Historical reconstructions of water quality in the Kimberley using sediment records

WAMSI Kimberley Research Program Project 2.2.9

Project Team

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Overview 1

There is an absence of long terms monitoring data for remote locations like the Kimberley.

Sediments in coastal waters accumulate over time and can retain an integrate record of the status of the water quality at the time the sediment was deposited.

Water quality and the pelagic biological oceanographic environment is influenced by natural climate variability, greenhouse induced climate change and other anthropogenic influences e.g. nutrients from grazing, agriculture and other catchment uses including those in coastal towns and cities.

Complacency over impacts to water quality has contributed to the decline in environmental health of the Great Barrier Reef and it will be important to avoid this scenario in the Kimberley.

Overview 2

The project used palaeoecological approaches, using sediment cores taken in coastal waters, to reconstruct a chronology of change over the last approximately 100 years.

A series of biogeochemical proxies for phytoplankton composition and biomass, temperature and terrestrial influences were used to construct chronologies that were matched, where possible to historical land/water use and meteorological or hydrological observational records.

The project examined sediment cores from three coastal locations, Koolama Bay (King George River), Cygnet Bay and Roebuck Bay.

Each sampling location provided a contrast with which to evaluate changes over either a spatial or temporal gradient of human or natural influence.

An attempt was made to interpret the cause of any changes in water quality inferred from the sediment record.

Coring methods

Left three panels showing coring method using a Vibecore-D (Speciality Products, USA) weighted vibrating head lowered from the CTD winch on the RV Solander, and right panel showing diver recovering a core from Cygnet Bay

Sediment cores

Close-up of sediment core prior to sectioning into 1 cm pieces

Geochemical and biomarker proxies

- ^{210}Pb and ^{137}Cs isotopes – age of core, integrity of age structure in sediment;
- ^{15}N isotope – a proxy for nitrogen source – anthropogenic or natural;
- ^{13}C isotope – proxy for carbon source – land or marine derived carbon;
- Carbon/Nitrogen ratio – can also be used to infer whether primary carbon source is marine or terrestrial;
- Sedimentation rate and grain size shows the variation of sedimentary environment (e.g. river input, sediment texture, other factors governing deposition and preservation);
- Total Organic Carbon (TOC) and Total Nitrogen (TN) indicate levels of productivity and deposition of organic matter;
- Biosilicate indicates siliceous phytoplankton deposits (e.g. diatoms, silicoflagellates), enhanced productivity;
- Biomarkers – sterols can be used as proxies for dinoflagellates (dinosterol), diatoms (brassicasterol), haptophytes (alkenones); TEX_{86} index for sea temperature; and long chain *n*-alkanes (C_{27}+C_{29}+C_{31}) for terrestrial influence.
- Elemental carbon (or black carbon) – indicators of biomass burning (e.g. from bushfires) or hydrocarbon burning (fossil fuels).

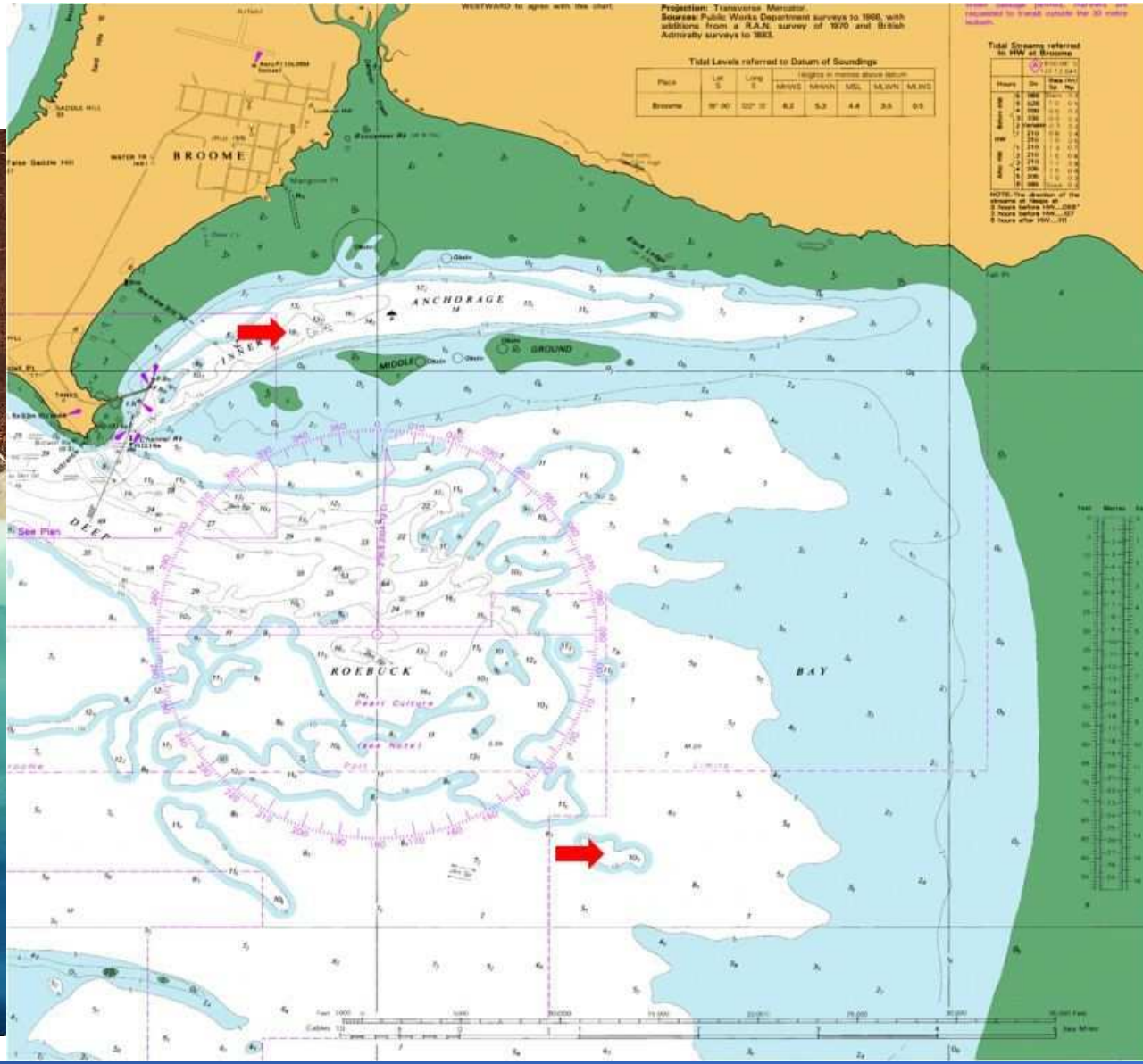
Roebuck Bay and Broome

Google Earth image of Broome and Roebuck Bay showing sampling sites and locations of industrial sites of interest to water quality studies. Core sampling sites in Roebuck Bay.

Roebuck Bay and Broome

Roebuck Bay offered a comparison of sites near/far from Broome city's anthropogenic inputs such as runoff from Dampier Creek as well as the waste water treatment plant, the golf course and an abattoir all built close to the coastline.

Roebuck Bay


BROOME
ANCHORAGE
INNER
MIDDLE
GROUND
DEEP
ROEBUCK
BAY
Pearl Culture
See Plan

Roebuck Bay and Broome

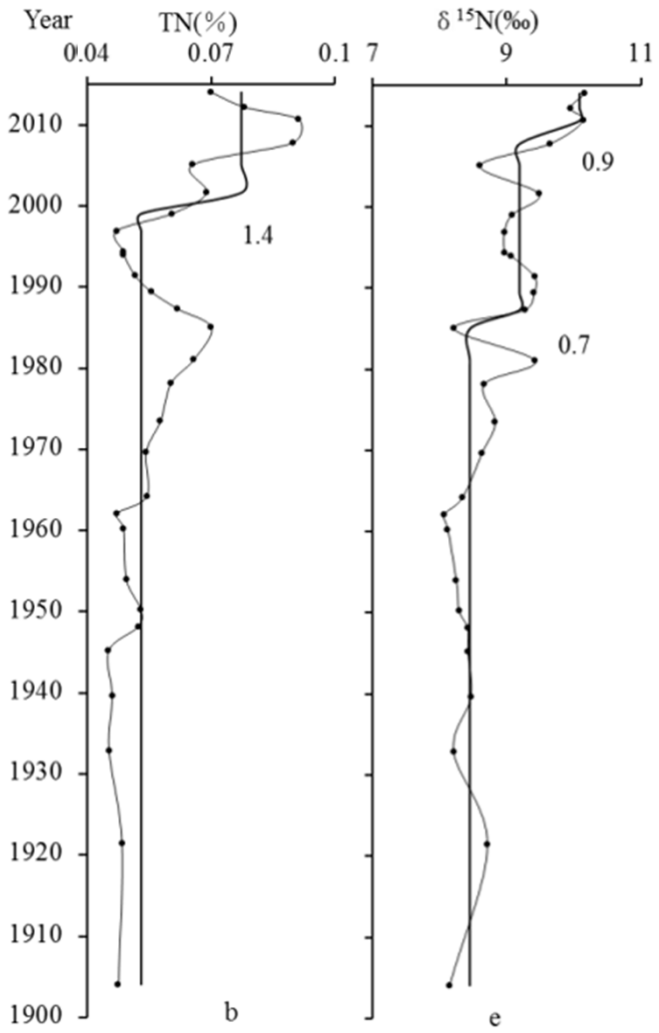
Two questions for Broome

There was recent controversy about whether leaking from the Broome WWTP is affecting water quality in Roebuck Bay.

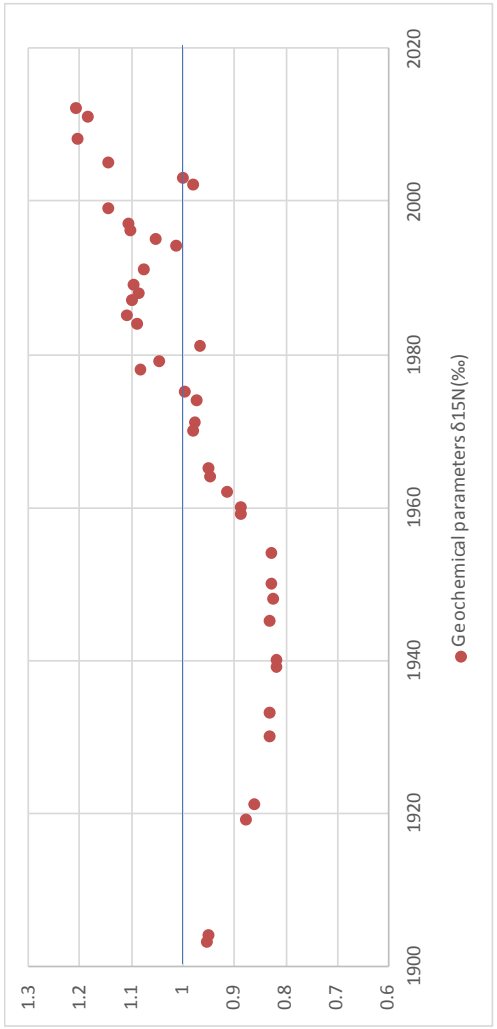
Is data from the cores consistent with increased levels of nutrients in Roebuck Bay?

Broome rainfall has increased 41% since 1997 compared to the average from 1941-1996.

Do the cores infer any changes in water quality as a result of this?



Total N and 15N at Broome site 1



Ratio of Site 1/Site 2

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Water corporation backtracks on sewage pollution in Roebuck Bay

ABC Kimberley By Ben Collins

Posted 30 Nov 2016, 12:03pm

PHOTO: The Broome south sewage treatment plant is located next to Roebuck Bay. (Supplied)

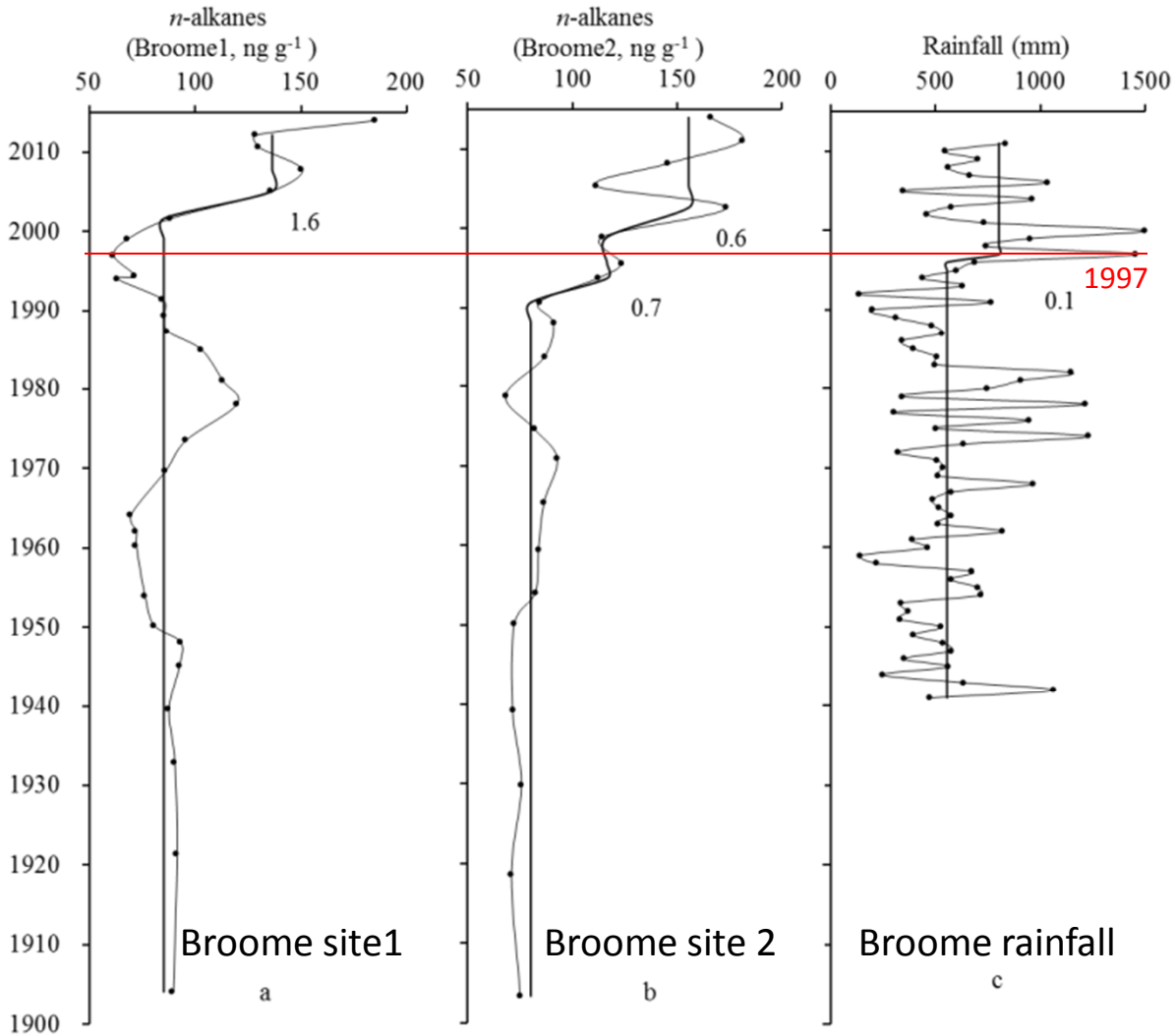
The cause of elevated nitrogen levels in Broome's recently-declared Roebuck Bay Marine Park is now being contested by the Water Corporation of WA, putting it at odds with a scientist and management group.

RELATED STORY: Probe into possible sewerage leak into Broome's Roebuck Bay

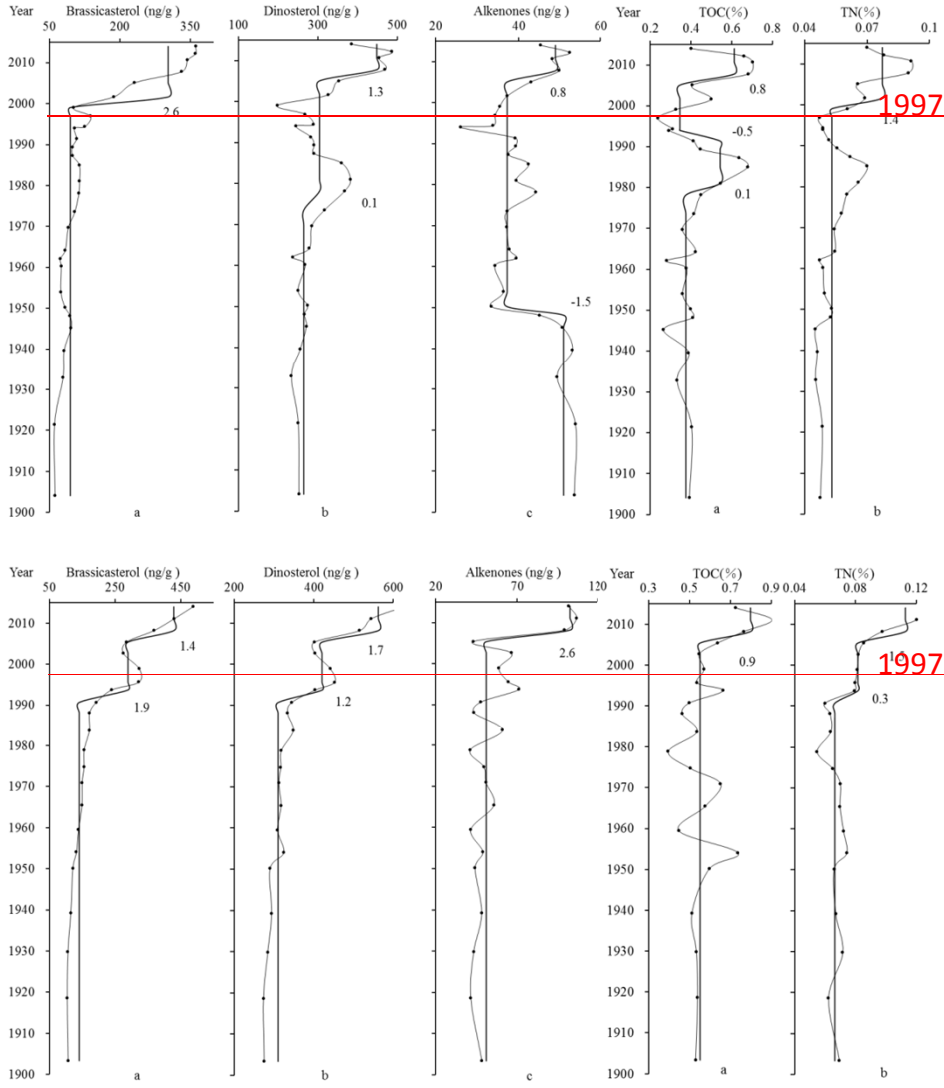
MAP: Broome 6725

In 2014 the water corporation's then-regional business manager Peter McAllister told community meetings and ABC Radio that the older of Broome's two sewage treatment plants was leaking 90 megalitres each year into Roebuck Bay.

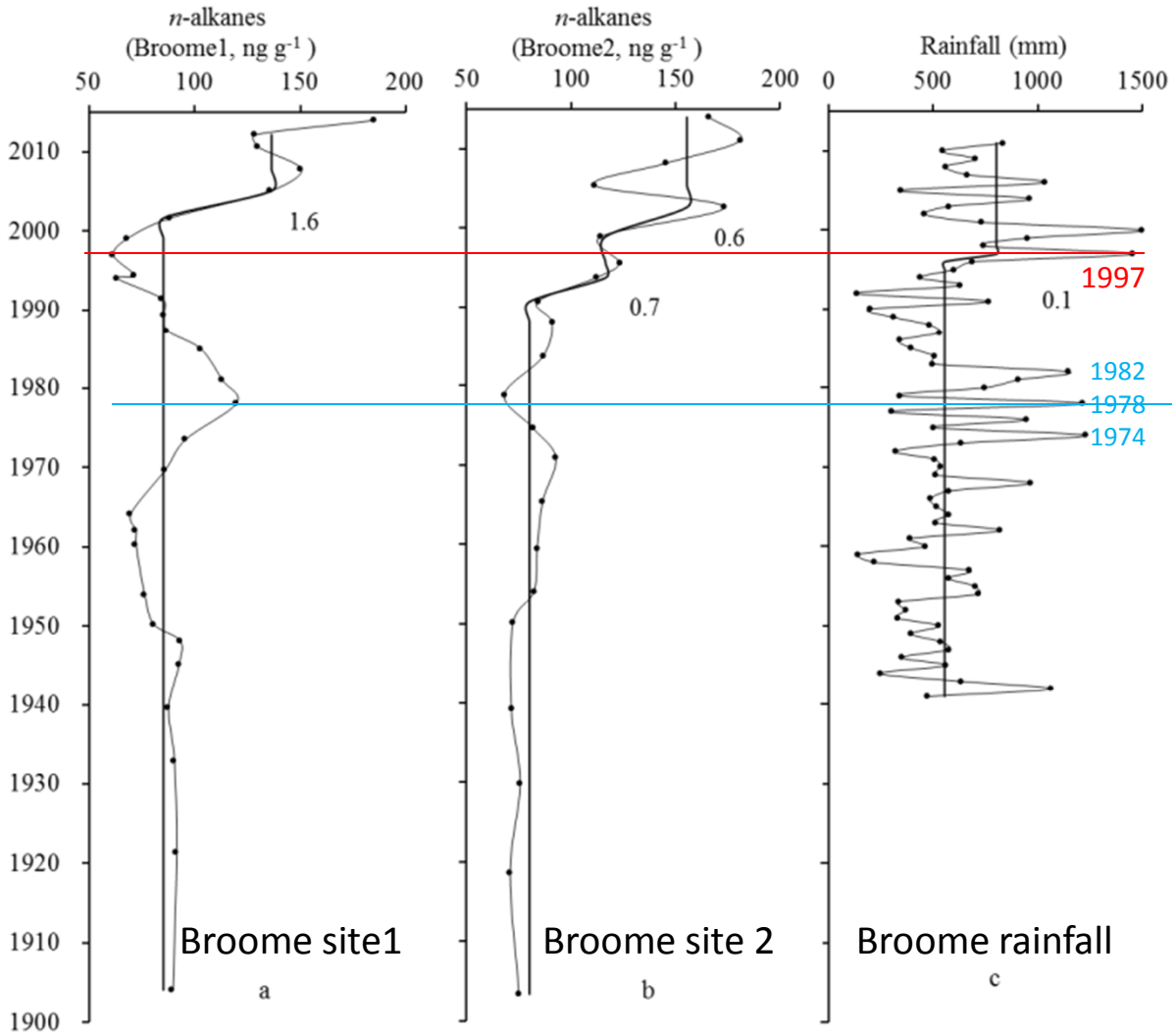
Biomarkers of terrestrial influence



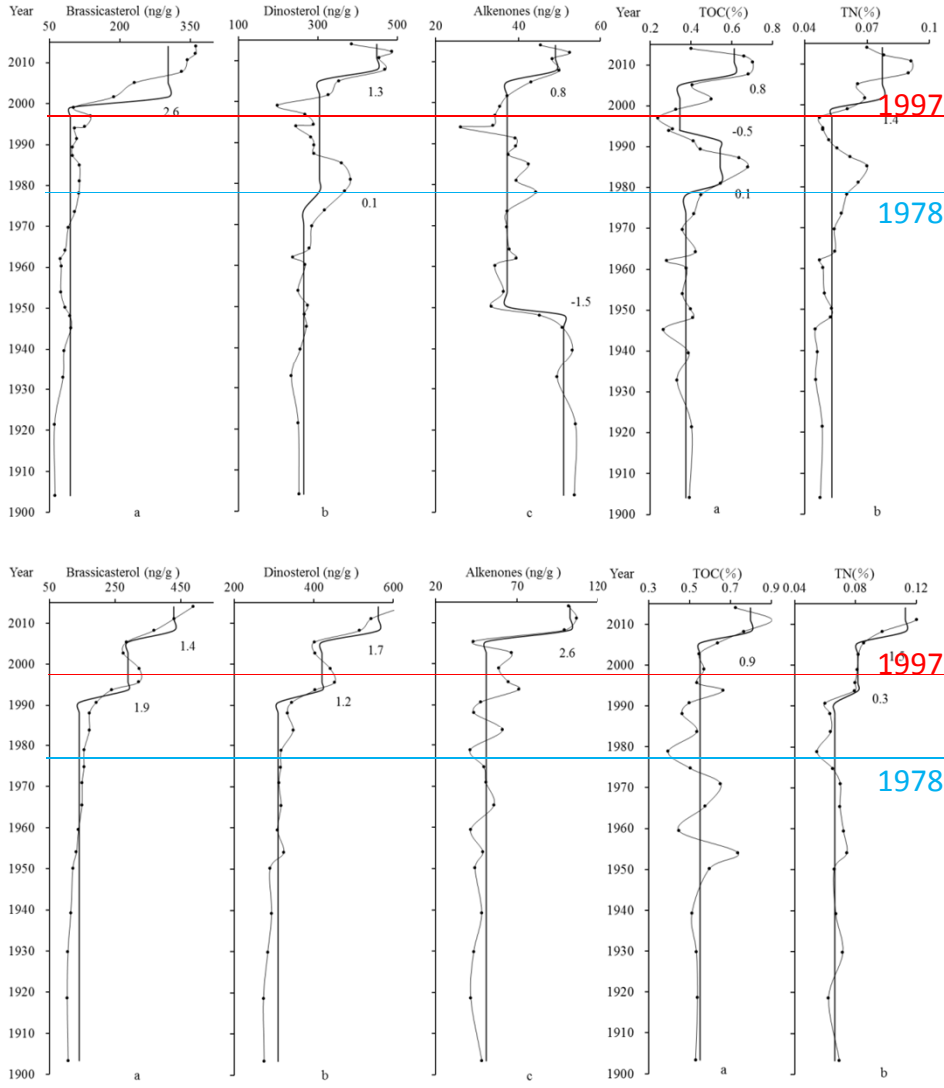
Broome site 1



Biomarkers of terrestrial influence



Broome site 1



Roebuck Bay and Broome

Two questions for Broome

There was recent controversy about whether leaking from the Broome WWTP is affecting water quality in Roebuck Bay.

Is data from the cores consistent with increased levels of nutrients in Roebuck Bay?

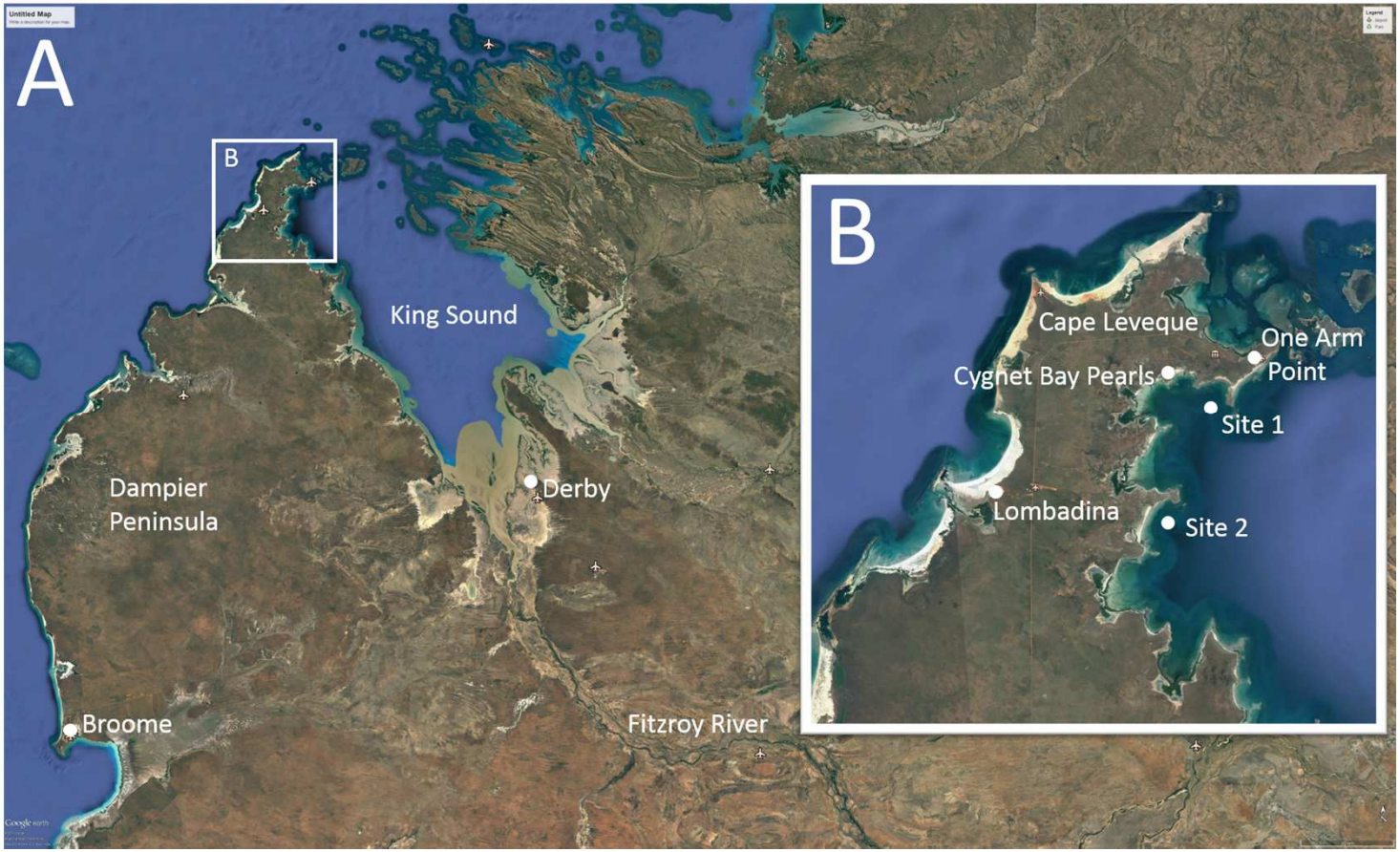
Nutrients have increased in sediments, probably more related to urban growth rather than specific event(s). But these changes also coincide with climate change impacts.

Broome rainfall has increased 41% since 1997 compared to the average from 1941-1996.

Do the cores infer any changes in water quality as a result of this?

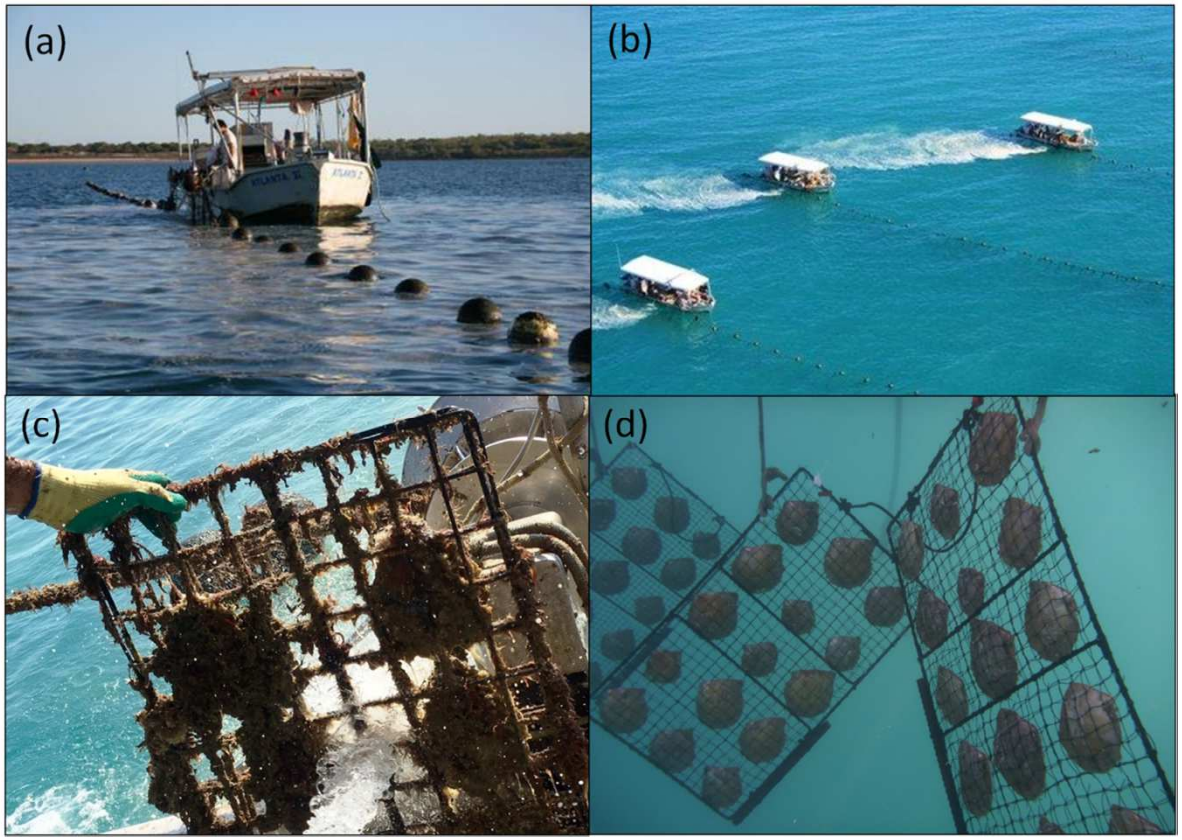
Both biomarkers of increased terrestrial influence and various indicators of increased productivity show a relationship with rainfall increase. But these changes coincide with temperature increases.

Cygnet Bay



Google Earth imagery showing, A. the location of study area in relation to King Sound and the Fitzroy River and influence of tidal creek systems and B, close up of Cape Leveque and sampling sites.

Cygnet Bay – pearl oyster farming



Modern long-line culture of pearl oysters in Cygnet Bay (a & b: cleaning/maintenance vessels tending long lines; c: biofouling of 8 shell culture cage before cleaning; d: 15 shell culture cages hanging on long line after cleaning).

Cygnet Bay

Two questions for Cygnet Bay

Pearl framing has been undertaken at Cygnet Bay since the 1960s and is traditionally regarded as an anthropogenic activity with low environmental risk.

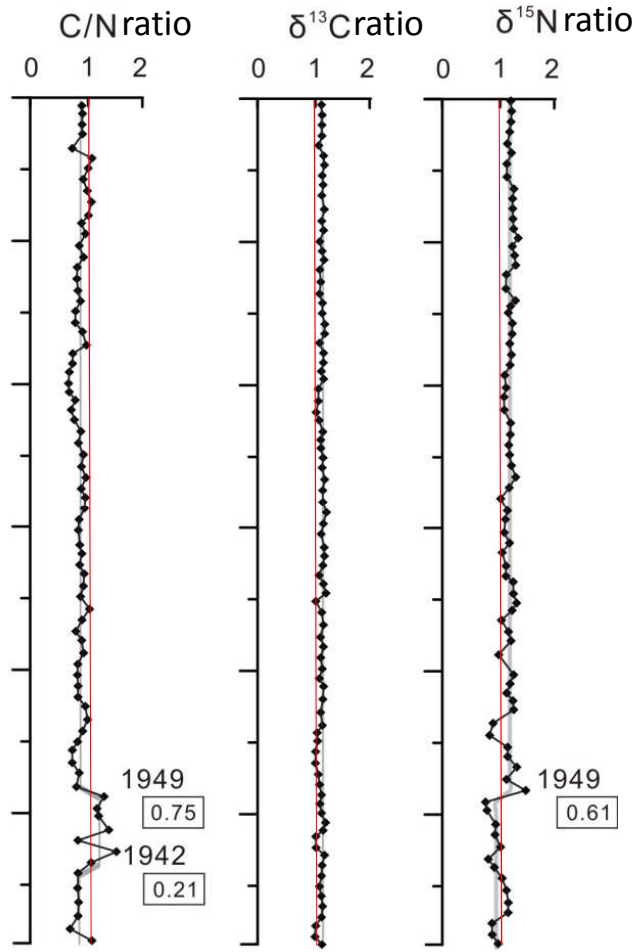
Does the sediment profile reveal any changes over time attributable to pearl oyster farming?

Climate change has resulted in rises in sea temperature and increased rainfall in the Kimberley.

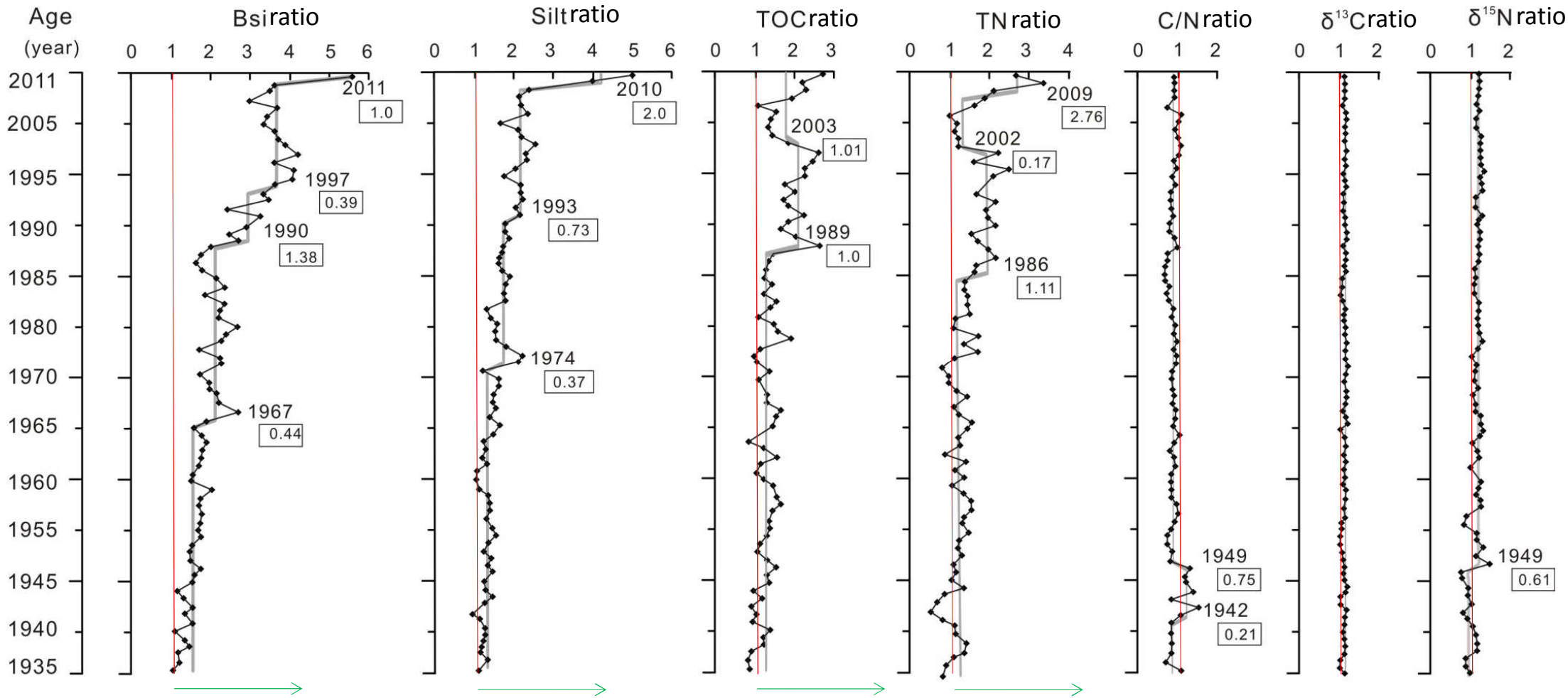
Do the cores indicate any changes in water quality as a result of this?

Same trends in C/N ratio, ^{13C} and ^{15}N in both on and off farm sites suggest:

- no anthropogenic nitrogen pollution
- similar natural environmental influences at both sites

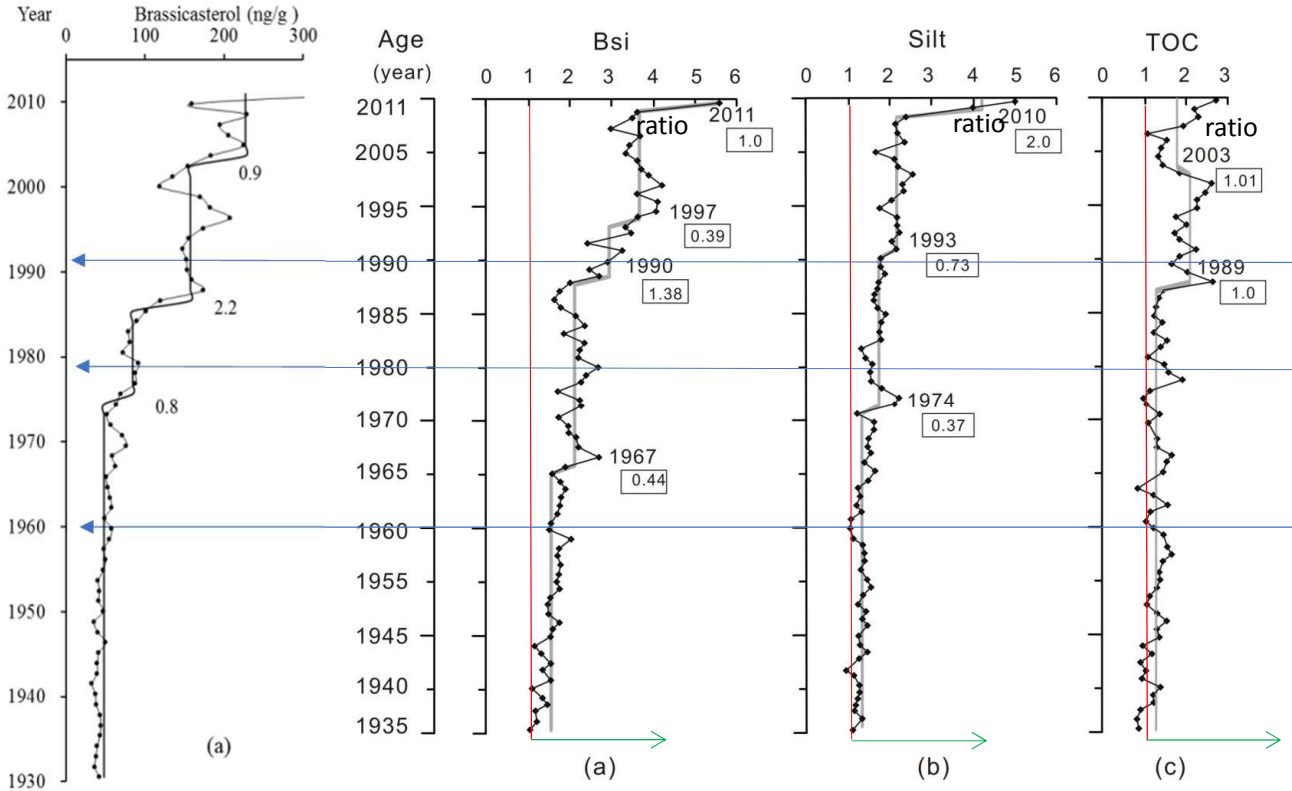


Ratios of each parameter farm site/ non farm site



Trend to right of red line (ratio of 1) means parameter is higher in farm core site

Ratios of each parameter farm site/ non farm site



Ratios of each parameter
farm site/ non farm site

Modern intensive long-lines introduced 1990s

Oyster stock levels expanded 1980s

Pearl farming starts 1960s

Trend to right of red line (ratio of 1)
means parameter is higher in farm site

Increasing trend in organic carbon, total nitrogen, biosilicate and silt suggest farm has influenced these parameters.

Possible explanations:

- Longlines slow current flow so more fine particles deposit in the sediment
- Oysters produce pseudofeces increasing organic deposition
- Cleaning of fouling on shells and cages contributes to organic deposition
- Diatoms respond to increased organic matter and consequent nutrient fluxes

Cygnet Bay

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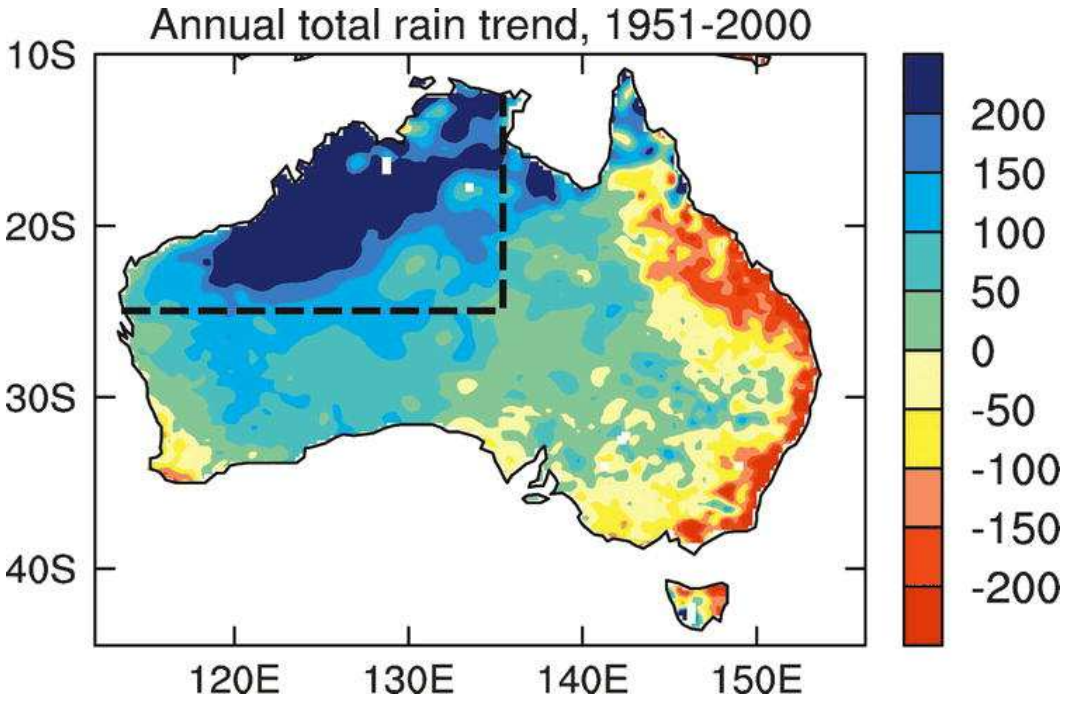
Increases in organic matter, diatom biomass and fine-grained sediment at the farm site displayed significant increases coincident with the advent of modern long-line culture methods and the expansion of oyster stocking. The results indicate that small environmental changes over long periods of time can be detected using these methods. (see Liu, D., Peng, Y., Keesing, J. K., Wang, Y., & Richard, P. 2016. Paleo-ecological analyses to assess long-term environmental effects of pearl farming in Western Australia. *Marine Ecology Progress Series*, *552*, 145-158).

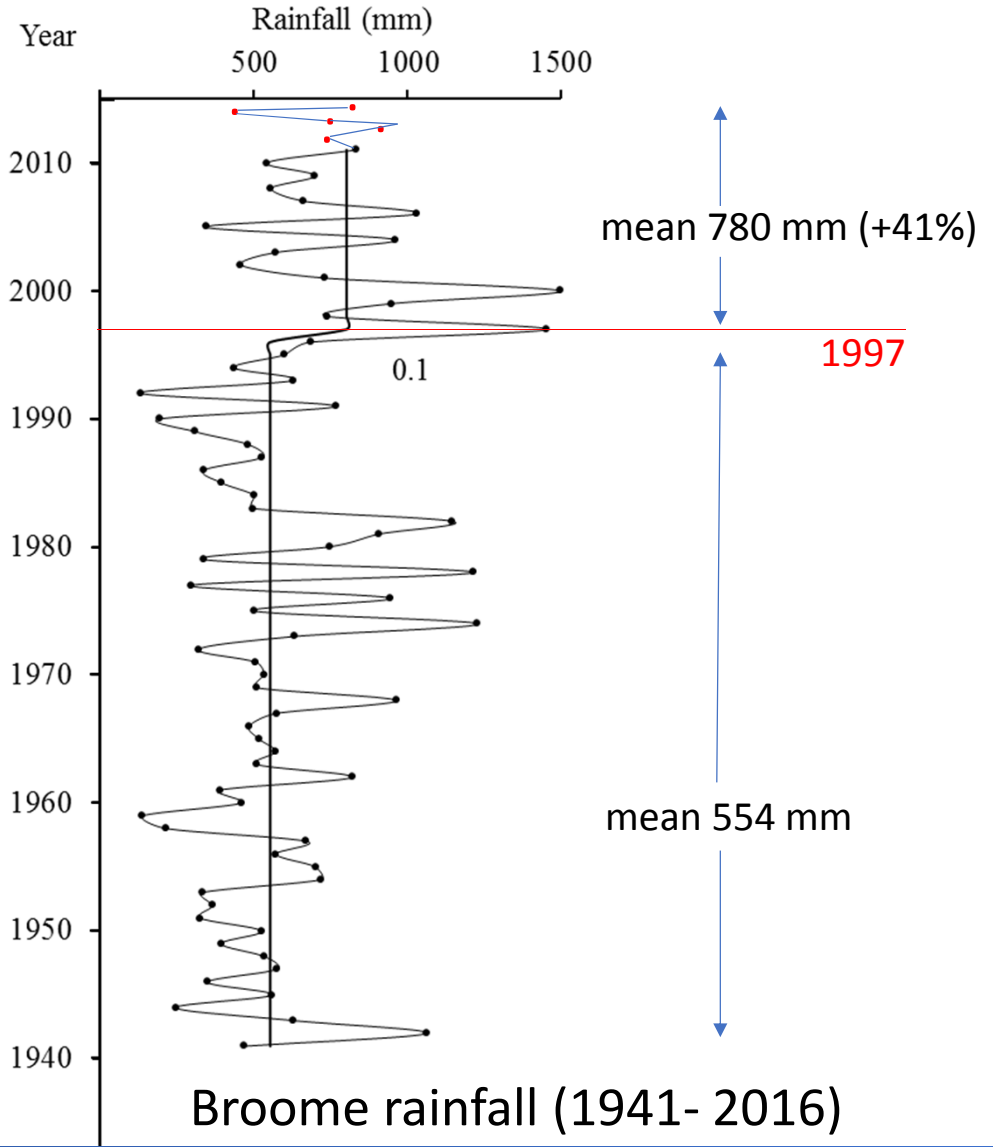
Climate change has resulted in rises in sea temperature and increased rainfall in the Kimberley.

Do the cores indicate any changes in water quality as a result of this?

Climate change in NW Australia

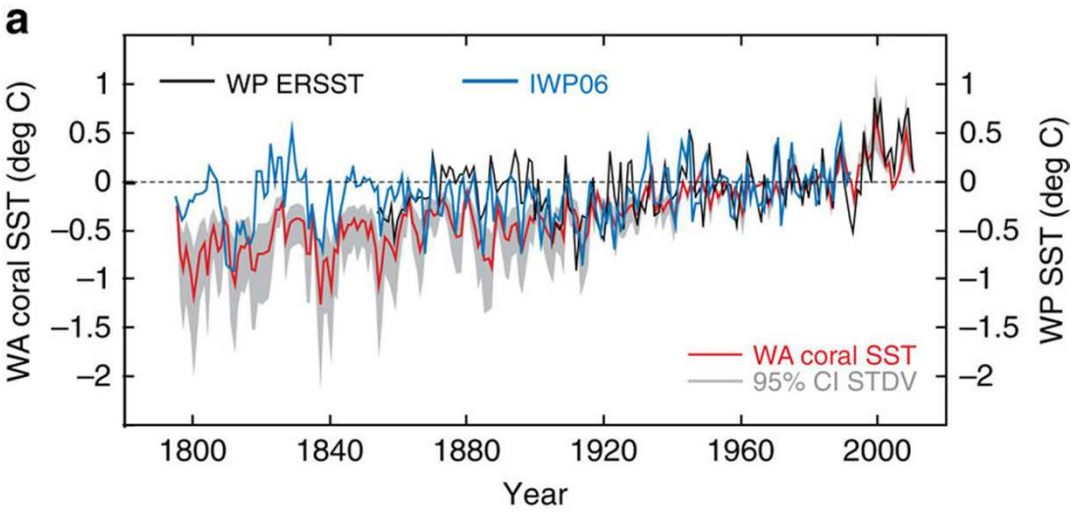


Observed annual total rainfall trend (mm) based on the BMRC rainfall data over 1951–2000. Blue color shows rainfall increase and red indicates rainfall reduction. Shi, G., Cai, W., Cowan, T., Ribbe, J., Rotstayn, L., & Dix, M. (2008). Variability and trend of North West Australia rainfall: observations and coupled climate modeling. Journal of Climate, 21(12), 2938-2959.

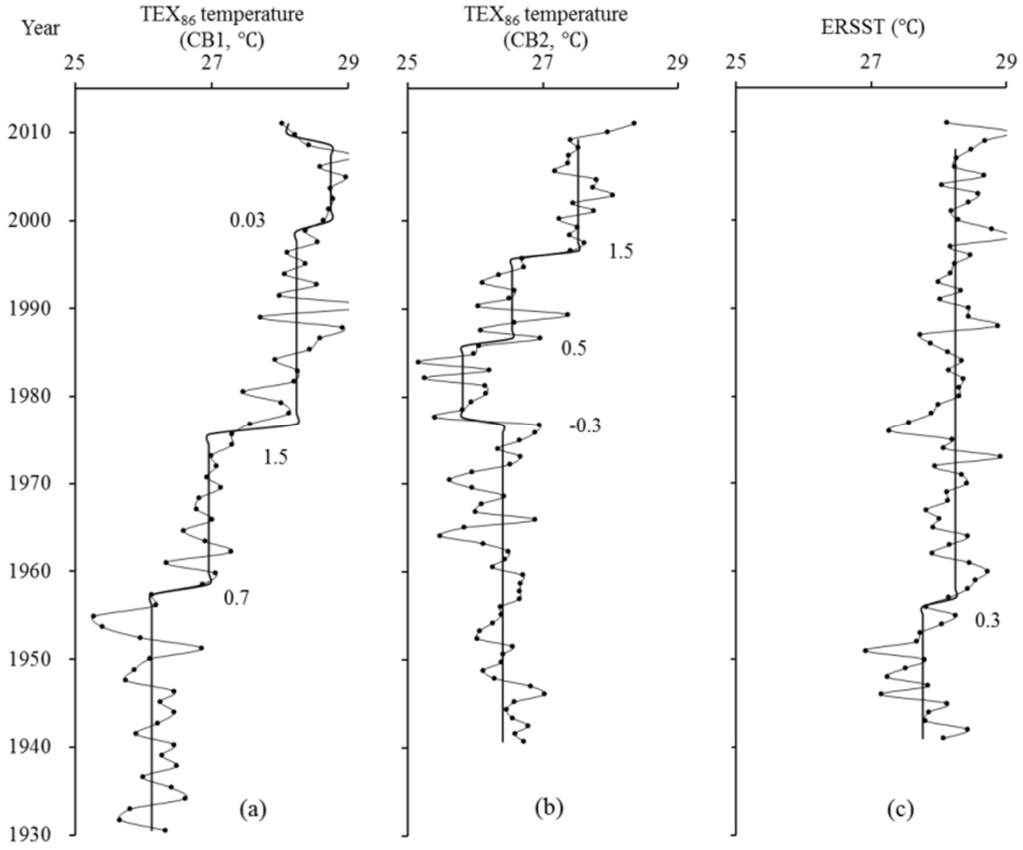


Broome rainfall (1941- 2016)

Cygnet Bay - Climate change in NW Australia

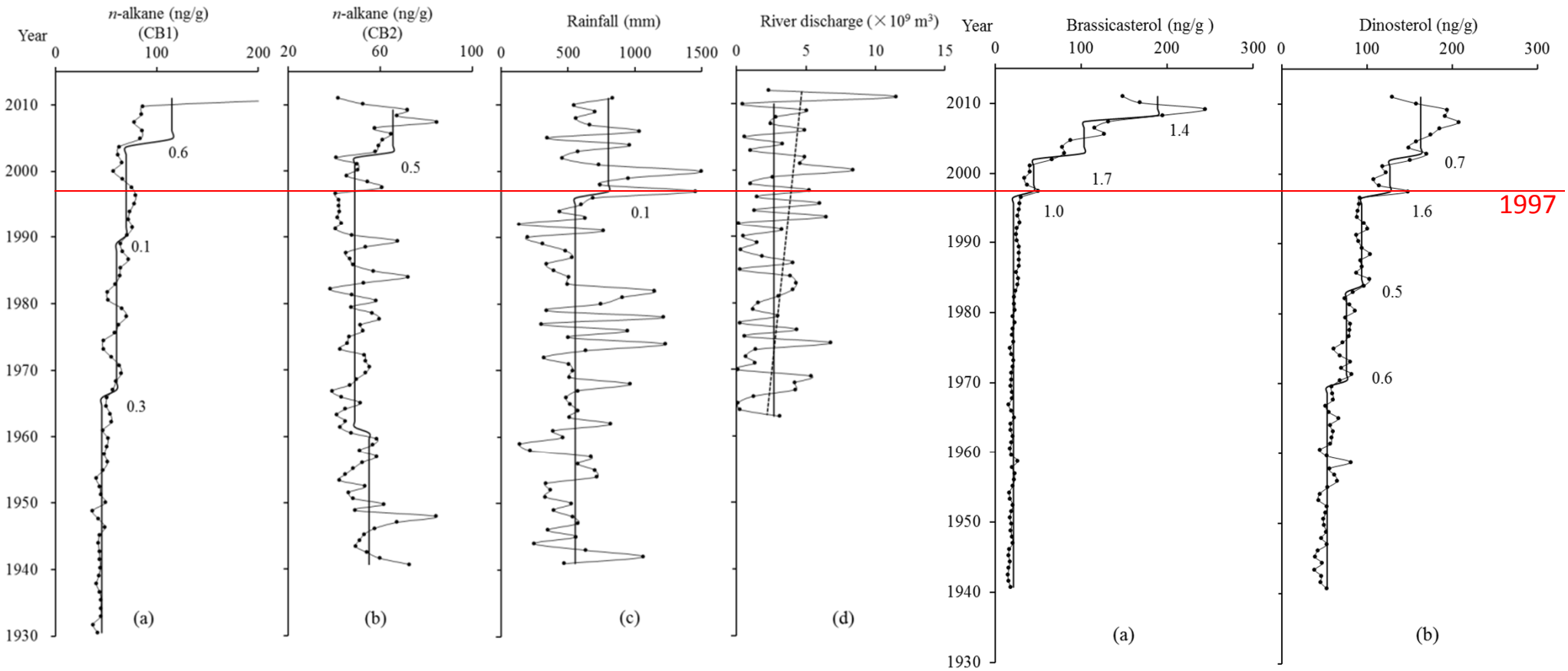


(**a**) Reconstructed annual WA coral SST anomaly (red) with 95% confidence interval (grey shaded) based on the spread of both coral and ERSST standard deviations between 1961 and 1990 compared with Indonesian warm pool (IWP06; blue) and WP SST anomaly reconstructions (WP ERSST; black). SST anomalies are relative to 1961–1990 mean. Zinke, J., Hoell, A., Lough, J. M., Feng, M., Kuret, A. J., Clarke, H., ... & McCulloch, M. T. (2015). Coral record of southeast Indian Ocean marine heatwaves with intensified Western Pacific temperature gradient. *Nature Communications*, *6*, 8562.

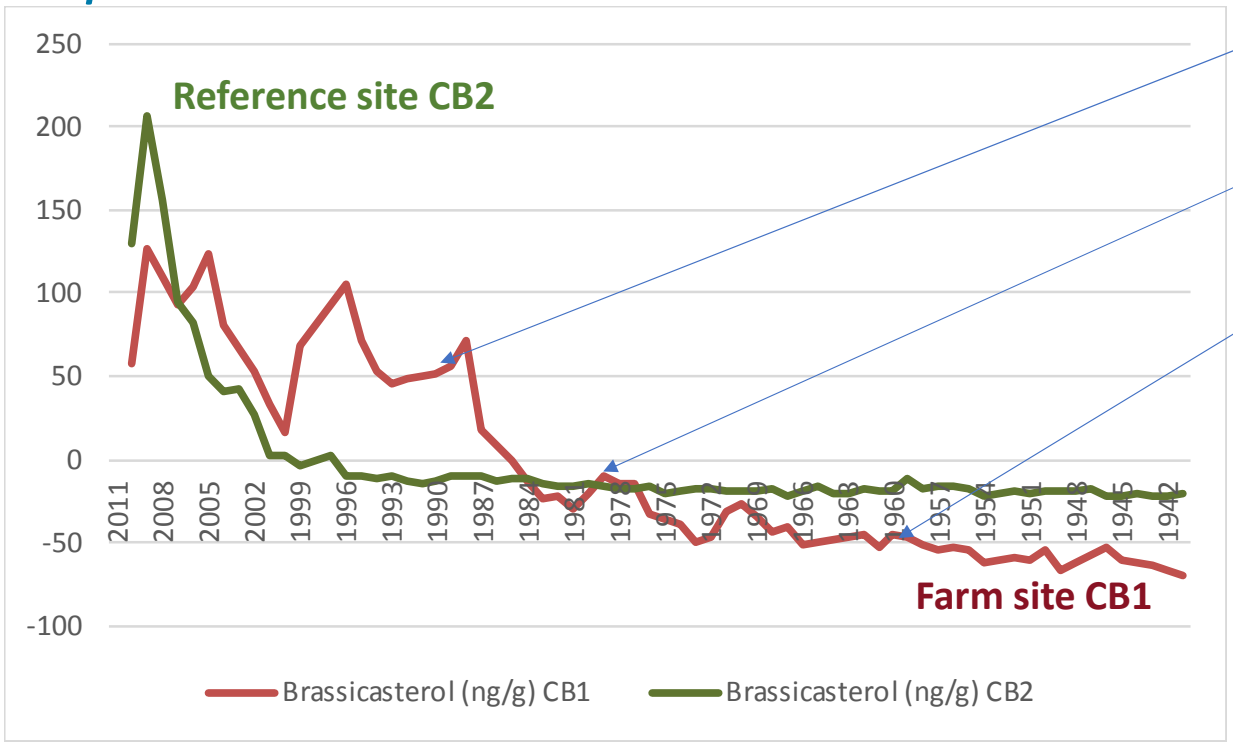


Profiles of sea temperature records (a: TEX_{86}^{H} temperature at CB1; b: TEX_{86}^{H} temperature at CB2; c: ERSST from 1940-2011).

Cygnet Bay - Climate change in NW Australia



Cygnet Bay – climate change vs aquaculture impacts



Long term levels of Brassicasterol (yearly minus long term average) at Cygnet Bay

Brassicasterol is a proxy for diatom biomass

Cygnet Bay

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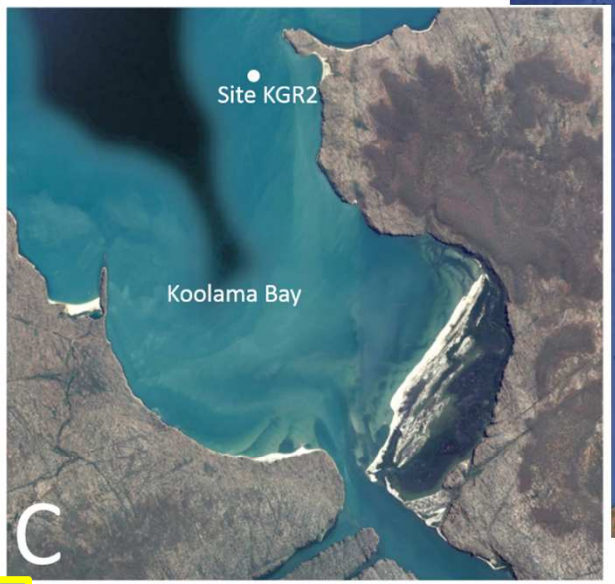
Climate change has resulted in rises in sea temperature and increased rainfall in the Kimberley.

Do the cores indicate any changes in water quality as a result of this?

An increase in phytoplankton biomass in the cores is coincident with increased temperature and rainfall. Correlation analysis suggests these changes are more related to temperature than rainfall.

King George River



Koolama Bay at the entrance to the King George River offered a chance to examine the influence of significant seasonal riverine input to the coastal environment and was compared with a reference site in a bay nearby without direct river flow into it.

In addition to other parameters, we also looked at black carbon as a proxy for bushfire occurrence

Bushfire

The Kimberley region. The red dots represent heat detected by a satellite October 10, 2016. The black areas near the dots are most likely recently burned. MODIS/Wildfire Today.

10-day composite hotspot map from the NASA MODIS Rapid Response website. 8-17 September 2007.

Black carbon

"Black carbon" or elemental carbon (EC) is produced from incomplete combustion of biomass and fossil fuels

There are two types of black carbon, i.e., char and soot.

Biomass burning (e.g. a bush fire) generates a much higher percentage of char than soot (char/soot ratio of >5–10). Motor vehicle exhausts have a ratio of char/soot typically lower than 1.

In remote area catchments like in the Kimberley, we would expect very low levels of soot relative to char.

Black carbon from bushfires can make its way into marine sediments in two ways; it can settle from the atmosphere, and it can be transported from the site of the fire by runoff and then discharged from rivers.

Thus the amount of EC in coastal sediments may depend not only on the extent of fires but also of rainfall and other factors affecting runoff and river discharge.

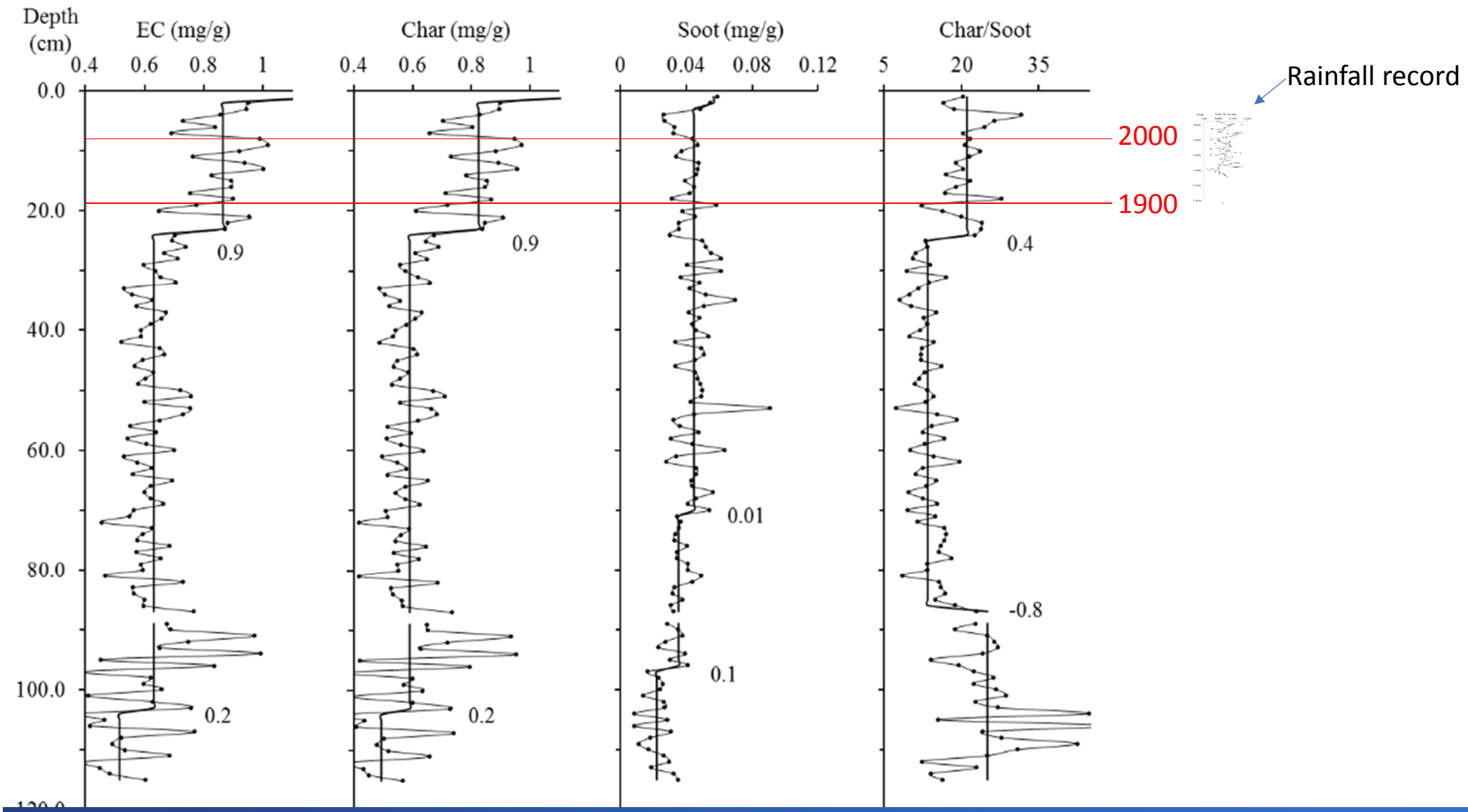
King George River

Three questions for King George River

Does the amount of black carbon vary over time in the sediment cores?

Can variation in the amount of black carbon be related to rainfall or river discharge in the King George River Catchment?

Can variation in the amount of black carbon be related to bush fire frequency and intensity in the King George River Catchment?


Depth (cm)
EC (mg/g)
0.4 0.6 0.8 1
Char (mg/g)
0.4 0.6 0.8 1
Soot (mg/g)
0 0.04 0.08 0.12
Char/Soot
5 20 35
0.0
20.0
40.0
60.0
80.0
100.0
0.9
0.9
0.4
0.01
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0.1
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2000
1900
Rainfall record


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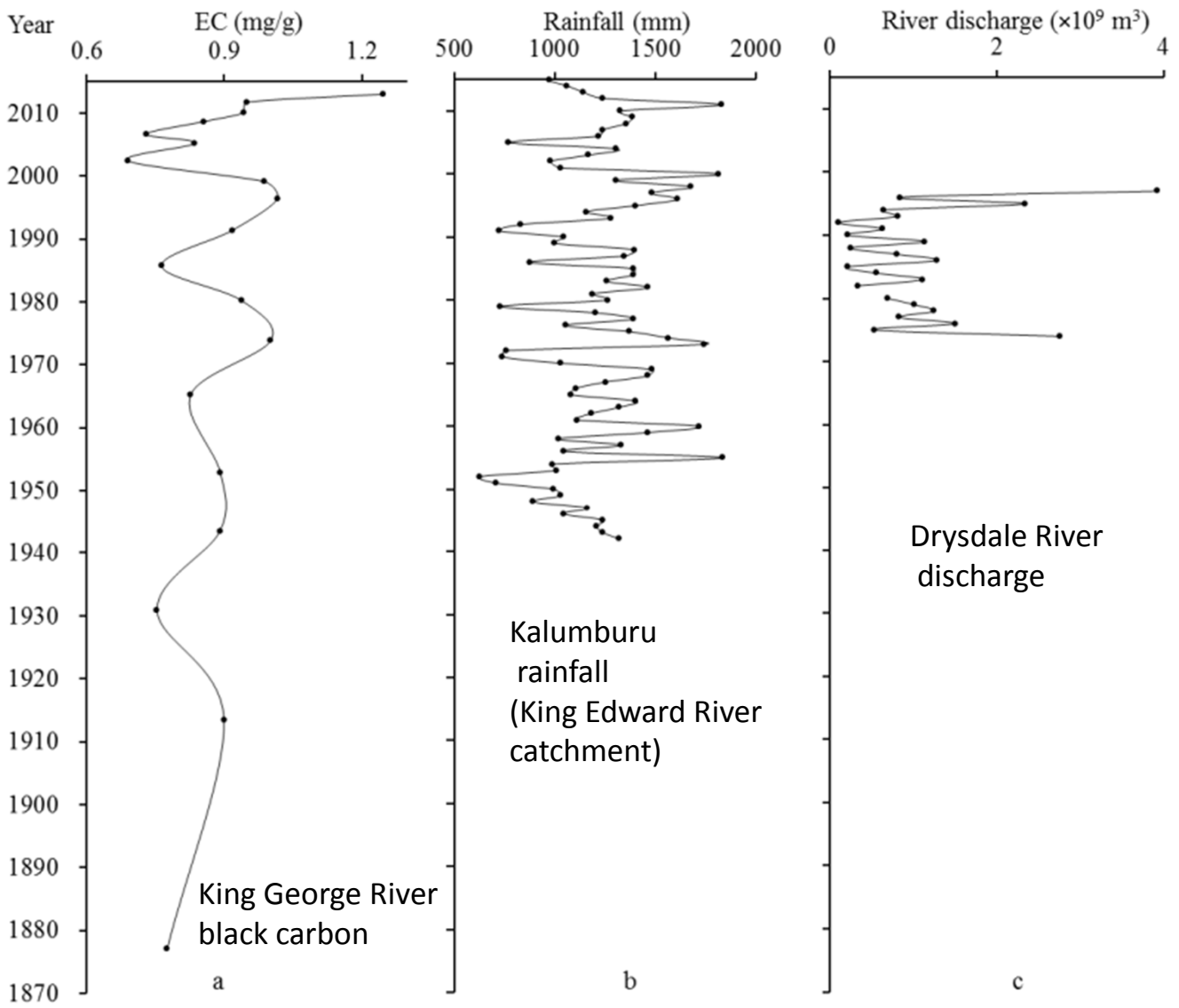
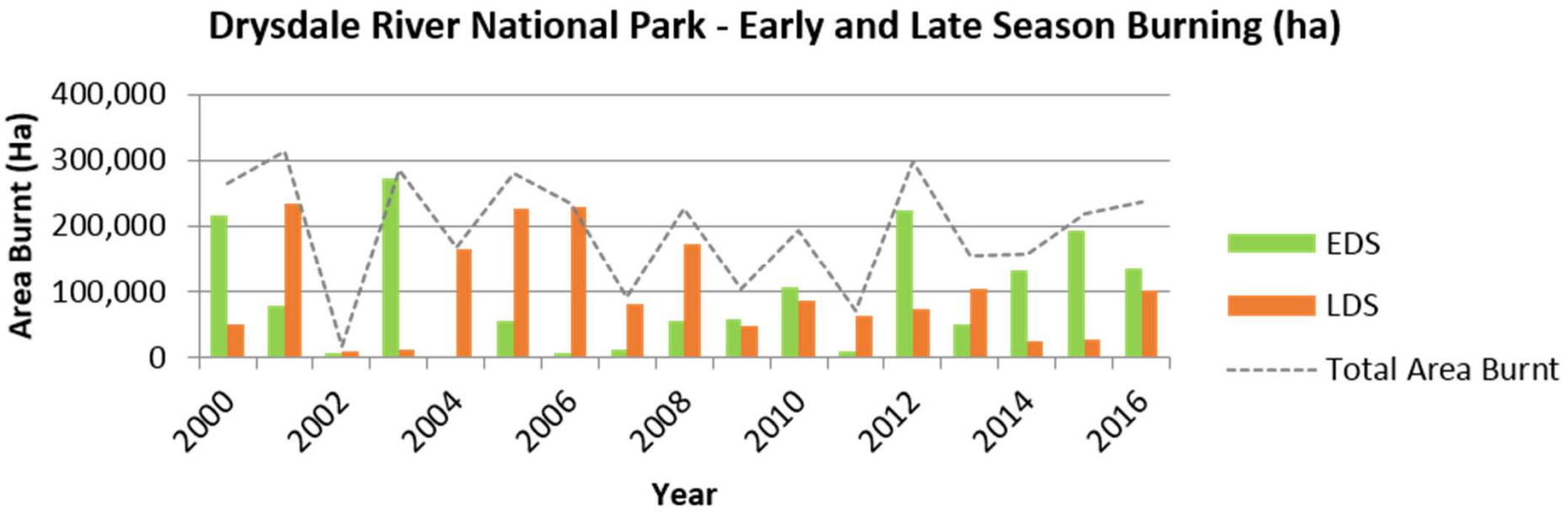

Year
EC (mg/g)
0.6
0.9
1.2
Rainfall (mm)
500
1000
1500
2000
River discharge (×10⁹ m³)
0
2
4
2010
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1880
1870
King George River black carbon
Kalumburu rainfall (King Edward River catchment)
Drysdale River discharge
a
b
c

Kimberley bush fire records



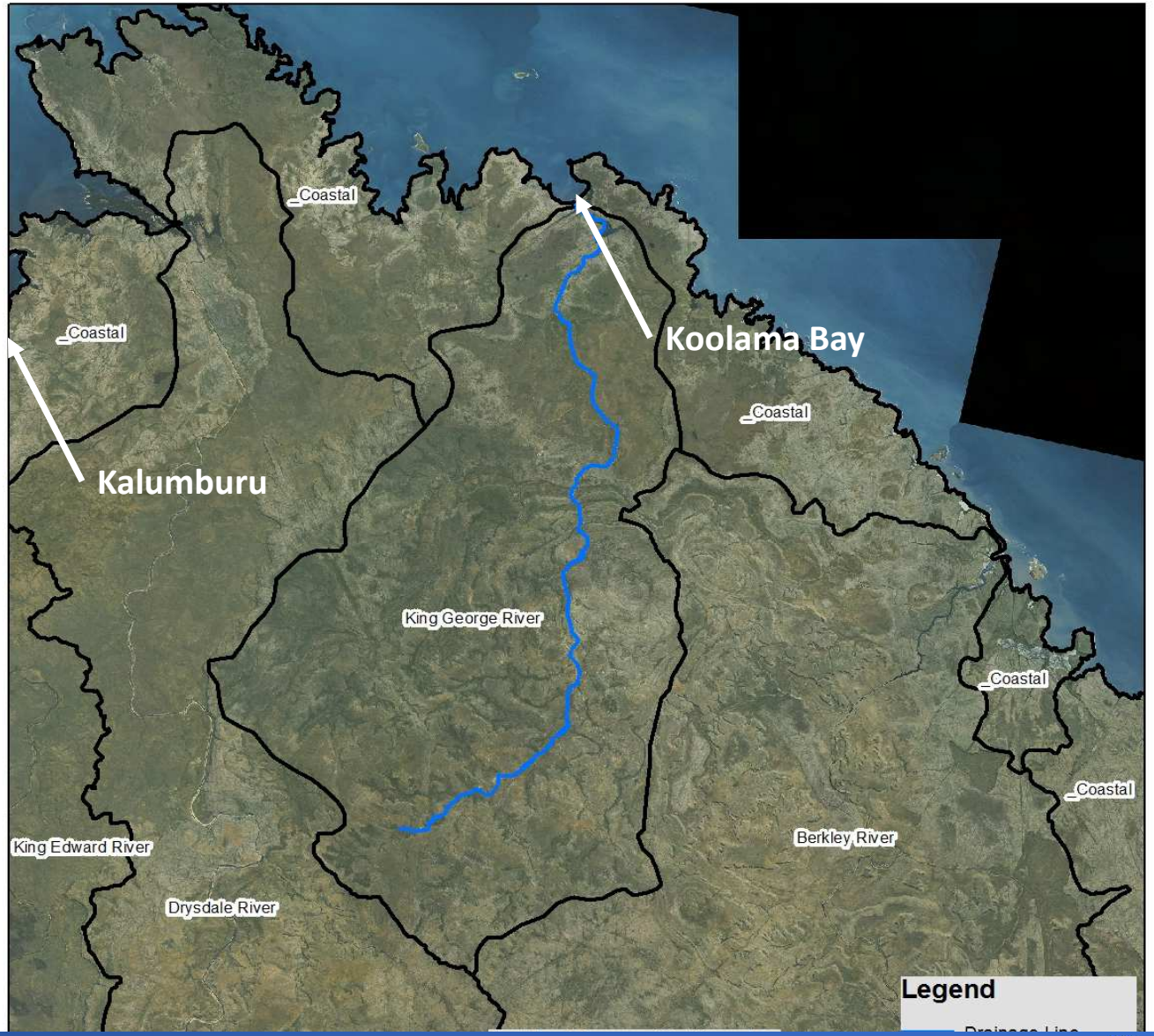
Courtesy J. Kinlock and G. Pitt (DPaW GIS)

King George River catchment

Nearest rainfall data is from Kalumburu in the King Edward River catchment (from 1941)

Nearest river discharge data is from the Drysdale River – incomplete set from mid 1970s to mid 1990s

Surprisingly low sedimentation rates in our cores limited the depth of the age profile (more than 100 years in top 20 cm)



King George River

Three questions for King George River

Does the amount of black carbon vary over time in the sediment cores?

The amount of black carbon, and char in particular increases from about 1850

Can variation in the amount of black carbon be related to rainfall or river discharge in the King George River Catchment?

?

Can variation in the amount of black carbon be related to bush fire frequency and intensity in the King George River Catchment?

?

Summary

Palaeoecological methods can be used to reconstruct a time series of environmental changes which can then be matched to other information to try and attribute cause and effect.

Has further potential for application in the Kimberley where long term data and environmental baselines are difficult to collect.

Core quality – sedimentation rate , sediment grain size and seabed disturbance all affect how well a core can be used to reconstruct a useful time series.