are also distributed in shallow water (<40 m) around the coast of the Gulf of Carpentaria (Figure 24 a & b). The predominant species making up the commercial catch are the banana prawn (*Penaeus merguiensis*), the brown tiger prawn (*P. esculentus*) and the grooved tiger prawn (*P. semisulcatus*). In the wet season hot spots of commercial catch are on the eastern side of the of the Gulf; corresponding to large banana prawn catches, and a smaller hot spot of tiger prawns north of Groote Eylandt (Fig. 24a). In the dry season the hot spots are more widespread including Albatross Bay, north of Mornington Island, near the Vanderlins, and both north and south of Groote Eylandt (Fig. 24b). These correspond to the two species of tiger prawns. Larval abundances (Fig. 23 a & b) in both the wet and dry represent small portions of the commercial catch that are reproductively active and correspond to most of the hot spots – with a particularly good overlap in the dry season.

a.



b.

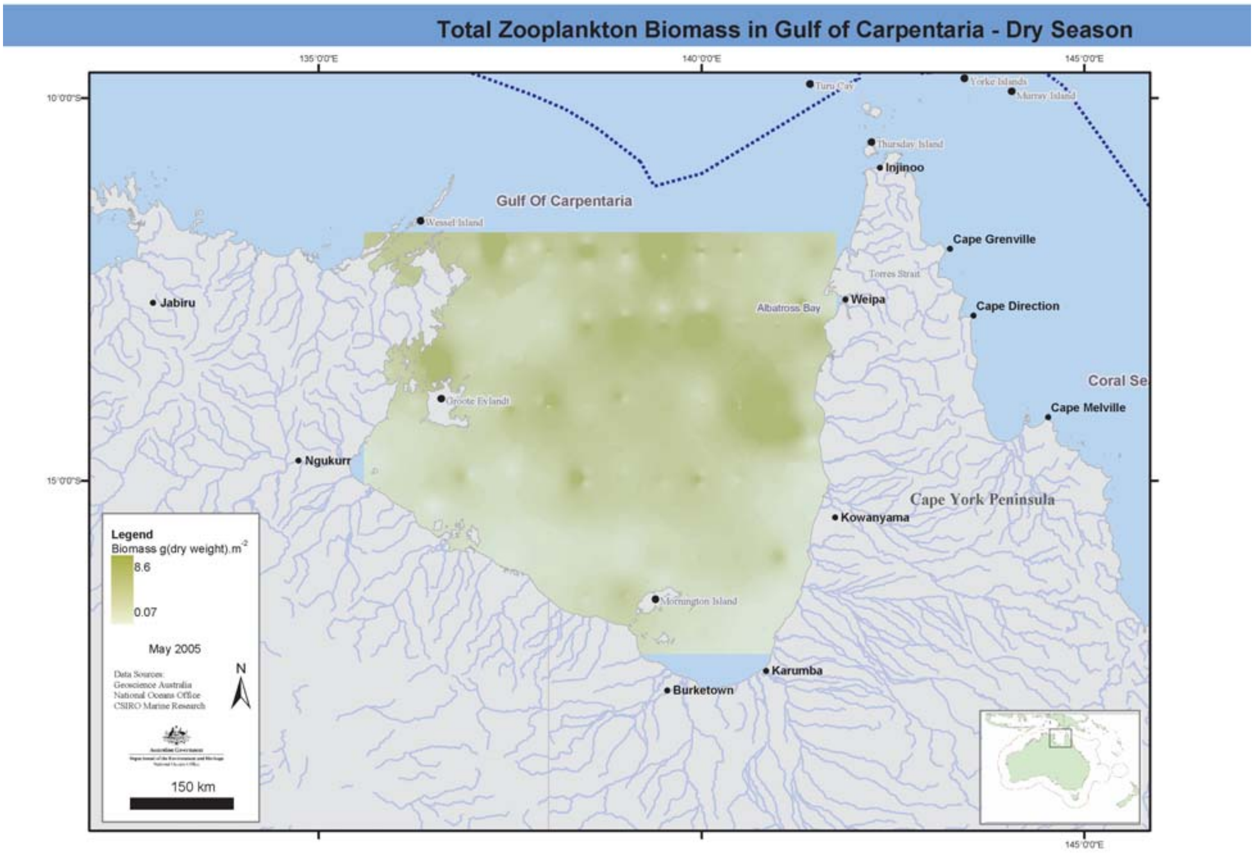
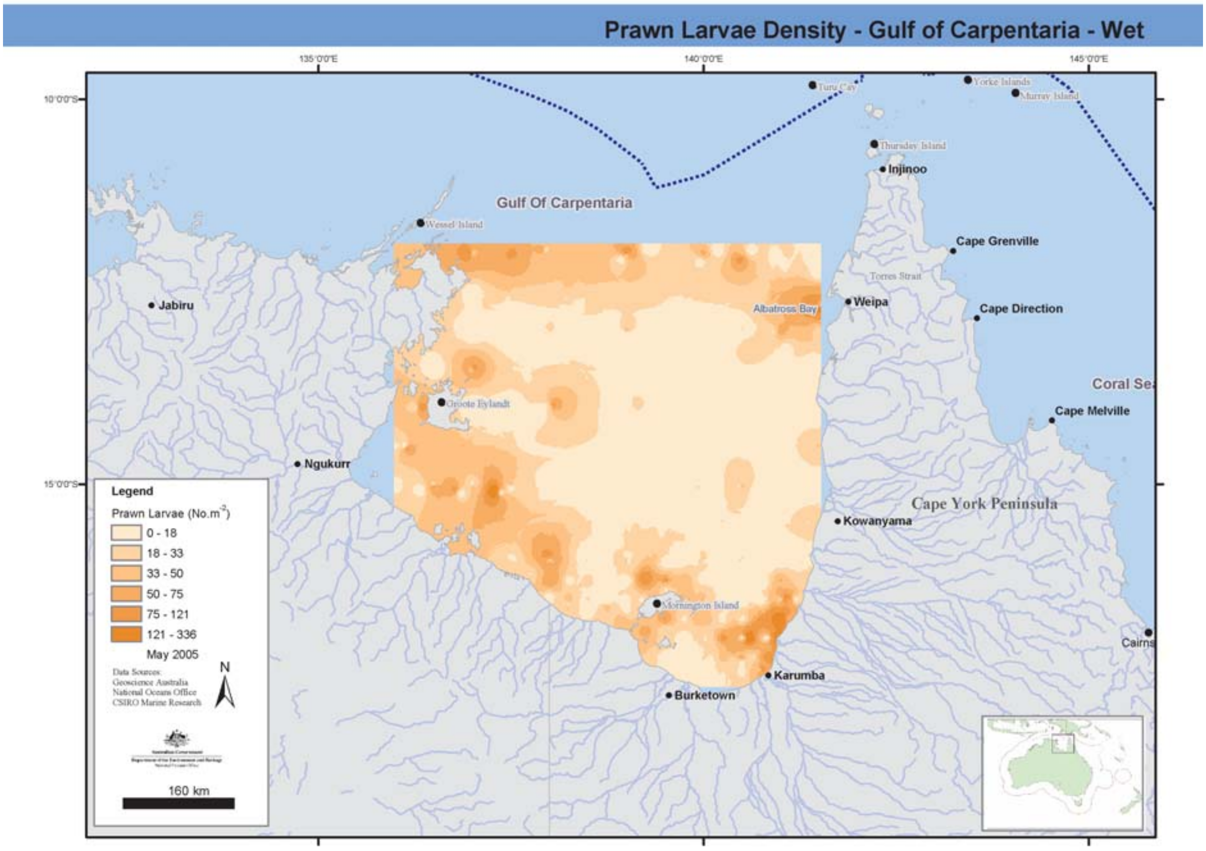


Figure 21. Total zooplankton biomass g (dry weight) m^{-2} : (a) Wet season; (b) Dry season. Data collected from 10 cruises (6 in the dry season and 5 in the wet season) over 3 years (1975-1977).

a.



b.

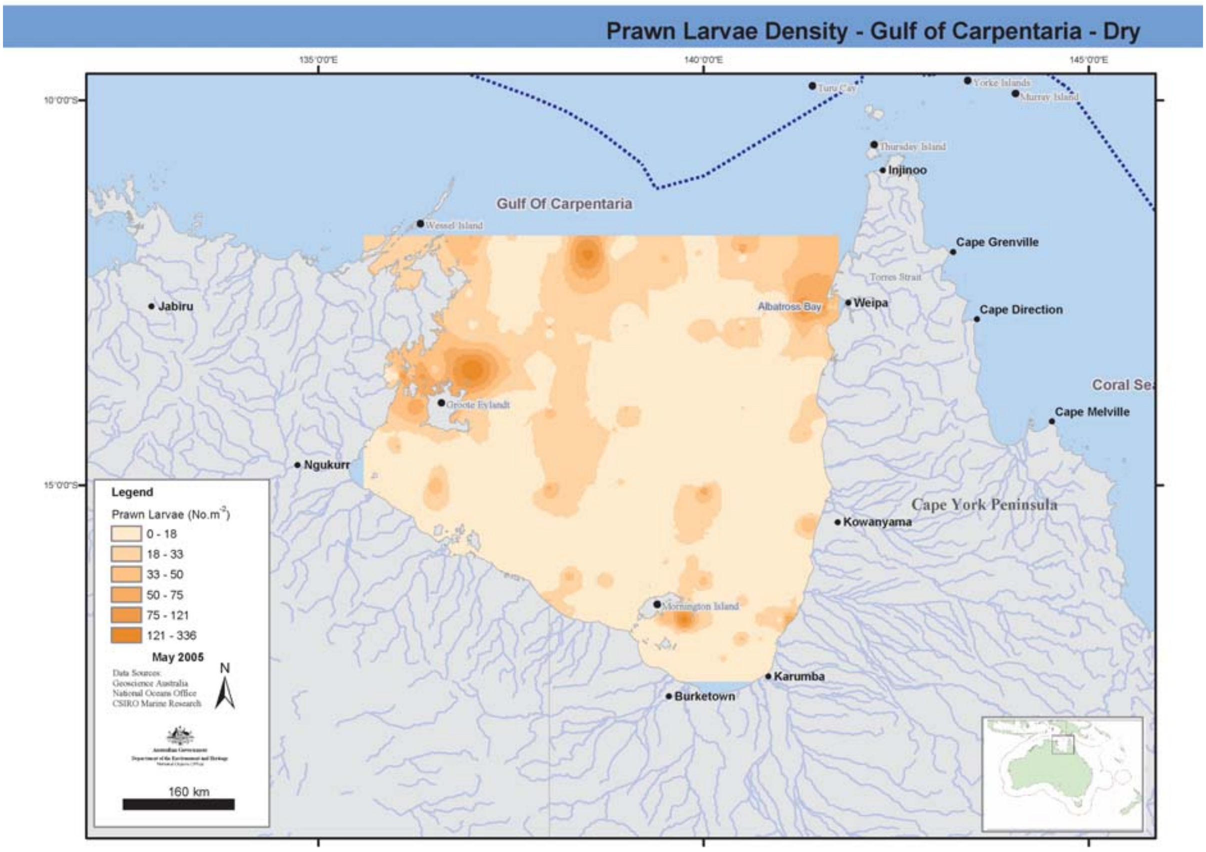
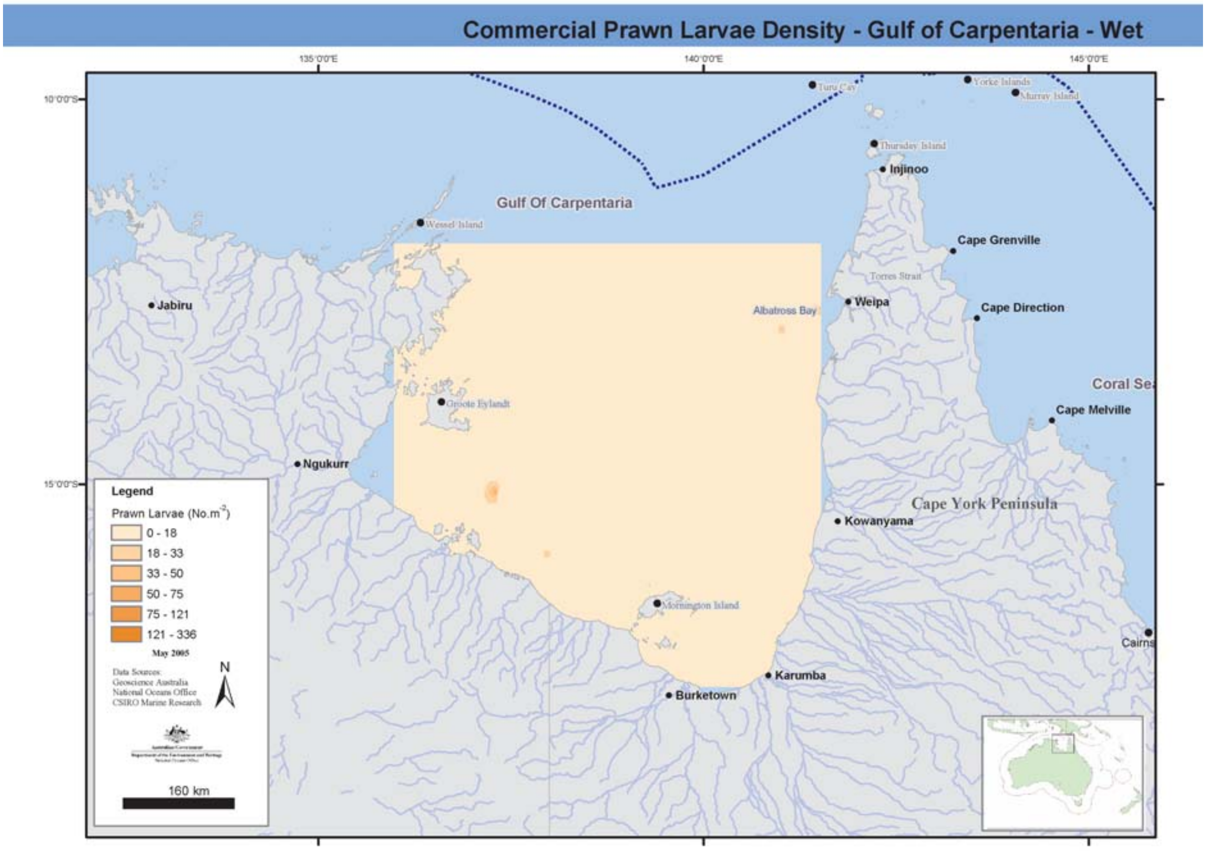


Figure 22. Penaeid prawn larval density (larvae m^{-2}) for all species combined: (a) Wet season; (b) Dry season

a.



b.

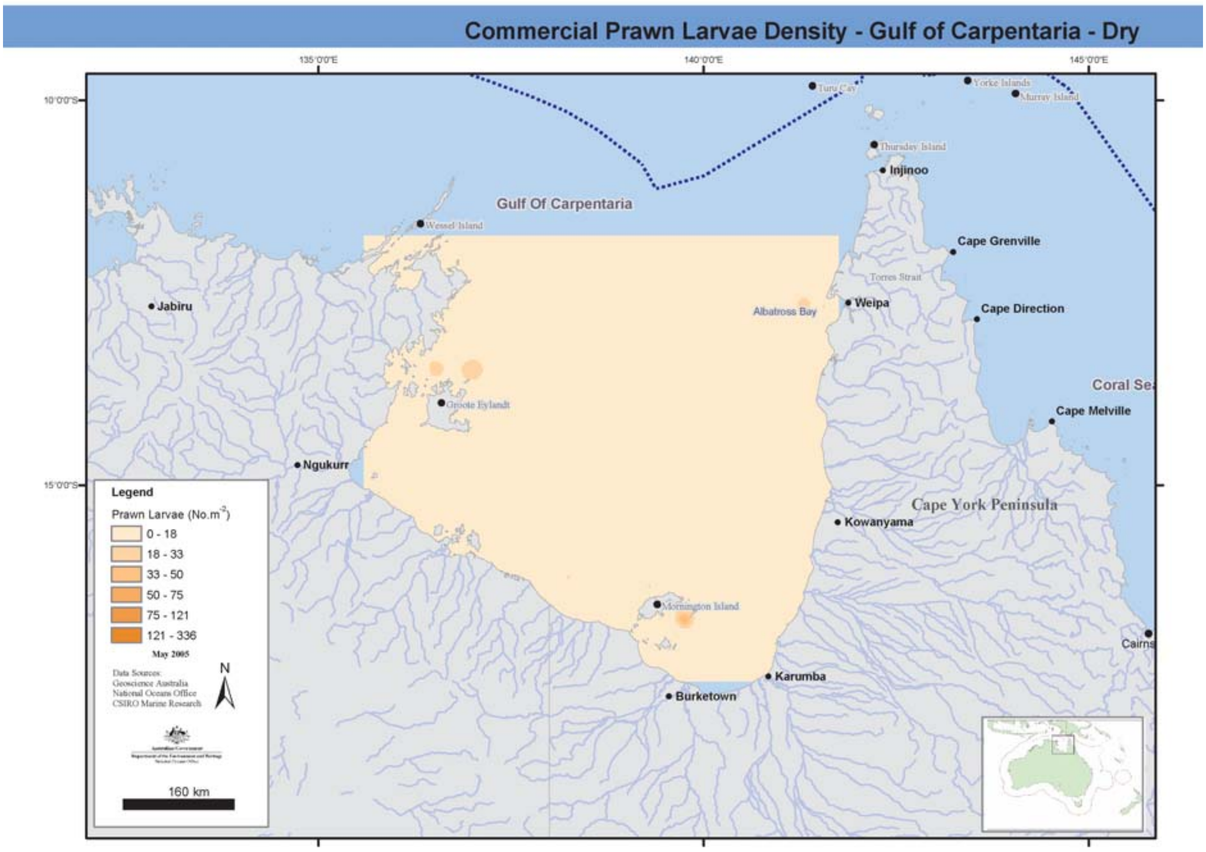
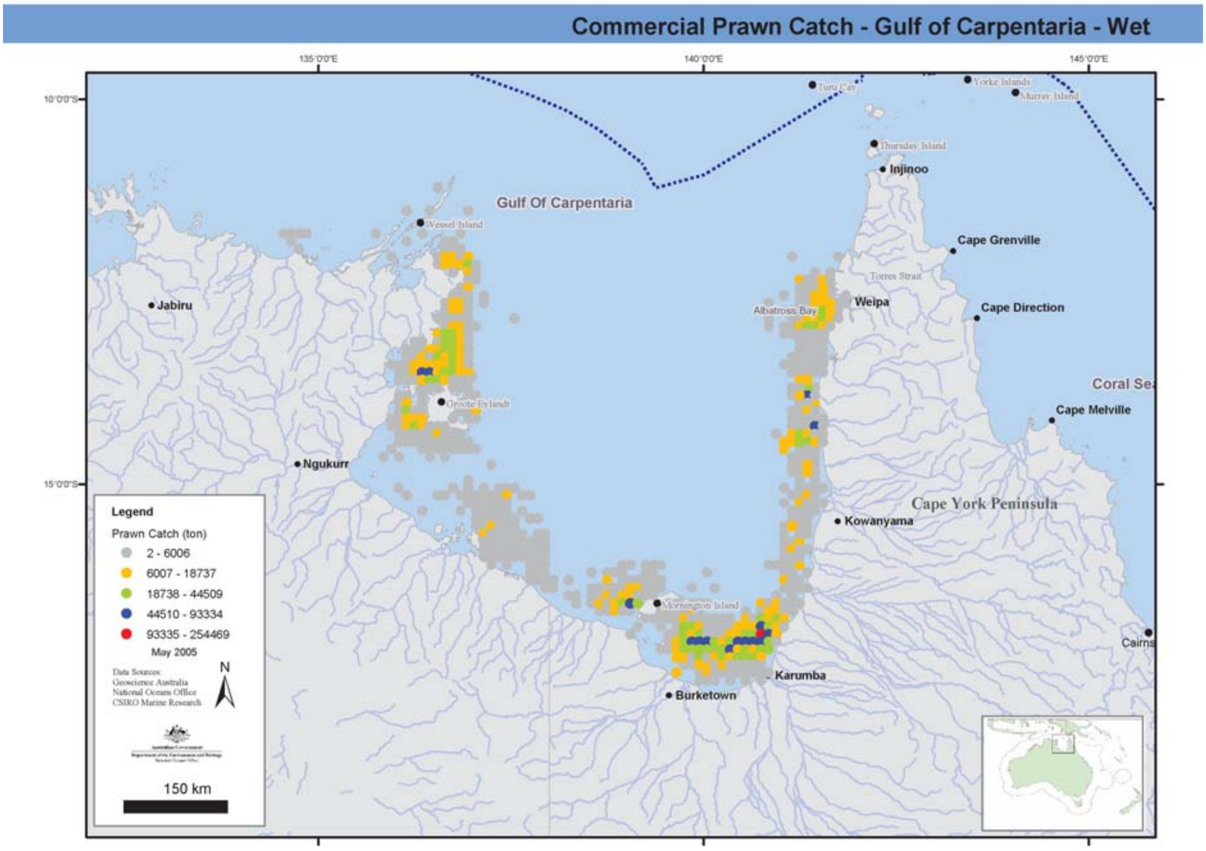


Figure 23. Commercial penaeid prawn larval density (larvae m^{-2}): (a) Wet season; (b) Dry season.

a.



b.

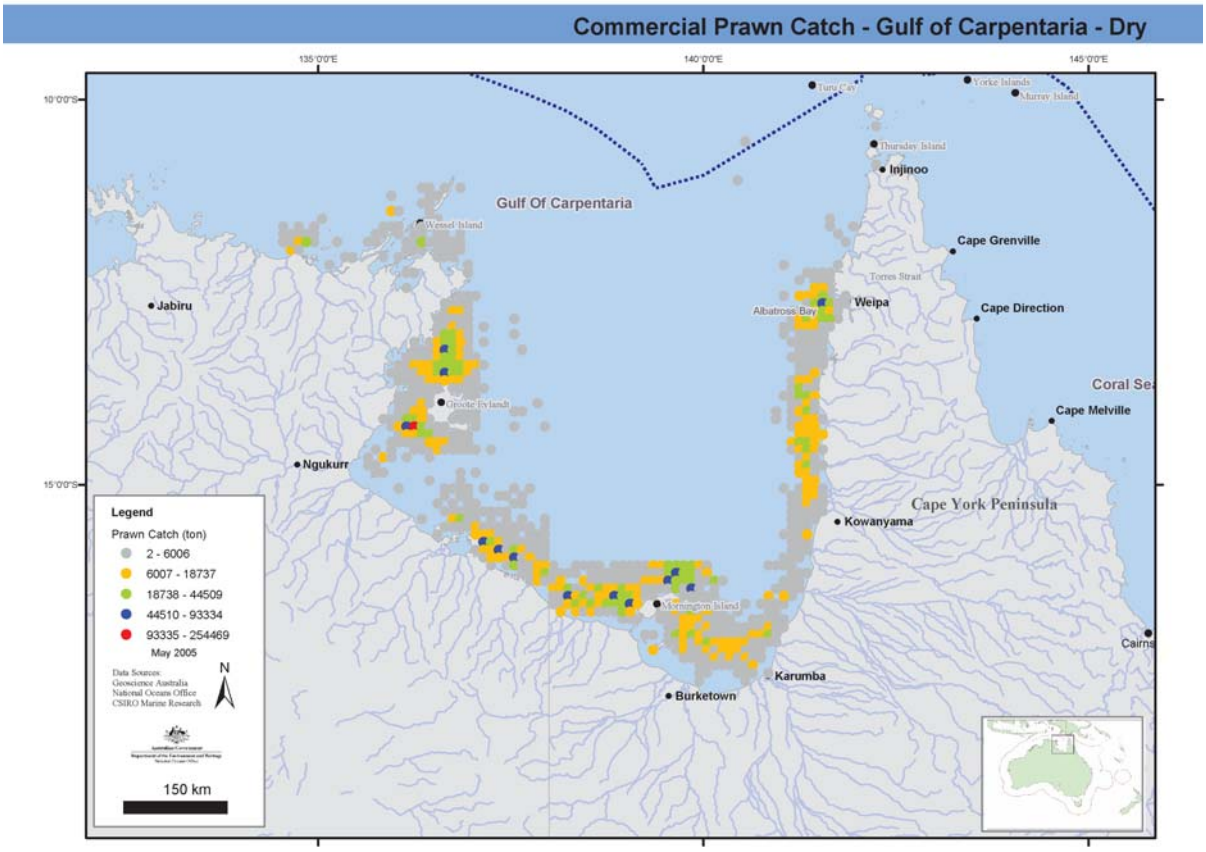


Figure 24. Commercial penaeid prawn catch (ton) for years 1975 - 1977: (a) Wet season; (b) Dry season.

10. Albatross Bay case study

The Albatross Bay Region in the north-eastern Gulf of Carpentaria supports localised fisheries for three species of commercially important penaeid prawns: banana prawns (*Penaeus merguiensis*), brown tiger prawns (*P. esculentus*) and grooved tiger prawns (*P. semisulcatus*). It is one of the few places in northern Australia where all three species co-occur. For this reason the area was chosen for an extensive study by CSIRO from 1986 to 1992. Over these 6 years, larval, juvenile and adult prawns, as well as phytoplankton and zooplankton were sampled on a lunar-monthly basis (Figure 25). This dataset provides rare coverage of both seasonal and inter-annual variability of biological and hydrographic parameters from tropical Australia. The following account summarizes key spatial and temporal aspects of that study.

Aerial shot of Weipa Seagrass (used with permission of the Department of Primary Industry, Queensland Government)

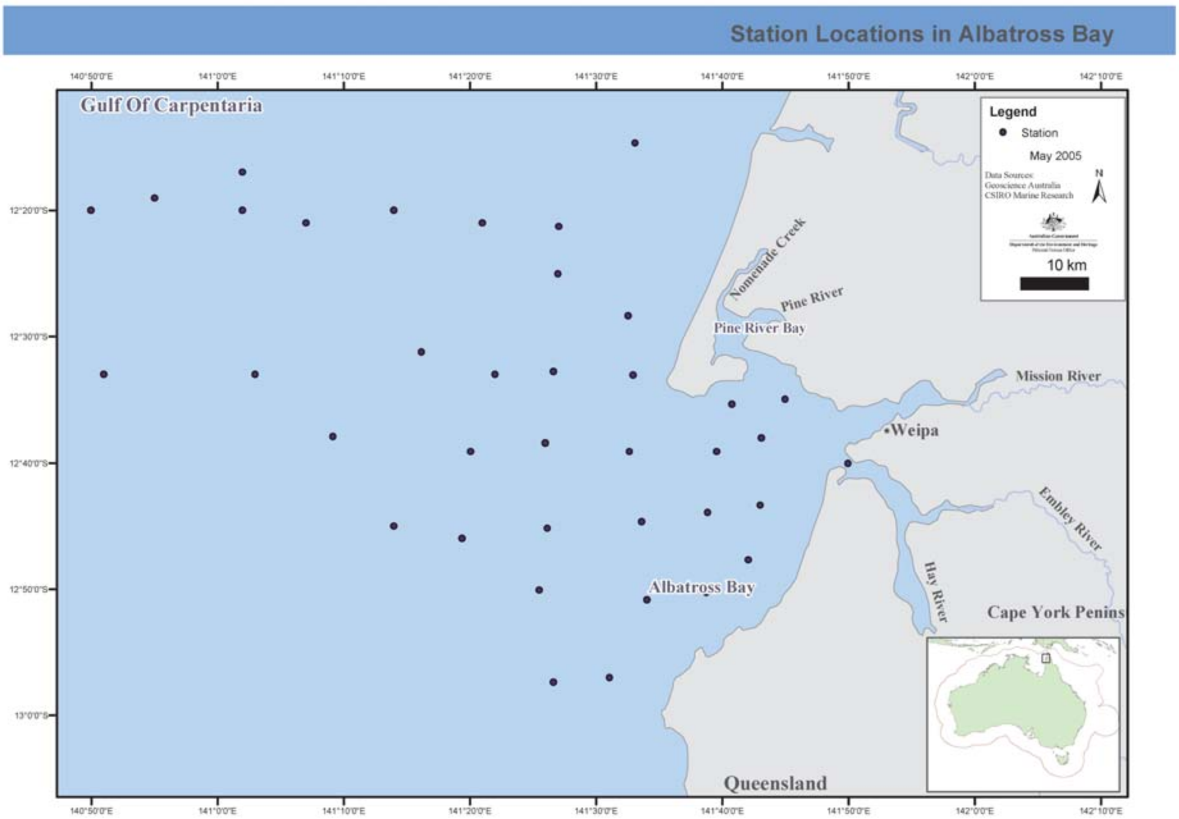


Figure 25. Albatross Bay sampling station array for zooplankton and penaeid prawn larvae Data collected from 66 cruises (29 in the dry season and 39 in the wet season) over 6 years (1986-1992).

10.1 Phytoplankton

Burford *et al*. (1995) used a 37 µm net to sample phytoplankton at four stations in the Albatross Bay region during the 6 year study (Figure 26). Ten fields of view were examined for each sample, and phytoplankton taxa were classified into three abundance categories following Hallegraeff and Jeffrey (1984):

- dominant – genus seen in every field of view
- common – present in more than 5 fields, but less than dominant genera
- rare – present in no more than 5 fields of view.

They found little evidence of seasonal succession amongst the 72 genera counted over the 6 year study (Burford *et al*. 1995). The most dominant genus by frequency of occurrence were: *Trichodesmium* (cyanobacteria), *Rhizosolenia* (diatoms) and *Protoperidinium* (dinoflagellates) (Figure 25). *Protoperidinium* (dinoflagellates) were relatively rare and only appeared in the two offshore stations during the wet season. The diatom *Rhizosolenia* was most abundant at the two stations close to shore and was dominant in the dry season. *Trichodesmium* (cyanobacteria) had the most pronounced seasonal changes in frequency of occurrence. It was most frequent during the wet season and dominated three of the four stations, especially offshore, during the wet season (Burford *et al*. 1995).

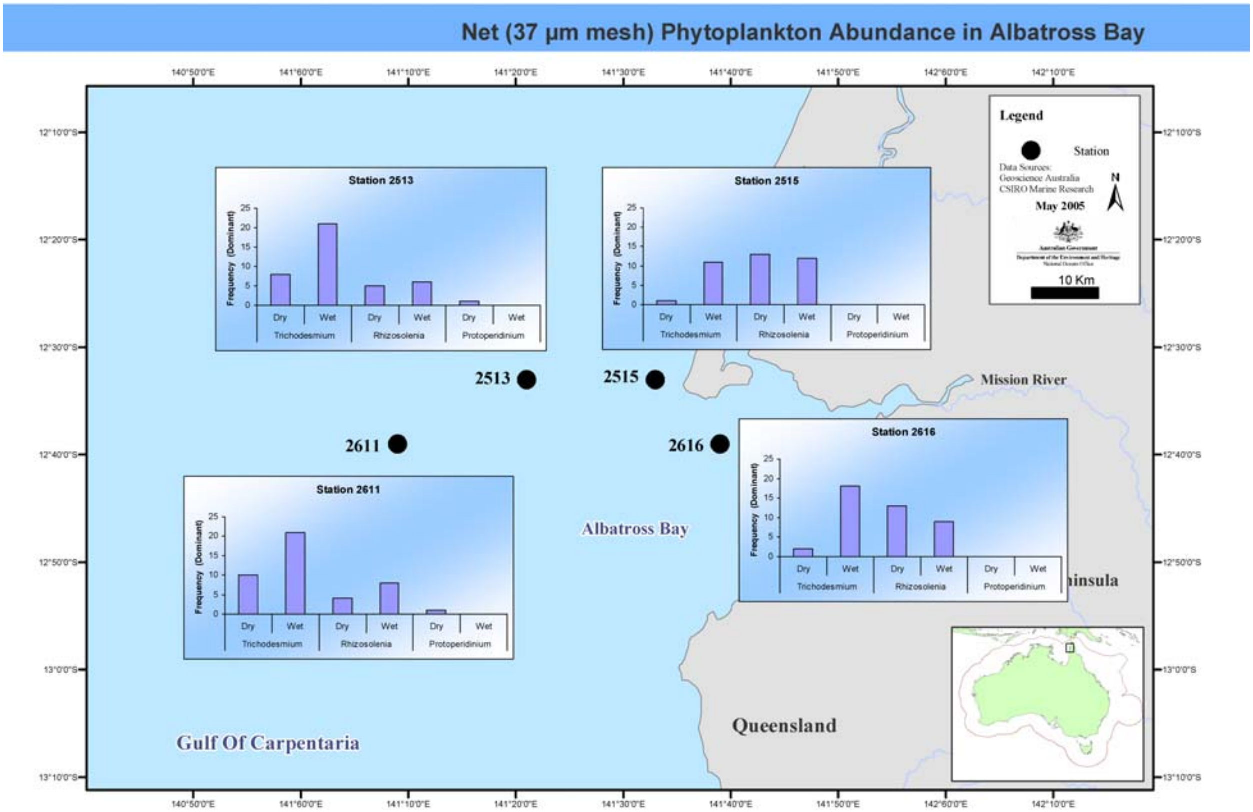


Figure 26. Frequency of occurrence of three dominant phytoplankton taxa (*Trichodesmium*, *Rhizosolenia* and *Protoperidinium*) at four stations in the wet and dry seasons. Data collect from 63 cruises (28 in the dry season and 35 in the wet Season) over 7 years (1986-1992).

10.2 Chlorophyll-*a* concentrations

The mean monthly chlorophyll-*a* concentrations at the four Albatross Bay stations are shown in Figure 27. Concentrations were highest (2.0 to 5.7 mg m^{-3}) in the wet season at the inshore sites, and high chlorophyll values usually coincided with low salinities (30 to 33 ppt) and high temperatures (29 to 32°C) (Burford *et al*. 1995). At the offshore sites, concentrations were lower (0.2 to 2.0 mg m^{-3}) and did not vary seasonally.

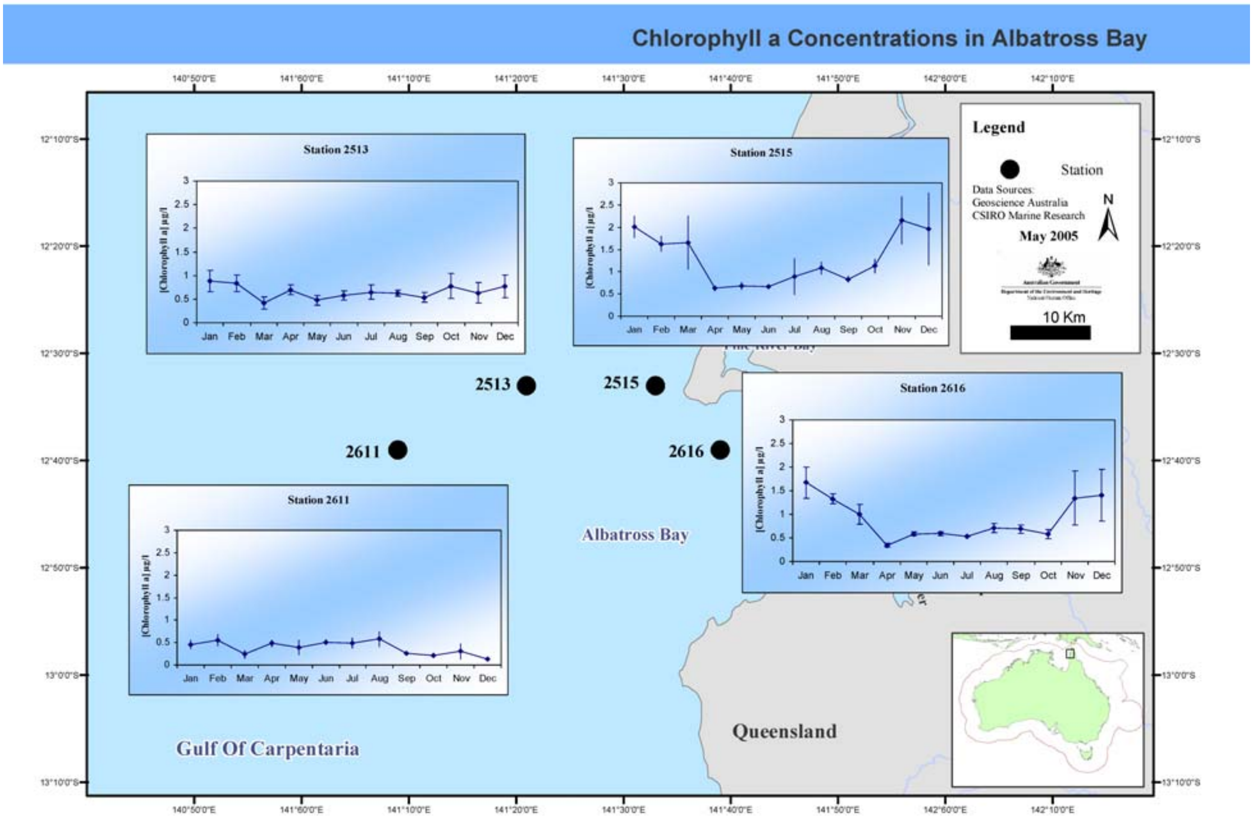
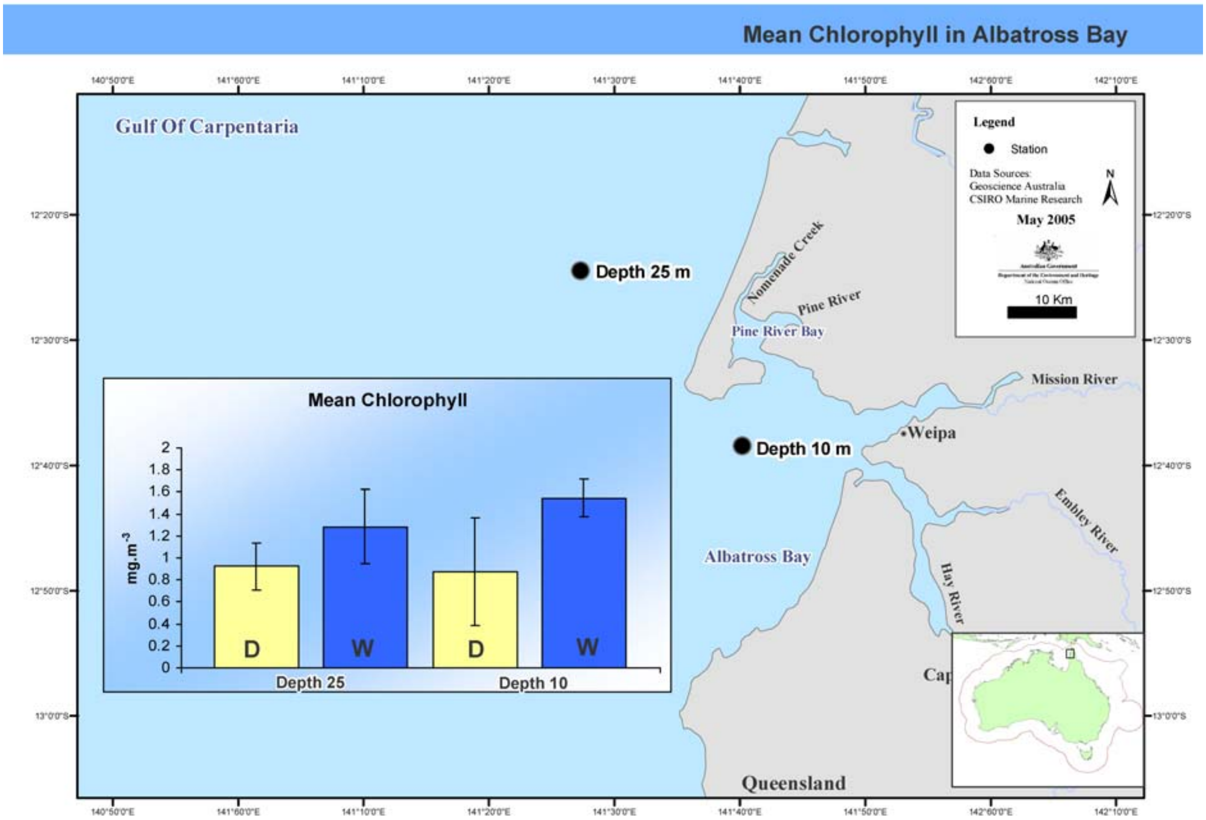


Figure 27. Chlorophyll-*a* concentrations – mean monthly values from 4 stations.

10.3 Primary productivity

Primary productivity was measured on seven cruises covering five wet seasons and two dry seasons (Burford and Rothlisberg 1999). Two near-shore stations were used; one inside Albatross Bay in 10 m of water and one outside in 25 m of water (Figure 28). The levels of chlorophyll and primary productivity were comparable at each station (Figures 28a and 28b). The levels of chlorophyll were higher in the wet season (1.3 to 1.5 mg m^{-3}) than in the dry season (0.9 mg m^{-3}) (Figure 28a) and are comparable with monthly mean chlorophyll levels at the stations shown in Figure 27. Primary productivity was also higher in the wet season (ca. 800 mg C m^{-2} d^{-1}) than in the dry season (ca. 650 mg C m^{-2} d^{-1}). However, these differences are probably not statistically significantly different given the degree of variation seen at the sites (indicated by error bars in Figure 28b). Unfortunately, the ocean colour satellite data does not have the spatial resolution to assist in making further generalisations about chlorophyll distribution and primary production estimates in Albatross Bay.

a.



b.

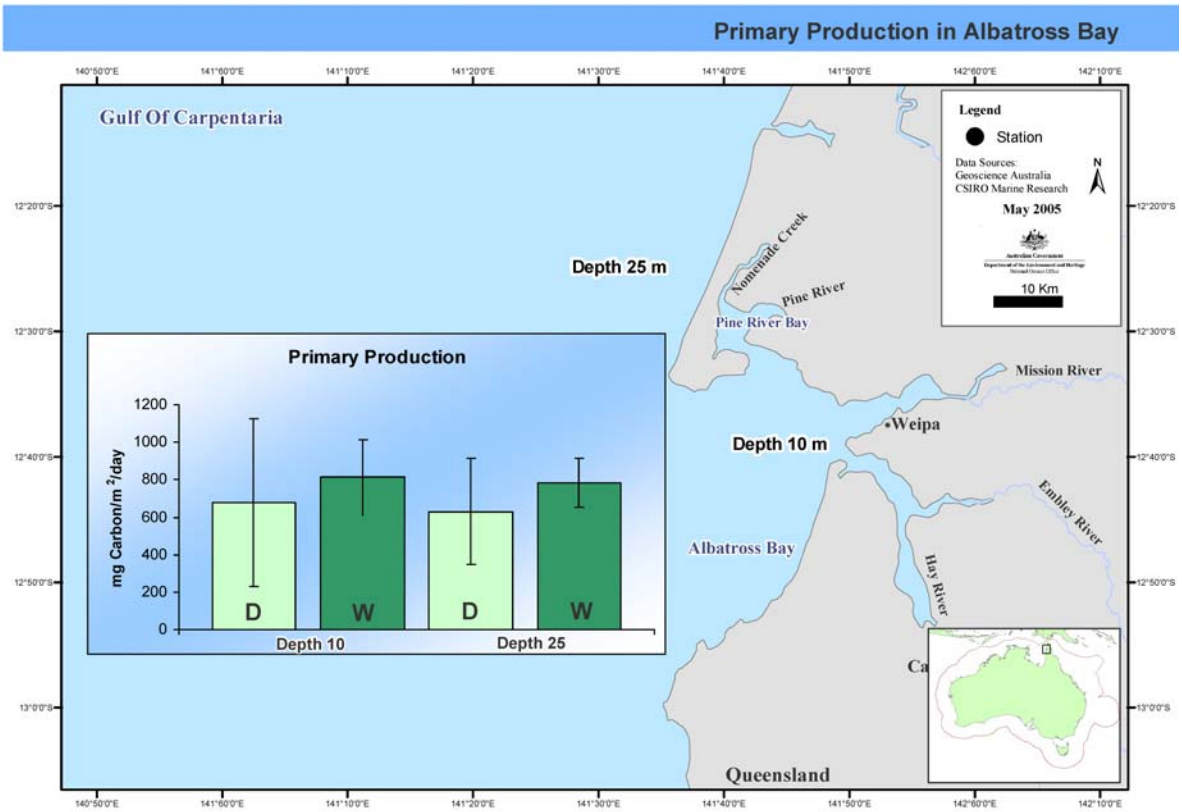


Figure 28. Albatross Bay mean chlorophyll-*a* and primary productivity at two stations: (a) mean chlorophyll-*a* (mg m^{-3}); (b) mean primary productivity (mg Carbon m^{-2} d^{-1}).

10.4 Zooplankton biomass

Zooplankton dry weight biomass estimates were determined by the methods described in Section 9 (Rothlisberg and Jackson 1982). Wet season biomass was highest (7.55 g m^{-2}) approximately 30 km offshore of the northern tip of Albatross Bay (Figure 29a). This region was also a relative hotspot in the dry season, although comparable patches were scattered across the sampling area out to 110 km offshore (Figure 29b). Inside the Bay, zooplankton biomass was comparatively low, reaching a minimum during the dry season.

10.5 Copepod abundance

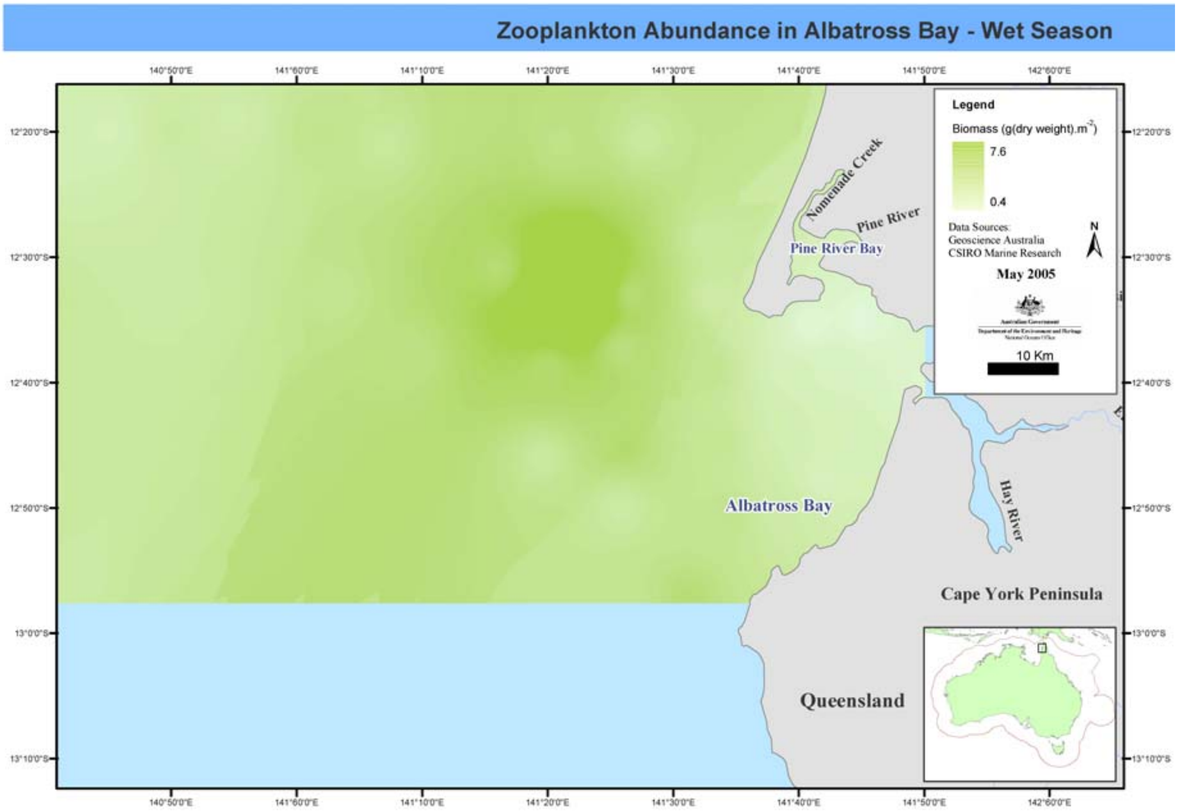
Copepods are a diverse group of small crustaceans and form a particularly important component of the zooplankton. They represent the most numerous multi-celled animals in the sea and are an important link in the food chain between microscopic phytoplankton cells and juvenile fish.

A copepod

A subset of five of the Albatross Bay plankton sampling stations were analysed for detailed copepod species abundance (Figure 30). The samples have not been thoroughly analysed and only summary data is presented here. However, in a similar copepod study of 23 Gulf of Carpentaria stations 102 species were found, 68 in the sub-order Calanoidea, 30 Cyclopoidea, 4 Harpacticoidea, and 13 species that were new to science (Othman 1986, Othman *et al*. 1990). In the Albatross Bay data set there are known to be an additional 10 to 12 new species yet to be described (Gina Newton, AAS Canberra, pers. comm., February 2005).

In the offshore stations (Stations 4 and 5) copepod abundances were low (60 to 70 m^{-3}) and there was no appreciable change between the wet and dry seasons (Figure 30). The abundances at the inshore stations were three to four times higher than offshore, with abundances in the wet season (150 to 220 m^{-3}) higher than the dry (140 to 160 m^{-3}), consistent with the trends in total zooplankton biomass.

a.



b.

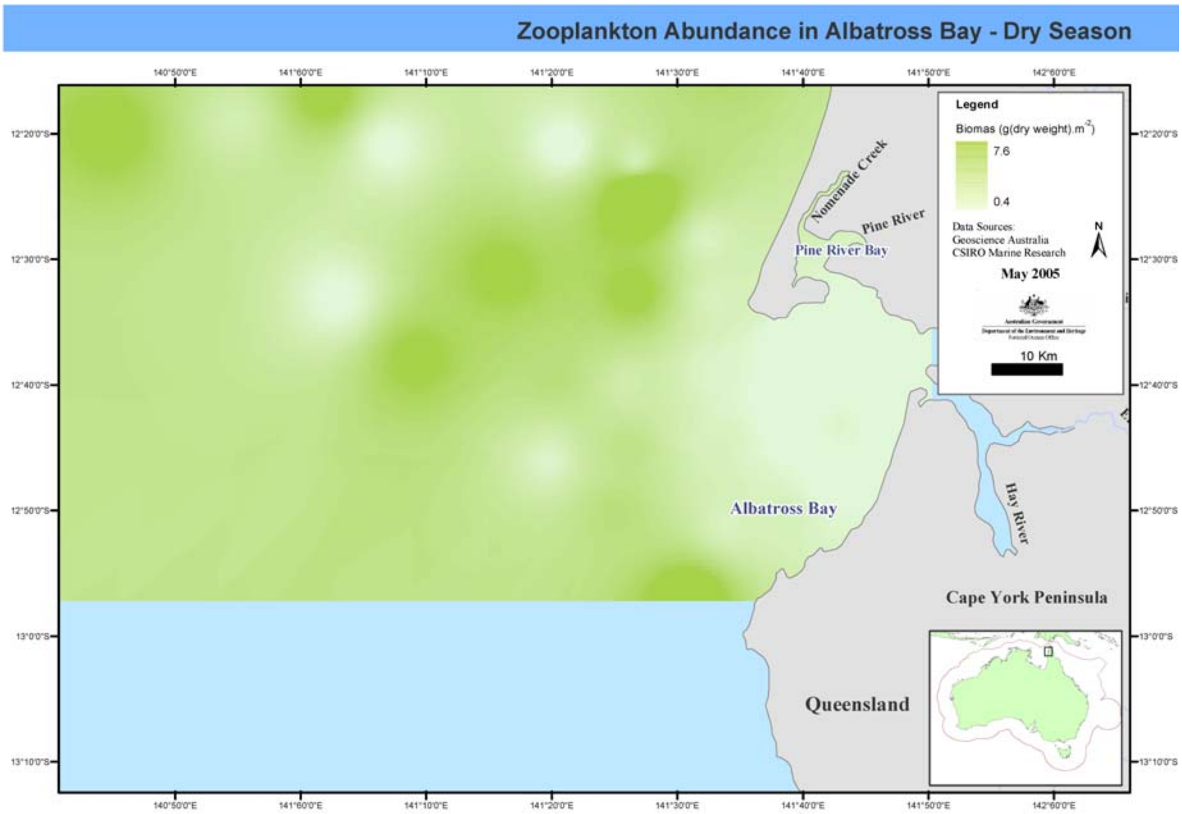


Figure 29. Albatross Bay zooplankton dry weight biomass (g m^{-2}): (a) Wet season; (b) Dry season. Data collected from 70 cruises (30 in the dry season and 41 in the wet season) over 7 years (1986-1992).

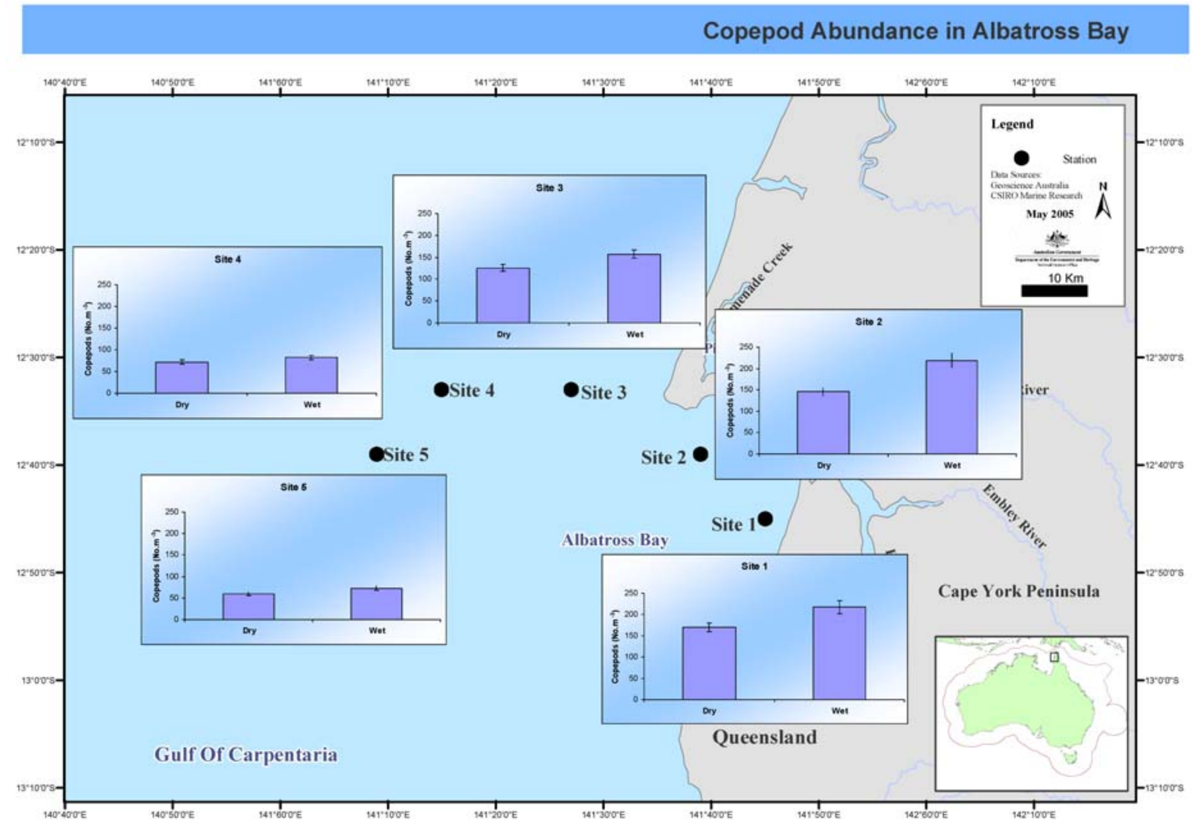


Figure 30. Albatross Bay mean copepod abundance (number m^{-3}) at five stations in the wet and dry seasons.

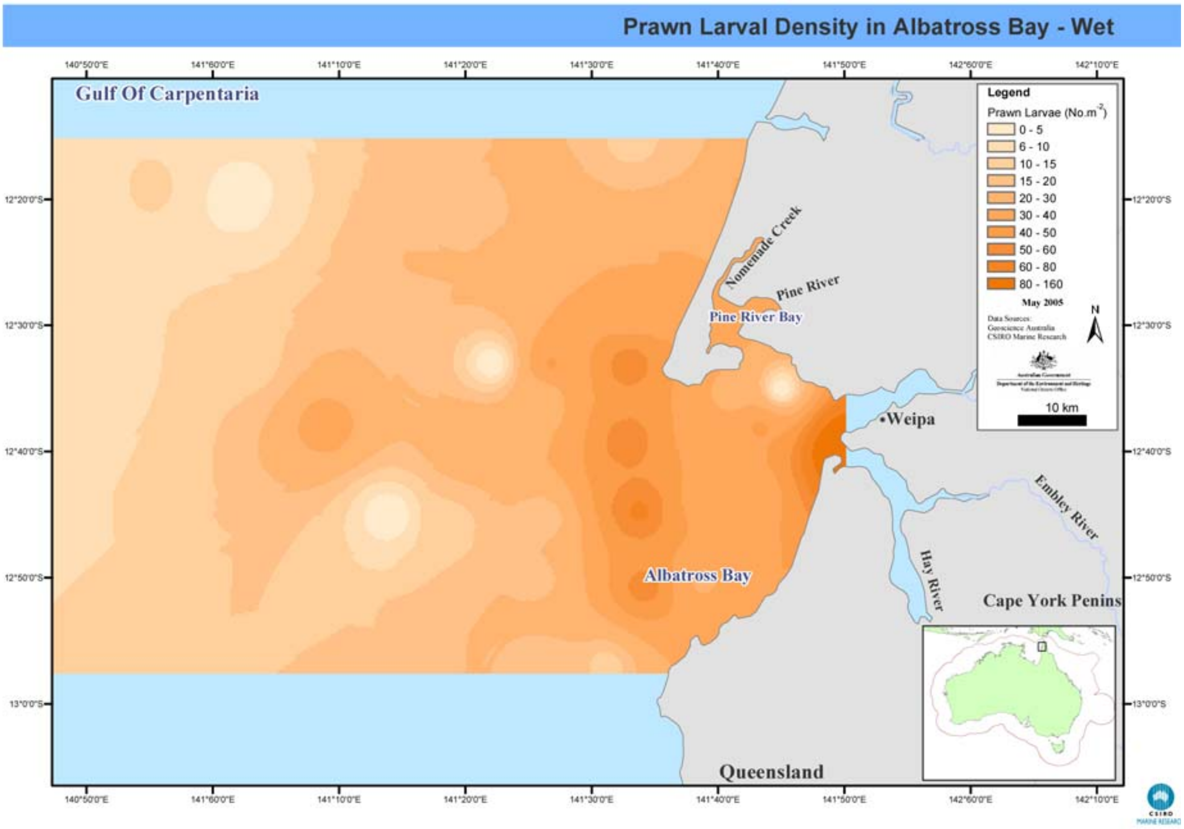
10.6 Prawn larval density

Banana Prawn ©CSIRO

Albatross Bay Region is one of the few places in the NLMD cohabited by the three major commercial penaeid species: banana prawns (*Penaeus merguiensis*), brown tiger prawns (*P. esculentus*) and grooved tiger prawns (*P. semisulcatus*). During the wet season, total prawn larval density was highest (> 80 larvae m^{-2} around the mouth of the confluence of the Mission, Embley and Hay Rivers (Figure 31a). Secondary peaks were measured across the mouth of Albatross Bay within 35 km of the coast (40 to 60 m^{-2}) and another localised concentration 80 km offshore (30 to 40 m^{-2}). During the dry season, larval densities were greatly diminished in the coastal region, with high concentrations (> 80 m^{-2}) found more than 100 km offshore (Figure 31b).

Most of the prawn larvae represented in Figure 30 are from small non-commercial species, such as *Metapenaeopsis* spp., *Parapenaeopsis* spp., *Trachypenaeus* spp., *Atypopenaeus* spp., and non-commercial species of *Metapenaeus*, such as *M. eboracensis*, *M. insolitus* (Jackson *et al*.1989). Commercially important species, such as *Penaeus semisulcatus*, *P. esculentus*, *P. merguiensis, P. latisulcatus* and *Metapenaeus endeavouri* and *M. ensis* represent only a small fraction (Rothlisberg *et al*. 1985,1987, Jackson *et al*. 2001, Rothlisberg and Jackson 1994). Of these, the banana prawn (*P. merguiensis*) was found at relatively high densities (15 to 20 m^{-2}) across the mouth of Albatross Bay following the main spawning period early in the wet season (Figure 32a). The grooved tiger prawn larvae (*P. semisulcatus*) also have their major spawning early in the wet season and a secondary one at the end of the wet season. However, high densities of their larvae (15 to 20 m^{-2}) were only encountered during the dry season 120 km offshore of Albatross Bay (Figure 32b) (unpublished data, Jackson *et al*. 2001).

a.



b
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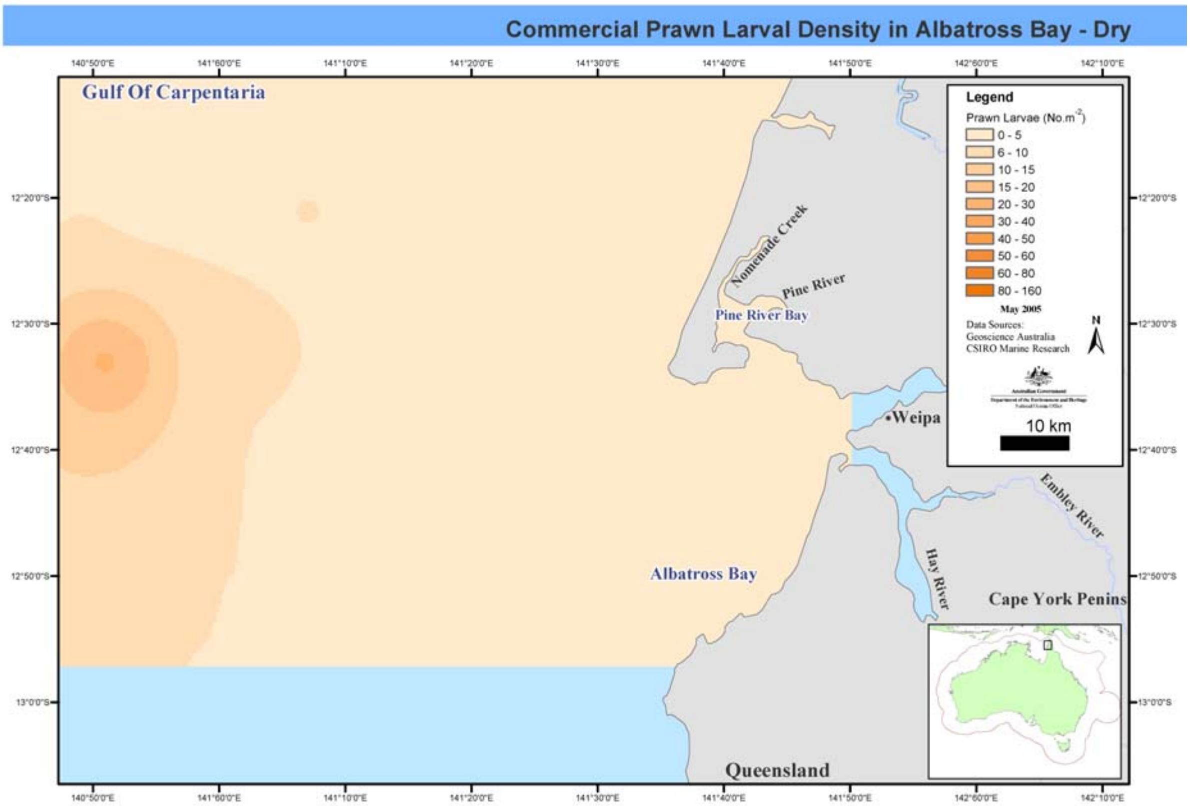
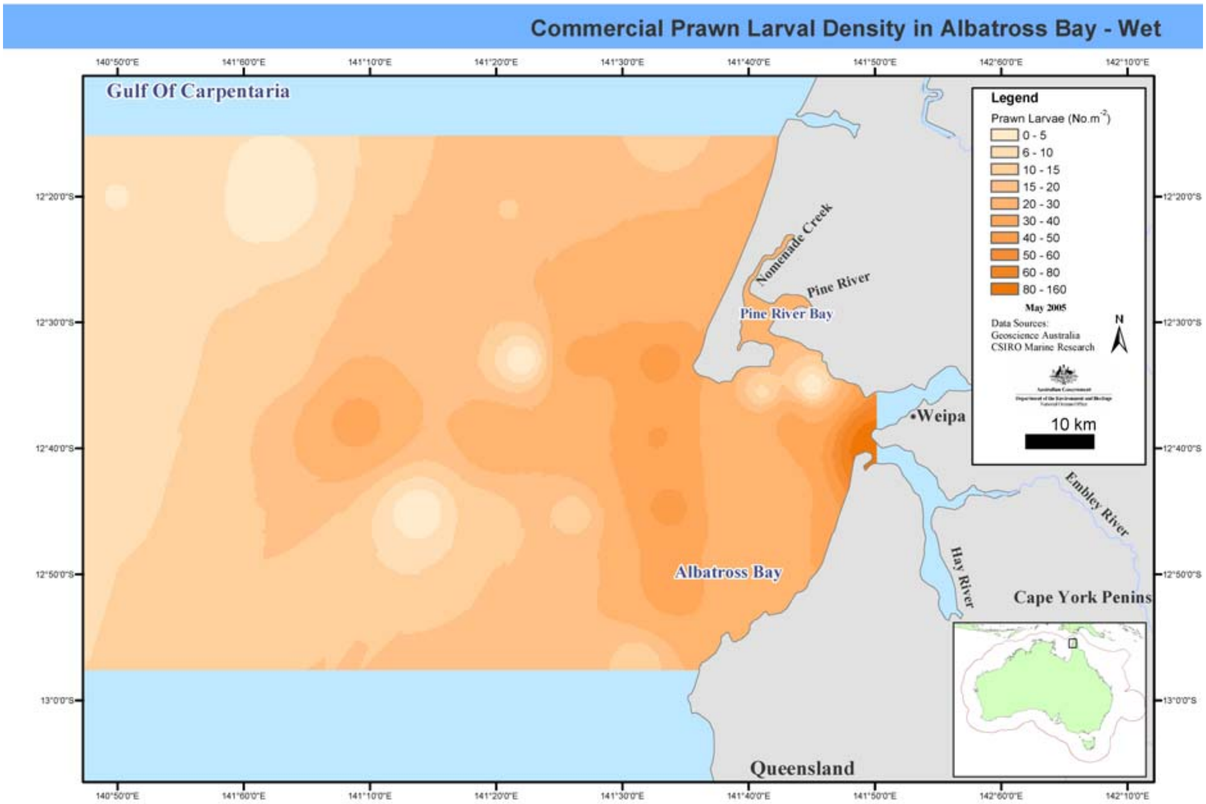


Figure 31. Albatross Bay total penaeid prawn larval density (number m^{-2}): (a) Wet season; (b) Dry season.

a.



b.

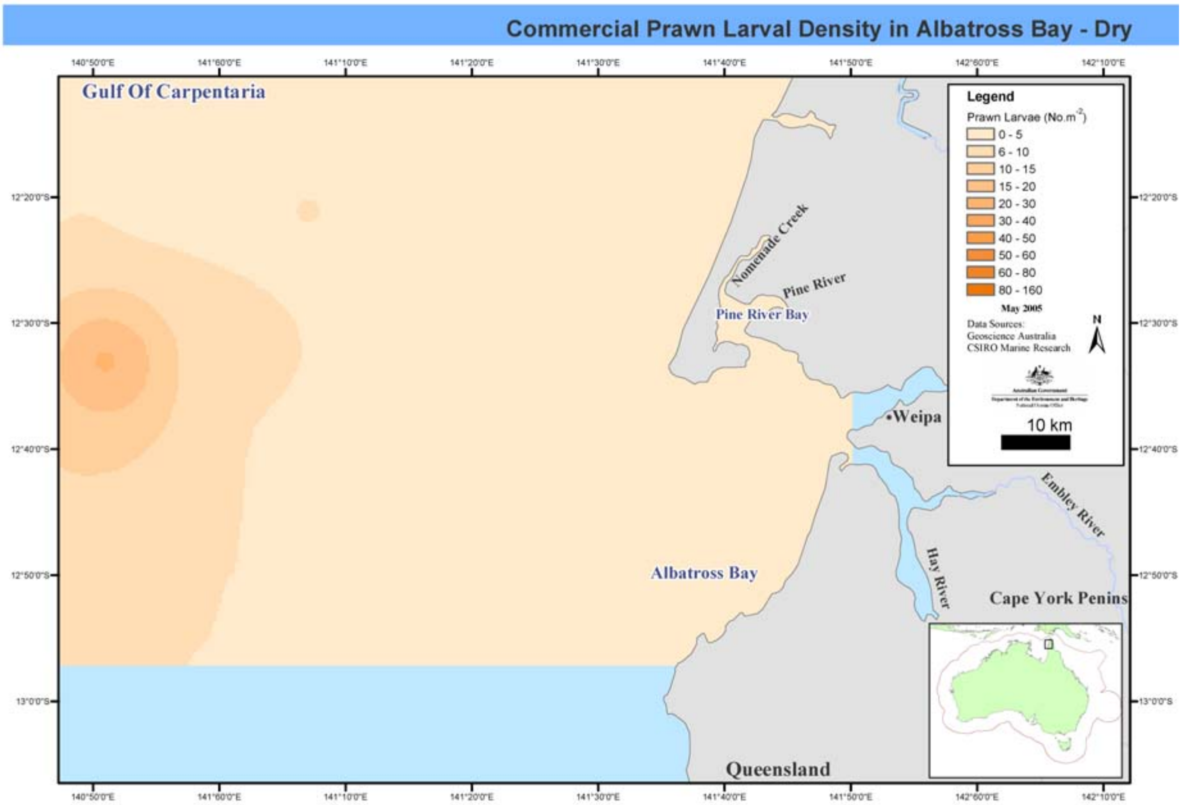


Figure 32. Albatross Bay commercial penaeid prawn larval density (number m^{-2}): (a) Wet season; (b) Dry season.

11. Recommendations for future research

There are four key recommendations for improving the quantity, quality, and type of information available for pelagic bioregionalisation in the NLMD:

1. Outside the Gulf of Carpentaria, physical hydrographic data (temperature, salinity, dissolved oxygen, and nutrients) are extremely sparse and biological oceanographic data is almost non-existent. There is substantial research currently being undertaken in Torres Strait as part of the Reef CRC program. However, dedicated multidisciplinary field programs will be required to address data gaps in the Timor Sea, Joseph Bonaparte Gulf, and the western Arafura Sea.

2. Seasonal and inter-annual changes in physical and biological characteristics need to be taken into account when applying them to pelagic bioregionalisation. This implies a need for more systematic monitoring of variability in the pelagic system associated with climate variability, climate change, and possible anthropogenic influences.

3. The utility of satellite datasets such as MODIS would be greatly enhanced by a systematic program of field validation. This is particularly true of the NLMD, where shallow water and large concentrations of suspended sediments complicates interpretation of the ocean colour signal.

4. Application of the pelagic bioregionalisation to issues such as the design and evaluation of marine protected areas will require additional dynamical oceanographic information. For example, connectivity of communities through pelagic larval phases (e.g. Condie et al. 2005) and the linkage between current regimes, seasonal reproductive activity, and recruitment dynamics (e.g. Rothlisberg *et al.* 1994, Condie *et al*. 1999).

References

Bishop JK and Rossow WB. 1991. Spatial and temporal variability of global surface solar irradiance. *Journal of Geophysical Research* **99**, 16839-16858.

Bureau of Meteorology. 1988. *Climate Atlas of Australia*. Department of Administrative Services, Canberra, 67pp.

Burford MA and Rothlisberg PC. 1999. Factors limiting phytoplankton growth in a tropical continental shelf ecosystem. *Estuarine, Coastal and Shelf Science* **48**, 541-549.

Burford MA, Rothlisberg PC and Wang Y-G. 1995. Spatial and temporal distribution of tropical phytoplankton species and biomass in the Gulf of Carpentaria, Australia. *Marine Ecology Progress Series* **118**, 255-266.

Condie SA and Dunn JR 2005. Seasonal characteristics of the surface mixed layer in the Australasian region: Implications for primary productivity and biogeography. *Marine and Freshwater Research* (submitted).

Condie SA, Loneragan NR and Die DJ. 1999. Modelling the recruitment of tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) to nursery grounds in the Gulf of Carpentaria, northern Australia: implications for assessing stock-recruitment relationships. *Marine Ecological Progress Series* **178**, 55-68.

Condie S, Ridgway K, Griffiths B, Rintoul S and Dunn J. 2003. National oceanographic description and information review for national bioregionalisation. CSIRO Marine Research Report for the National Oceans Office. 51p.

Condie SA, Waring J, Mansbridge JV, Cahill ML. 2005. Marine connectivity patterns around the Australian continent. *Environmental Modelling and Software* **20**, 1149-1157.

Cresswell G, Frische A, Peterson J and Quadfasel D. 1993. Circulation in the Timor Sea. *Journal of Geophysical Research* **98,** 14379-14389.

Dunn JR and Ridgway KR. 2002. Mapping ocean properties in regions of complex topography. *Deep-Sea Research I* **49**, 591-604.

Egbert GD and Ray RD. 2000. Significant dissipation of tidal energy in the deep ocean inferred from satellite altimeter data. *Nature* **405**, 775-778.

Forbes AMG. 1984. The contribution of local processes to seasonal hydrology of the Gulf of Carpentaria. *Océanographie Tropicale* **19**, 193-201.

Godfred-Spenning CR and Reason CJC. 2002. Interannual variability of lower-tropospheric moisture transport during the Australian monsoon. *International Journal of Climatology* **22**, 509-532.

Hallegraeff GM and Jeffrey SW. 1984. Tropical phytoplankton species and pigments of continental shelf waters of north and north-west Australia. *Marine Ecology Progress Series* **20**, 59-74.

Harris P, Heap A, Passlow V, Sbaffi L, Fellows M, Porter-Smith R, Buchanan C and Daniell J. (no Date) Geomorphic Features of the Continental margins of Australia. http://www.oceans.gov.au/pdf/National_Bathymetry_Report.pdf

Hayes, D, Lyne, V, Condie, S, Griffiths, B and Hallegraeff G (2005) Collation and analysis of oceanographic datasets for National Marine Bioregionlaisaion. CSIRO Marine Research. A report to the National Oceans Office. Australia.

Hill BJ, et al. 2002. Surrogates I - Predictors, Impacts, Management and Conservation of Benthic Biodiversity of the Northern Prawn Fishery. Final Report on FRDC Project 2000/160. CSIRO, Cleveland, 437 pp.

Holland, GJ. 1986. Interannual variability in the Australian summer monsoon at Darwin: 1952-82. *Monthly weather review* **114**, 594-604.

Jackson CJ, Rothlisberg PC and Pendrey RC. 2001. Role of larval distribution and abundance in overall life-history dynamics: a study of the prawn *Penaeus semisulcatus* in Albatross Bay, Gulf of Carpentaria, Australia. *Marine Ecology Progress Series* **213**, 241-252.

Jackson CJ, Rothlisberg PC, Pendrey RC and Beamish MT. 1989. A key to the genera of Indo-Pacific penaeid larvae and early postlarvae and descriptions of *Atypopenaeus formosus* Dall and

Metapenaeopsis palmensis Haswell (Decapoda: Penaeoidea) reared in the laboratory. *Fishery Bulletin US* **87**, 703-733.

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J, Zhu Y, Chelliah M, Ebisuzaki W, Higgins W, Janowiak J, Mo KC, Ropelewski C, Wang J, Leetmaa A, Reynolds R, Jenne R, and Joseph D. 1996. The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society* **77**, 437-471.

Kirk JTO. 1994. *Light and photosynthesis in aquatic ecosystems*. 2nd Ed. Cambridge University Press, Cambridge, U.K. 500p

Kramer D, Kalin MJ, Stevens EG, Thrailkill JR, and Zweifel JR. 1972. Collecting and processing data in fish eggs and larvae in the California Current Region. *NOAA Technical Report, NMFS Circular* **370**, 38p.

Lyne V, Last P, Scott R, Dunn, J, Peters, D, Ward, T (1998), *Large Marine Domains of Australia's EEZ.* CSIRO Marine Research and Department of Environment and Land Management, Tasmania. A report commissioned by Environment Australia, March 1998

Lyne V and Hayes D (2005) Pelagic regionalisation: National Marine Bioregionalisation Integration Project. CSIRO Marine Research. National Oceans Office.

LeProvost C and Lyard F. 1997. Energetics of the M_2 barotropic ocean tides: an estimate of bottom friction dissipation from a hydrodynamic model. *Progress in Oceanography* **40**, 37-52.

McEwen GF, Johnson MW and Folsom TR. 1954. A statistical analysis of the Folsom sample splitter based on test observations. *Archiv fur Meteorologie, Geophysik and Bioklimatologie, Serie A: Meteorologie und Geophysik* **6**, 502-527.

Othman BHR. 1986. Copepods of the Gulf of Carpentaria. PhD Thesis. University of Queensland, St Lucia. 392p.

Othman BHR, Greenwood JG and Rothlisberg PC. 1990. The copepod fauna of the Gulf of Carpentaria, and its Indo-west Pacific affinities. Proceedings of the Snellius II Symposium, Jakarta, Indonesia. *Netherlands Journal of Sea Research* **24**, 561-572.

Racek AA and Dall W. 1965. Littoral Penaeinae (Crustacea Decapoda) from northern Australia, New Guinea, and adjacent waters. Verhandelingen der Koninklijke Nerderlandse Akademie van Wetenschappen, Afd. Natuurkunde. Tweed Reeks Vol 56, No. 3, 116p. +13 plates.

Ridgway KR, Dunn JR and Wilkin JL. 2002. Ocean interpolation by four-dimensional least squares - Application to the waters around Australia. *Journal of Atmospheric and Oceanic Technology* **19**, 1357-1375.

Rothlisberg PC and Jackson CJ. 1982. Temporal and spatial variation of plankton abundance in the Gulf of Carpentaria, Australia 1975-1977. *Journal of Plankton Research* **4**, 19-40.

Rothlisberg PC and Jackson CJ. 1987. Larval ecology of penaeids in the Gulf of Carpentaria, Australia. II. Hydrographic environment of *Penaeus merguiensis*, *P. esculentus*, *P. semisulcatus* and *P. latisulcatus* zoeae. *Australian Journal of Marine and Freshwater Research* **38**, 19-28.

Rothlisberg PC and Jackson CJ. 1994. Larval ecology and reproductive activity of *Metapenaeus ensis* and *M. endeavouri* in the Gulf of Carpentaria, Australia, assessed from the distribution and abundance of the protozoeal stages. *Journal of Plankton Research.* **16**, 219-231.

Rothlisberg PC, Forbes AMG and White N. 1989. *Hydrographic Atlas of the Gulf of Carpentaria.* CSIRO Marine Laboratories Report 209, 51 p.

Rothlisberg PC, Jackson CJ and Pendrey RC. 1983. Specific identification and assessment of distribution and abundance of early penaeid shrimp larvae. *Biological Bulletin* **164**, 279-298.

Rothlisberg PC, Jackson CJ and Pendrey RC. 1985. Distribution and abundance of early penaeid larvae in the Gulf of Carpentaria, Australia. pp. 23-30. *In:* Rothlisberg PC, Hill BJ and Staples DJ (Eds.) *Second Australian National Prawn Seminar*. NPS2, Cleveland, Australia 368p

Rothlisberg PC, Jackson CJ and Pendrey RC. 1987. Larval ecology of penaeids in the Gulf of Carpentaria, Australia. I. Assessing the reproductive activity of five species of *Penaeus* from the distribution and abundance of the zoeal stages. *Australian Journal of Marine and Freshwater Research* **38**, 1-17.

Rothlisberg PC, Pollard PC, Nichols PD, Moriarty DJW, Forbes AMG, Jackson CJ and Vaudrey D. 1994. Phytoplankton community structure and productivity in relation to the hydrological regime of the Gulf of Carpentaria in summer. *Australian Journal of Marine and Freshwater Research* **45**, 265-82.

Appendix Products List

The following tables list the datasets, mapsets and GIS layers that have been provided to the National Oceans Offfice.

The Northern Large Marine Domain

Neptune Record	Products	Location		
		Data	**Maps**	**Grid**
DRAFT: Sea Surface Temperature Monthly Means and Variance in the Australian Region (record # 868)	**Dataset: Sea Surface Temperature Monthly an Annual Means in the Northern Marine Region**	Contact donna.hayes@csiro.au	sst_dry.pdf sst_dry.jpg sst_wet.pdf sst_wet.jpg sst_ave.jpg sst_ave.pdf	all_sst_avg.zip jan_sst_avg.zip july_sst_avg.zip
DRAFT: Mapset: Sea Surface Temperature wet/dry Means in the northern Marine Region (record # 907)	**Mapset: Sea Surface Temperature wet/dry season Means in the Northern Marine Region** (3 maps)			
DRAFT: GIS Layer: Sea Surface Temperature in the Australian Region (record # 1032)				

Neptune Record	Products	Location		
DRAFT: Sea Surface Silicate in the Australian Region (record # 809) **DRAFT: Map: Silicate Annual Means in the Northern Marine Region (record # 889)** **DRAFT: GIS Layer: Sea Surface Silicate in the Australian Region (record # 1040)**	**Dataset: Sea Surface Silicate** **Map: Silicate Annual Means in the Northern Marine Region**	**Data** Silicate_10thdeg.nc.gz	**Maps** silicate.pdf	**Grids** CARS_Silicate.zip silicate_amp.zip silicate_mean.zip
DRAFT: Sea Surface Phosphate in the Australian Region (record # 811) **DRAFT: Map: Phosphate Annual Means in the Northern Marine Region (record # 890)** **DRAFT: GIS Layer: Sea Surface Phosphate in the Australian Region (record # 1041)**	**Dataset: Sea Phosphate** **Map: Phosphate Annual Means in the Northern Marine Region**	**Data** phosphate_10thdeg.nc.gz	**Maps** Phosphate.pdf	**Grids** CARS_Phos.zip phosphate_amp.zip phosphate_mean.zip

Neptune Record	Products	Location		
DRAFT: Sea Surface Nitrate in the Australian Region (record # 813) **DRAFT: Map: Nitrate Annual Means in the Northern Marine Region (record # 891)** **DRAFT: GIS Layer: Sea Surface Nitrate in the Australian Region (record # 1042)**	**Dataset: Sea Nitrate** **Map: Nitrate Annual Means in the Northern Region**	**Data** nitrate_10thdeg.nc.gz	**Maps** nitrate.pdf nitrate.jpg	**Grids** CARS_Nitrate.zip nitrate_amp.zip nitrate_mean.zip
DRAFT: Sea Surface Dissolved Oxygen in the Australian Region (record # 812) **DRAFT: Map: Dissolved Oxygen Annual Mean in the Northern Marine Region (record # 849)** **DRAFT: GIS Layer: Sea Surface Dissolved Oxygen in the Australian Region (record # 1043)**	**Dataset: Dissolved Oxygen Annual Mean** **Map: Dissolved Oxygen in the Northern Marine Region**	**Data** Oxygen_10thdeg.nc.gz	**Maps** oxygen.pdf oxygen.jpg	**Grids** CARS_Oxy.zip oxy_mean.zip oxy_amp.zip

Neptune Record	Products	Location		
DRAFT: Salinity in the Australian Region (record # 810) **DRAFT: Map: Salinity in the Northern Marine Region (record # 848)** **DRAFT: GIS Layer: Sea Salinity in the Australian Region (record # 1045)**	**Dataset: Salinity Annual Mean** **Map: Salinity Annual Means in the Northern Marine Region**	**Data** Salinity_10thdeg.nc.gz	**Maps** salinity.pdf	**Grids** CARS_Salinity.zip salinity_mean.zip satinity_amp.zip
Draft: Sea Temperature Monthly and Annual Means in the Australian Region (record # 808) **DRAFT: Map: Sea Temperature in the Northern Marine Region *map* (record # 933)** **GIS Layer: Sea Temperature in the Australian Region (record #1044)**	**Dataset: Temperature at depth** **Map: Temperature in the Northern Marine Region**	**Data** North_temp.ascc	**Map** North_temp_jan.pdf north_temp_jul.pdf	**Grid** North_temp

Neptune Record	Products	Location		
DRAFT: Currents from the Northern Region Circulation Model (record # 975) **DRAFT: Mapset: Currents in the Northern Marine Region (record # 875)** **DRAFT: GIS Layer: Currents from the Northern Region Circulation Model (record #)**	**Dataset: Currents from the Northern Region Circulation Model**	**Data** npfzip.zip	**Maps** Current_jan.jpg Current_jan.pdf Current_jul.jpg Current_jul.pdf	**Grids and shape** current_grd.zip current_shape.zip npf_jan_sub.shp npf_jul_sub.shp npf_jancur.grd npf_julcur.grd
DRAFT: Tidal Range from the Northern Marine Circulation Model (record # 999) **DRAFT: Map: Maximum Tidal Range for the Northern Marine Region (record #998)**	**Map: Maximum Tidal Range for the Northern Marine Region** **Dataset: Tidal Range from the Northern Marine Circulation Model**	**Data** Npf1zip.txt	**Maps** max_tide.jpg max_tide.pdf	**Grids** max_tide.zip

Neptune Record	Products	Location		
DRAFT: Bottom Stress from the Northern Marine Region (record # 874) **DRAFT: Mapset: Bottom Stress in the Northern Marine Region (record # 912)**	**Dataset: Bottom Stress from the Northern Region Circulation Model** **Mapset: Bottom Stress in the Northern Marine Region** (3 maps)	**Data** Npf1.txt.gz	**Maps** max_stress.pdf max_stress.jpg mean_stress.pdf mean_stress.jpg stdev_stress.pdf stdev_stress.jpg	**Grids** strmax strmn strdev
DRAFT: Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons (record # 995) **DRAFT: Mapset: Prawn Larval Distributions in the Gulf of Carpentaria for Wet and Dry Seasons (record # 986)**	**Dataset: Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons** **Map: Prawn Larval Distributions in the Gulf of Carpentaria for Wet and Dry Seasons.** (2 maps)	**Data** M4870_gen2_w.csv M4870_gen2_d.csv	**Maps** M4870_totd.jpg M4870_totw.jpg M4870_totd.pdf M4870_totw.pdf	**Grids** m4870_totw m4870_totd

Neptune Record	Products	Location		
		Data	**Maps**	**Grids**
DRAFT: Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons (record # 995)	**Dataset: Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons**	M4870_gen2_w.csv M4870_gen2_d.csv	M4870_comd.jpg M4870_comw.jpg M4870_comd.pdf M4870_comw.pdf	m4870_comw m4870_comd
DRAFT: Mapset: Commercial Prawn Larval Distributions in the Gulf of Carpentaria for Wet and Dry Seasons (record # 983)	**Map: Commercial Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons** (2 maps)			

Neptune Record	Products	Location		
		Data	**Maps**	**Grids**
DRAFT: Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons (record # 995)	**Dataset: Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons**	M4870_gen2_w.csv M4870_gen2_d.csv	M4870_ncomd.jpg M4870_ncomw.jpg M4870_ncomd.pdf M4870_ncomw.pdf	m4870_ncomw m4870_ncomd
DRAFT: Mapset: Non-Commercial Prawn Larval Distributions in the Gulf of Carpentaria for Wet and Dry Seasons (record # 985)	**Map: Non-Commercial Prawn Larval Distribution in the Gulf of Carpentaria for Wet and Dry Seasons** (2 maps)	M4870_goc_genus_all.shp m4870_gen2.csv		

Neptune Record	Products	Location		
DRAFT: Zooplankton biomass in the Gulf of Carpentaria for Wet and Dry Seasons (record # 987) **DRAFT: Mapset: Total Zooplankton biomass in the Gulf of Carpentaria for Wet and Dry Seasons (record # 989)**	**Dataset: Zooplankton Biomass in the Gulf of Carpentaria for the Wet and Dry Seasons** **Map: Total Zooplankton Biomass in the Gulf of Carpentaria for Wet and Dry Seasons** (2 maps)	**Data** M4870_bio_d.csv M4870_bio_w.csv M4870_bi.zip	**Maps** M4870_bio_w.jpg M4870_bio_d.jpg M4870_bio_w.pdf M4870_bio_d.pdf	**Grids** m4870_bio_w m4870_bio_d
DRAFT: Ocean Colour Monthly Means and Variances in the Australian Region (record # 880) **DRAFT: Mapset: Ocean Colour Chlorophyll wet/dry Means in the Northern Marine Region (record # 908)** **DRAFT: GIS Layer: Ocean Colour Chlorophyll (MODIS) in the Australian Region (record: # 1047)**	**Dataset: Ocean Colour Chlorophyll Annual Mean in the Northern Marine Region** **Mapset: Ocean Colour Chlorophyll wet/dry Means in the Northern Marine Region** (2 maps)	**Data** Chlorophyll_monthly_means.zip Chlororphyll_monthly_std_dev.zip	**Maps** chlor_dry.pdf chlor_dry.jpg chlor_wet.pdf chlor_wet.jpg	**Grids** Chloro_means.zip Chloro_std_dev.zip Chlor_grids.zip

Neptune Record	Products	Location		
		Data	**Maps**	**Grids**
DRAFT: Incident Light and Photosynthetically Active Radiation (PAR) Monthly Means in the Australian Region (record # 872) **DRAFT: Mapset: Incident Light for the Wet and Dry Seasons in the Northern Marine Region (record # 1055)** **DRAFT: GIS Layer: Incident Light (PAR) in the Australian Region (record # 1049)**	**Dataset: Incident of Light and Photosynthetically Active Radiation (PAR) Monthly Means** **Mapset: Incident of Light in Northern Marine Region** (2 maps)	light_incident_ascii.zip	light_wet.pdf light_wetl.jpg light_dry.pdf light_dry.jpg	grids_monthly_light.zip

Neptune Record	Products	Location		
		Data	**Maps**	**Grids**
DRAFT: Primary Production Data from (MODIS) in the Australian Region (record #1057) **DRAFT: Mapset: Primary Production wet/dry Seasonal Mean in the Northern Marine Region (record # 948)** **DRAFT: GIS Layer: Primary Production (MODIS) in the Australian Region (record # 1048)**	**Dataset: Primary Production Data (Monthly) from Ocean Colour Data (MODIS)** **Mapset: Primary Production wet/dry Seasonal Mean in the Northern Marine Region** (2 maps)	MOD_P1_8D_4KM.nc	pp_dry.pdf pp_dry.jpg pp_wet.pdf pp_wet.jpg	primary_production.zip

Case Study: Albatross Bay

Neptune Record	Products	Format	input datasets

DRAFT: Prawn Larval Distribution in the Albatross Bay for Wet and Dry Seasons (record # 996) **DRAFT: Mapset: Prawn Larval Distributions in Albatross Bay for Wet and Dry Seasons (record # 976)**	**Dataset: Prawn Larval Distribution in the Albatross Bay for Wet and Dry seasons** **Map: Prawn Larval Distributions in Albatross Bay for Wet and Dry seasons** (2 maps)	**Data** m1663_ab_genus_shp m1663_gend.csv m1663_genw.csv	**Maps** M1663_genw.jpg M1663_gend.jpg M1663_genw.pdf M1663_gend.pdf	**Grids** m1663_gend m1663_gend	Prawn larval density from stepped oblique bottom to surface plankton tows M1663_ab_genus.shp **m4870_pl.zip (78 Kb)** **Neptune record 'Prawn Larval Distribution of Commercial and Non-Commercial Species in Albatross Bay'**
DRAFT: Prawn Larval Distribution in the Albatross Bay for Wet and Dry Seasons (record # 996) **DRAFT: Mapset: Commercial Prawn Larval Distributions in Albatross Bay for Wet and Dry Seasons (record # 991)**	**Dataset: Prawn Larval Distribution in the Albatross Bay for Wet and Dry seasons** **Mapset: Commercial Prawn Larval Distributions in Albatross Bay Wet and Dry Seasons** (2 maps)	**Data** m1663_ab_genus_shp m1663_gend.csv m1663_genw.csv	**Maps** M1663_comd.jpg M1663_comw.jpg M1663_comd.pdf M1663_comw.pdf	**Grids** m1663_gencomd m1663_gencomw	Prawn larval density from stepped oblique bottom to surface plankton tows M1663_ab_genus.shp **m4870_pl.zip (78 Kb)** **Neptune record 'Prawn Larval Distribution of Commercial and Non-Commercial Species in Albatross Bay'**

DRAFT: Prawn Larval Distribution in the Albatross Bay for Wet and Dry Seasons (record # 996) **DRAFT: Mapset: Non-Commercial Prawn Larval Distributions in Albatross Bay for Wet and Dry Seasons (record # 992)**	**Dataset: Prawn Larval Distribution in the Albatross Bay forWet and Dry seasons** **Map: Non-Commercial Prawn Larval Distributions in Albatross Bay. Wet and Dry Seasons** (2 maps)	**Data** m1663_ab_genus_shp m1663_gend.csv m1663_genw.csv	**Maps** M1663_noncomd.jpg M1663_noncomw.jpg M1663_noncomd.pdf M1663_noncomw.pdf	**Grids** m1663_noncomw m1663_noncomd	Prawn larval density from stepped oblique bottom to surface plankton tows M1663_ab_genus.shp **m4870_pl.zip (78 Kb)** **Neptune record 'Prawn Larval Distribution of Commercial and Non-Commercial Species in Albatross Bay'**
DRAFT: Chlorophyll-*a* concentrations in Albatross Bay (record # 977) **DRFAT: Map: Chlorophyll-*a* concentrations in Albatross Bay (record # 978)**	**Dataset: Chlorophyll-*a* concentrations in Albatross Bay** **Map: Chlorophyll-*a* concentrations in Albatross Bay** (1 map)	**Data** m1381_ab_chl.xls	**Map** M1381_chl.jpg M1381_chl.pdf		M1381_chl

DRAFT: Mean Chlorophyll and Primary Production at two sites in Albatross Bay (record # 994) **DRAFT: Map: Mean Chlorophyll in Albatross Bay (record # 984)**	**Dataset: Mean Chlorophyll and Primary Production at two sites** **Map: Mean Chlorophyll in Albatross Bay.** (1 map)	**Data** m1664_prod.xls	**Maps** M1664_clor.jpg M1664_chlor.pdf	Northern_data/covers/ m1582_phy Coverage M1664_prod
DRAFT: Mean Chlorophyll and Primary Production at two sites in Albatross Bay (record # 994) **DRAFT: Primary Production of Chlorophyll at two sites in Albatross Bay (record # 993)**	**Dataset: Primary Production and Mean Chlorophyll at two sites in Albatross Bay** **Map: Primary Prduction of Chlorophyll in Albatross Bay at two sites** (1 map)	**Data** m1664_prod.xls	**Maps** M1664_prod.pdf M1664_prod.jpg	^{14}C primary productivity incubations at 2 stations over 7 cruises Northern_data/covers/ m1664_prod **Neptune record 'Primary Productivity Data in Albatross Bay 1988-1991'** **m1664_prod.zip (16Kb)**
DRAFT: Copepod Abundance in Albatross Bay (record # 979) **DRAFT: Map: Copepod Abundance in Albatross Bay (record # 980)**	**Dataset: Copepod Abundance in Albatross Bay** **Map: Copepod Abundance in Albatross Bay** (1 map)	**Data** m6332_copepods.xls	**Maps** m6332_cpp.jpg m6332_cpp.pdf	Coverage M6332_cpp

DRAFT: Phytoplankton Abundance in Albatross Bay (record 982) **Map: Phytoplankton Abundance in Albatross Bay (record # 981)**	**Dataset: Phytoplankton Abundance in Albatross Bay** **Map: Phytoplankton Abundance in Albatross Bay** (1 map)	**Data** m1582_phy.xls	**Maps** M1582_phy.pdf M1582_phy.jpg		Northern_data/covers/ m1582_phy **Neptune record 'Phytoplankton Biomass in Albatross Bay'** **m1582_phy.zip (132Kb)**
DRAFT: Zooplankton Biomass in Albatross Bay (record # 988) **DRAFT: Mapset: Zooplankton Biomass in Albatross Bay (record # 990)** **DRAFT: GIS Layer: Biomass in Albatross Bay (record # 1056)**	**Dataset: Zooplankton Biomass in Albatross Bay** **Mapset: Zooplankton Abundance in Albatross Bay**	**Data** m1663_ab_biocd.csv m1663_ab_biocw.csv	**Maps** M1663_ab_biocd.jpg M1663_ab_biocw.jpg M663_ab_biocd.pdf M1663_ab_biocw.pdf	**Grids** m1663_biocw.zip m1663_biocd.zip	Total zooplankton biomass (dry weight) from stepped-oblique bottom to surface plankton tows Northern_data/covers/ m1663_ab_bioc **Neptune record 'Zooplankton Biomass 1986 -1992 in Albatross Bay'** **m1663_bio.zip (108 Kb)**
DRAFT: Seagrass Sites in the Port of Weipa, Gulf of Carpentaria (record #1003)	**Dataset: Seagrass Sites in the Port of Weipa, Gulf of Carpentaria**	**Data** WeipaSeagrassMetadata.zip WeipaGIS.zip			