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Ningaloo in Perspective: directing the research agenda of coral reefs in the NW of WA and globally

Gary Kendrick

School of Biological Sciences and Oceans Institute, UWA

Ningaloo Reef

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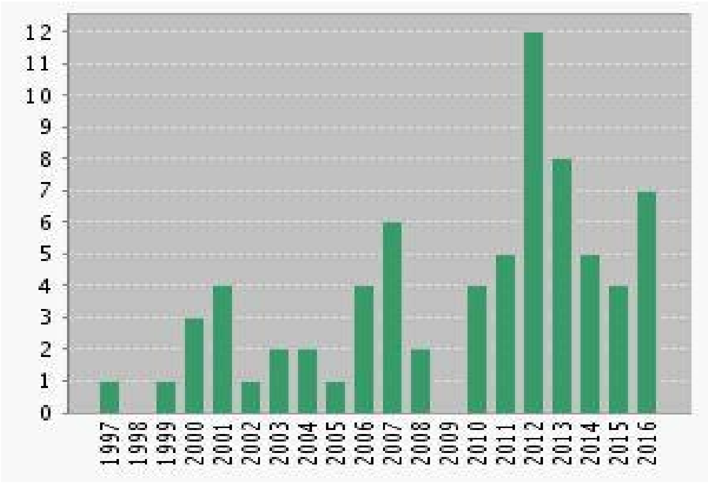
- Cape Range Declared a National Park in 1984.
- Ningaloo Marine Park established in 1987 (260 km of coastline)
- Ningaloo Coast World Heritage Area was inscribed in 2011 (705,015 ha)

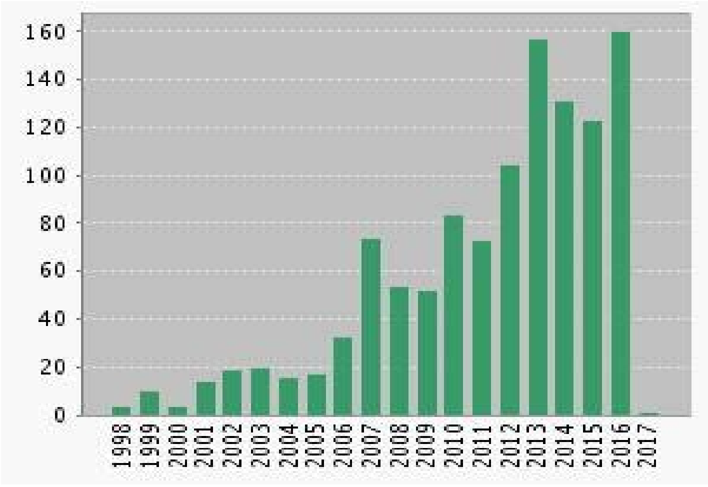
Modern Nature of Ningaloo Research

- Google Scholar search 'Ningaloo'
  - 2,270 articles total
  - 203 published since 2016
  - 1,106 since 2010
  - 75% (1,730) since 2000
- ISI Web of Science (Science and Social Science)
  - 358 articles total
  - 65% (233) since 2010

Publications (year)



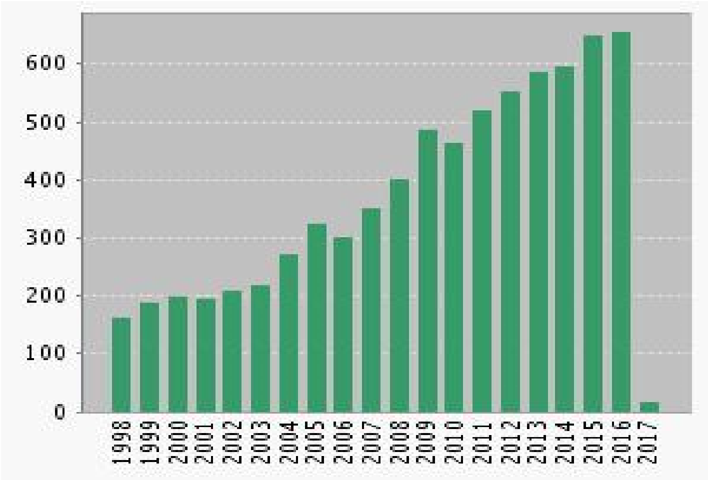
Citations (year)



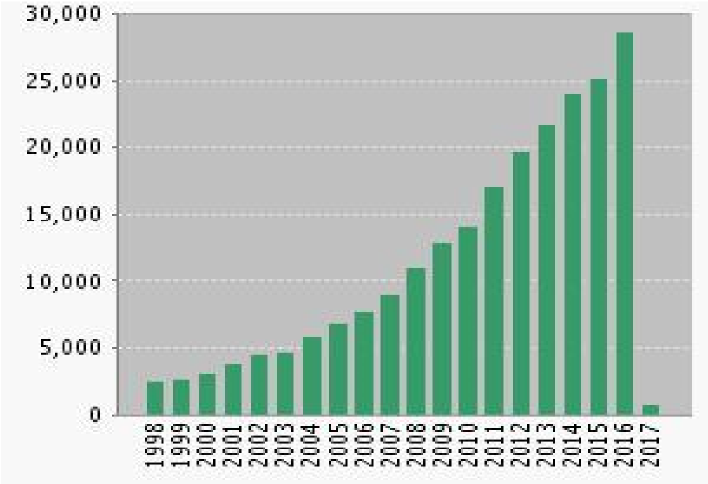
Great Barrier Reef

- 8710 published articles in ISI Web of Science
  - Over 600 publications each year for 2015 and 2016
  - 46% (4053) published since 2010

Publications (per year)



Citations (per year)



What is the impact of your research?

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- “World’s largest airborne hyperspectral survey of a coral reef” (Halina Kobryn, Murdoch)
- “Discovery of the offshore sponge gardens of Ningaloo, with diversity likely double that of the reef building corals. This work added additional evidence to the notion that for marine sponges Australia is a global biodiversity hotspot” (Andrew Heyward, AIMS)
- “The non-coral ecosystem components such as the seaweed beds in the lagoon are important” (Chris Fulton, ANU,Thomas Wernberg UWA)
- “Ningaloo research has really played a dominant role in understanding how oceanic processes shape reefs, globally”(Ryan Lowe, UWA)
- “A new method for mapping human use at Ningaloo has received global attention” (Claire Smallwood, Murdoch)

Mapping the Reef

Ningaloo Reef: Shallow Marine Habitats Mapped Using a Hyperspectral Sensor

Halina T. Kobryn[1]*, Kristin Wouters[1], Lynnath E. Beckley[1], Thomas Heege[2]

1 School of Veterinary and Life Sciences, Murdoch University, Murdoch, Western Australia, Australia, 2 EOMAP, Gilching, Germany

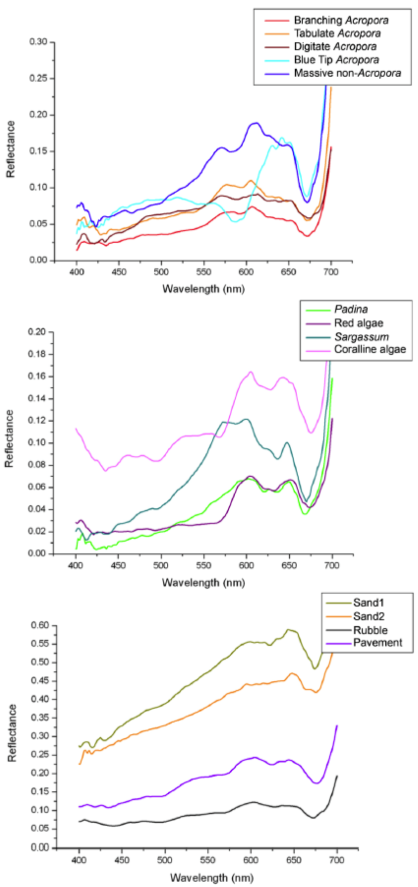

Figure 3. Spectral reflectance (mean values) for selected hard corals (top), macro-algae (centre) and abiotic cover (bottom) at Ningaloo Reef.
doi:10.1371/journal.pone.0070105.g003

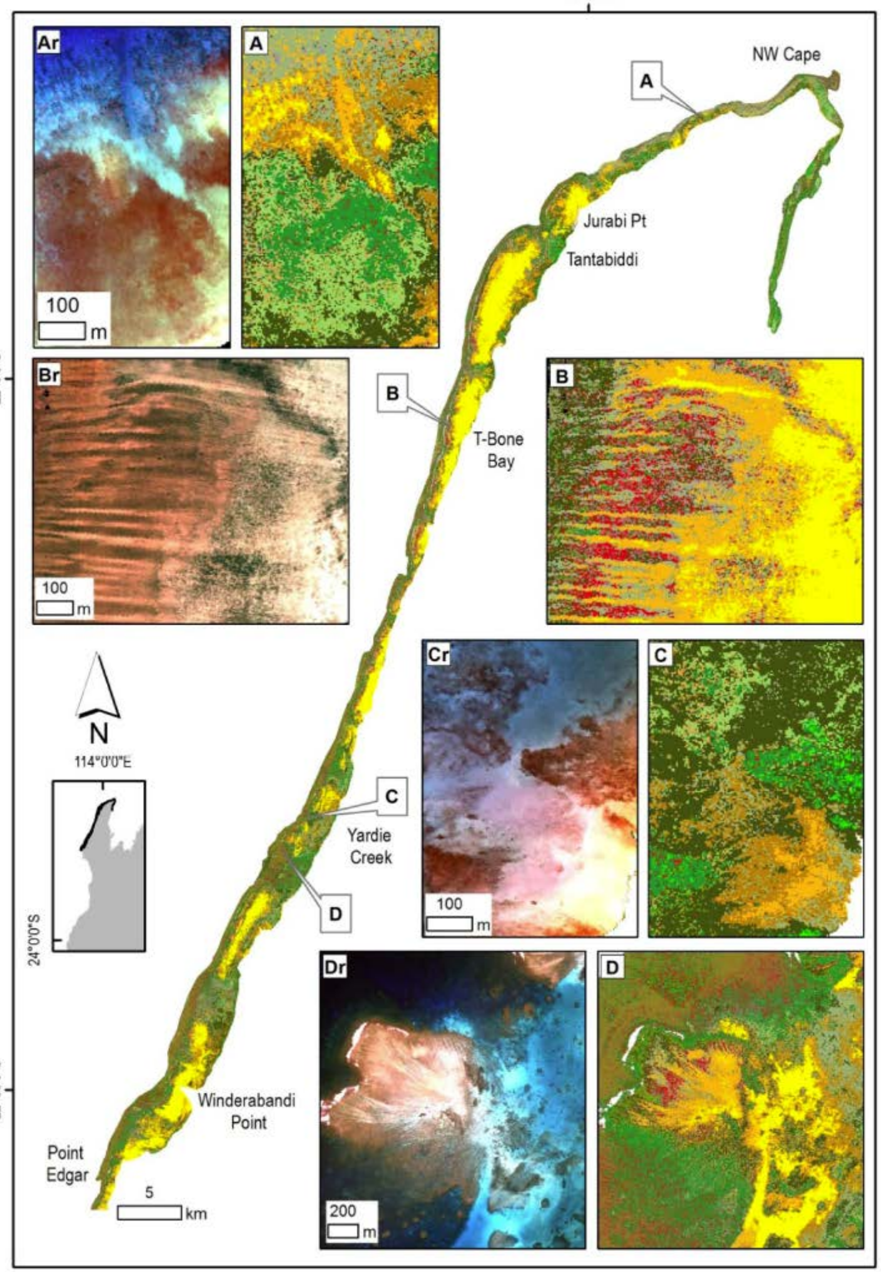

Figure 9. Overview of the northern region of the Ningaloo Reef with insets illustrating selected habitat maps and corresponding subsurface reflectance. (Ar) Subsurface reflectance of nearshore, sublittoral pavement along a rocky shore, (A) habitats of extensive macro-algae, limestone pavement and sand. (Br) Subsurface reflectance of outer reef flat, (B) spur and groove structures with coral and macro-algae transitioning to tabulate coral and sand in the deeper lagoon. (Cr) Subsurface reflectance of the littoral alluvial fan off Yardie Creek, (C) habitats with limestone pavement and adjacent macro-algae with sparse coral. (Dr) Subsurface reflectance of the back reef, (D) back reef on the northern edge of the reef pass with clusters of bommies south and east of the reef flats. Legend from Figure 5 applies.
doi:10.1371/journal.pone.0070105.g009

Deep Water Reefs

Colquhoun& Heyward 2007
WAMSI Node 3
AIMS, Curtin, UWA, WAM

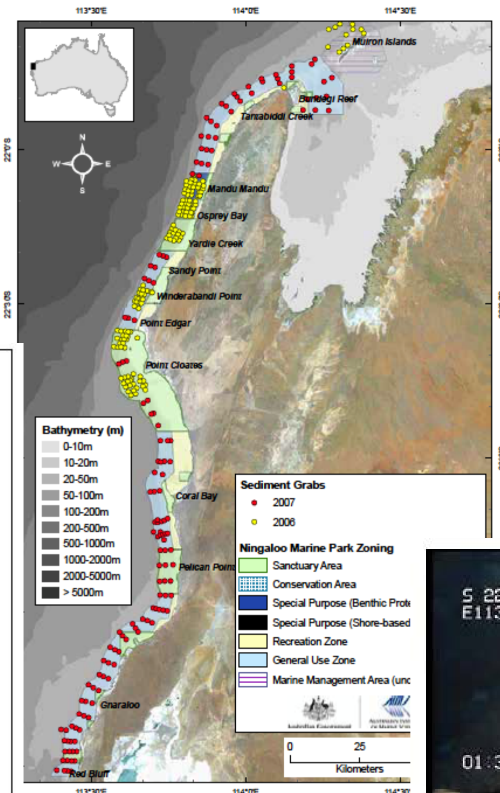

Figure 5. Offshore sediment grab sampling locations in the Ningaloo I

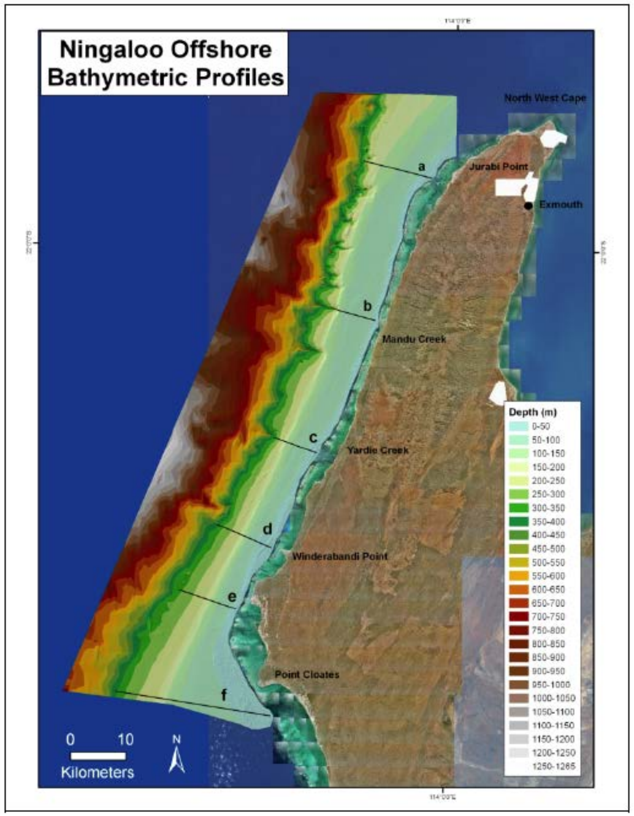

Figure 7. Locations of bathymetric profiles for the northern Ningaloo overlaid on RAN bathymetric model (created in ArcGIS™).

Figure 46. Limestone outcrops with prolific sponge growth.

Figure 47. Gorgonians, sponges and bryozoans (*Adeona* sp.).

Oceanography

The reef filters over 10,000 sq. kilometers of ocean

Courtesy: Anya Waite

Mechanics of wave-driven flows on reefs

Ryan Lowe, Greg Ivey and others

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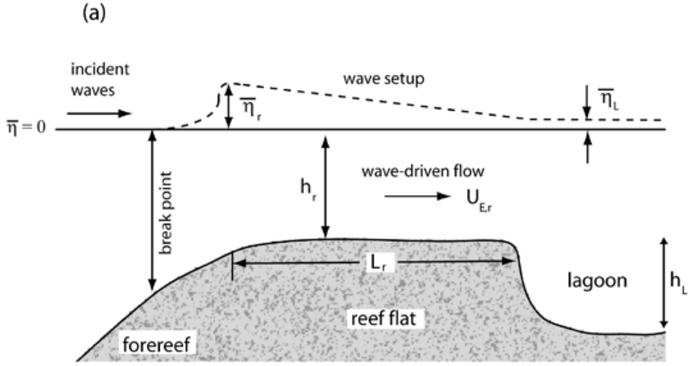
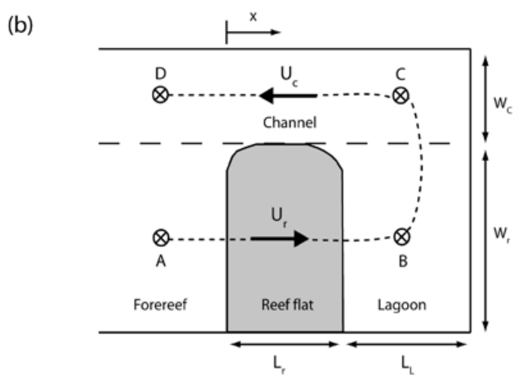
Large literature has been developed based on studying Ningaloo Reef

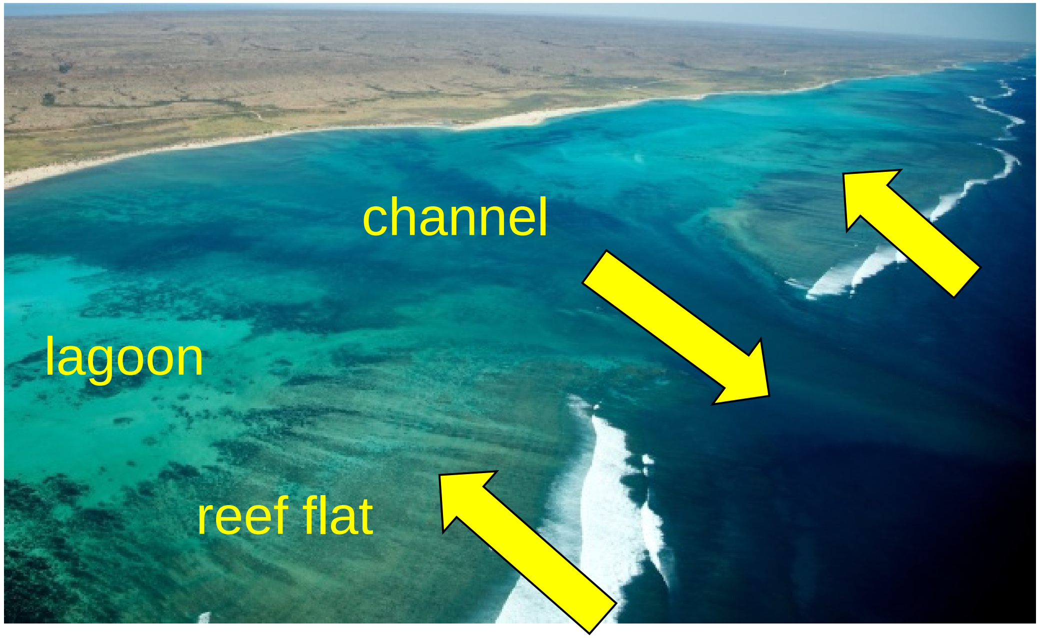
side view



plan view

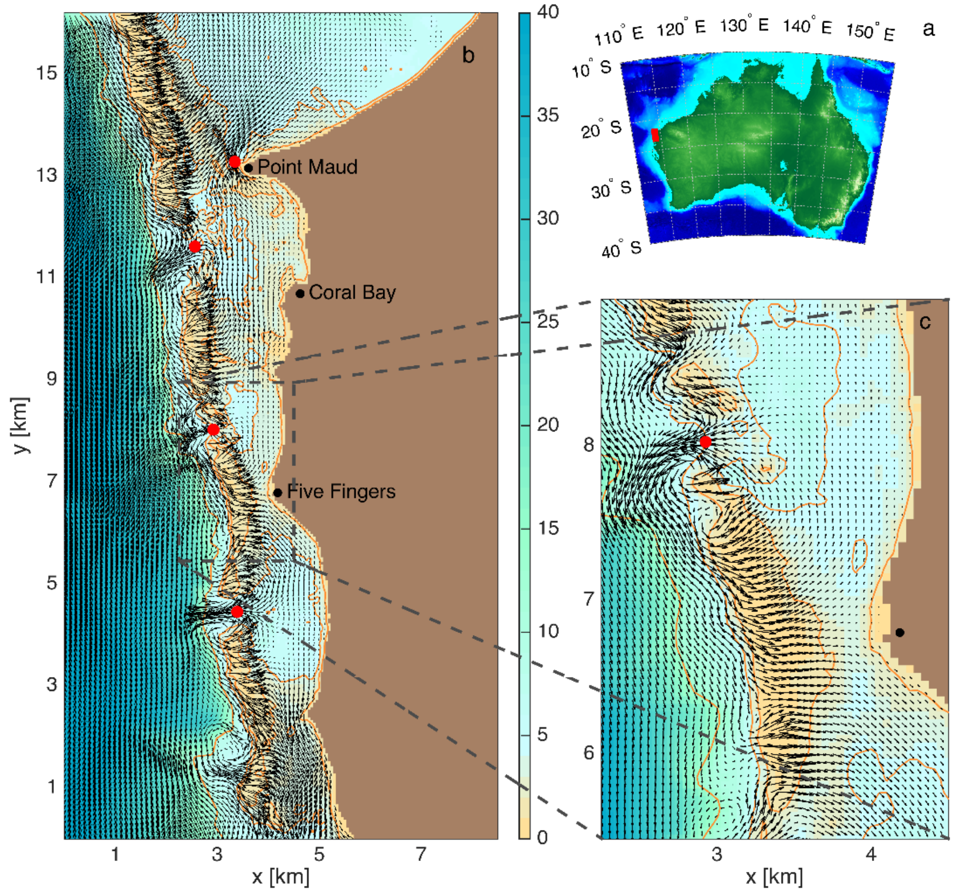


(Lowe et al. 2009)



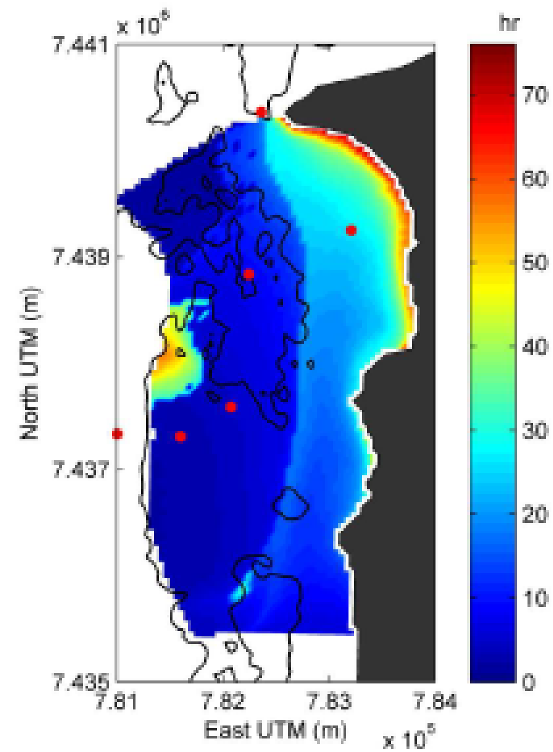
Drives fine-scale spatial variability in circulation and residence times

Implications for patterns of reef bleaching, fine-scale connectivity, nutrient recycling, etc.



(Leclair et al., 2017)

Coral Bay residence times



(Zhang et al. 2012)

Coral Research over time

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Destruction of corals and other reef animals by coral spawn slicks on Ningaloo Reef, Western Australia

C. J. Simpson, J. L. Cary and R. J. Masini

1990s

Mass spawning of corals on a high latitude coral reef

R. C. Babcock[1,*], B. L. Wills[2] and C. J. Simpson[3]

Enhancement of coral recruitment by *in situ* mass culture of coral larvae

2000

A. J. Heyward[1,*], L. D. Smith[1], M. Rees[1], S. N. Field[2]

Growth of Western Australian Corals in the Anthropocene

2010

Timothy F. Cooper,[1*] Rebecca A. O'Leary,[1] Janice M. Lough[2]

PeerJ

Coral reproduction in Western Australia

James Gilmour[1,2], Conrad W. Speed[1,2] and Russ Babcock[2,3]

[1] Australian Institute of Marine Science, The UWA Oceans Institute, Crawley, Western Australia, Australia
[2] Western Australian Marine Science Institution, Perth, Western Australia, Australia

Genetic structure within Ningaloo Reef

- Microsatellite analyses of population genetic structure of *Pocillopora damicornis*
- Significant population structure within Ningaloo Reef
- But large genetic neighborhoods and a high capacity for dispersal

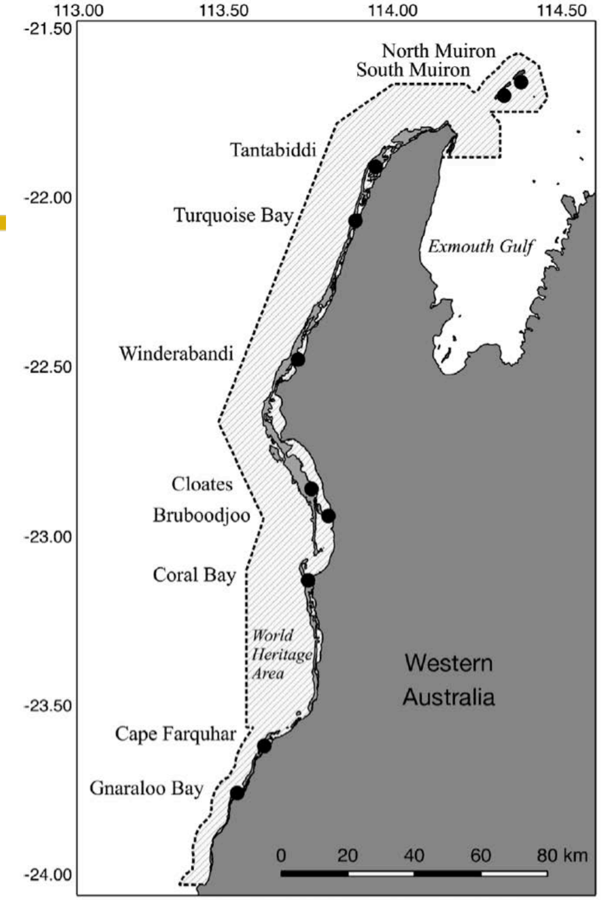
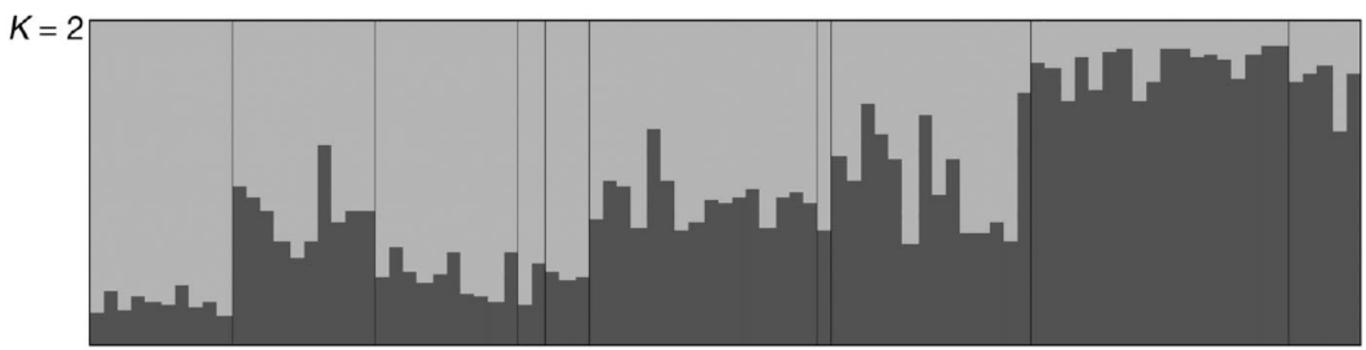
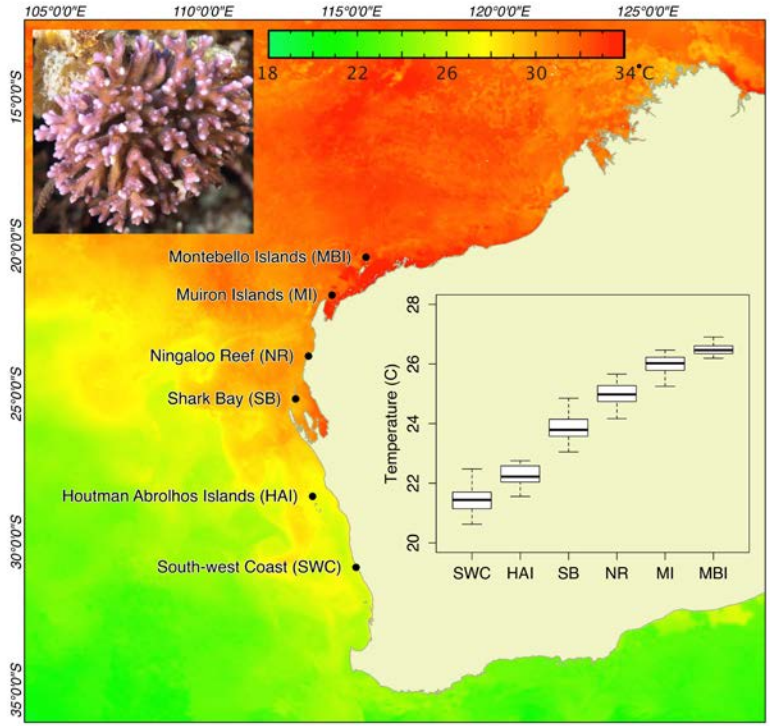


Fig. 1. Sample sites along Ningaloo Reef and Muiron Islands Management Area

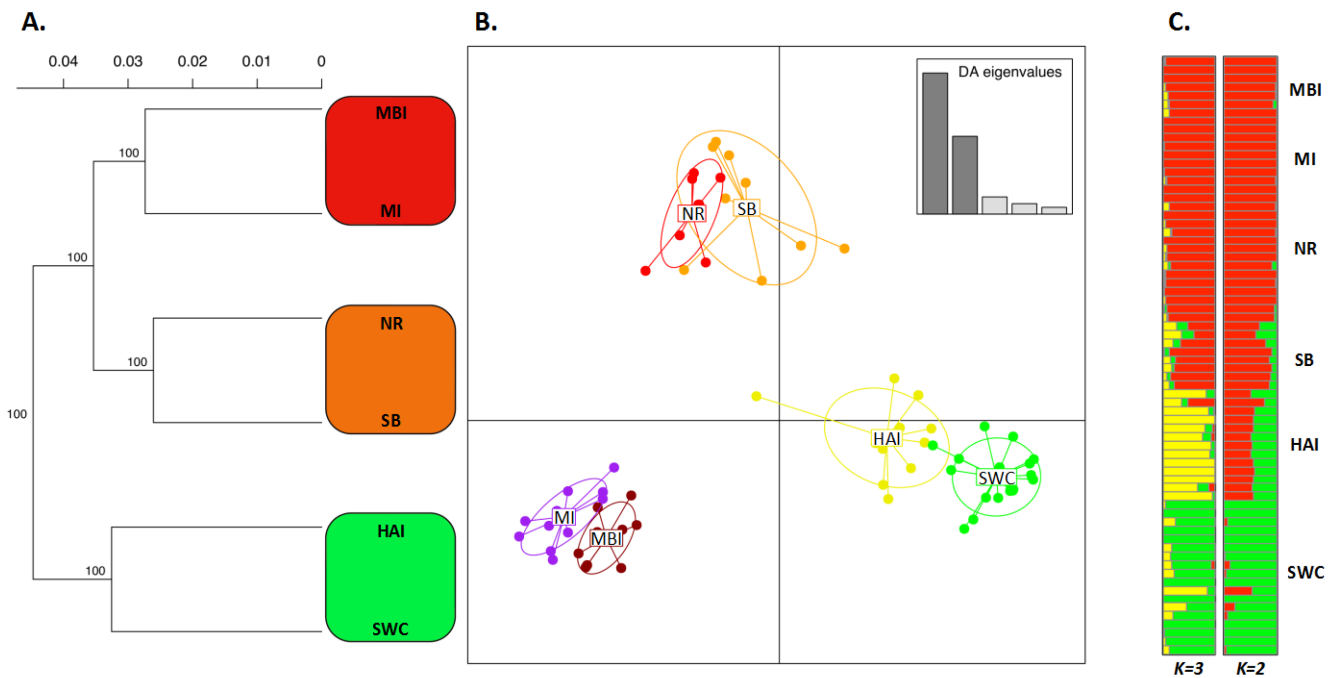


Thomas et al. 2014

Genetic structure among regions



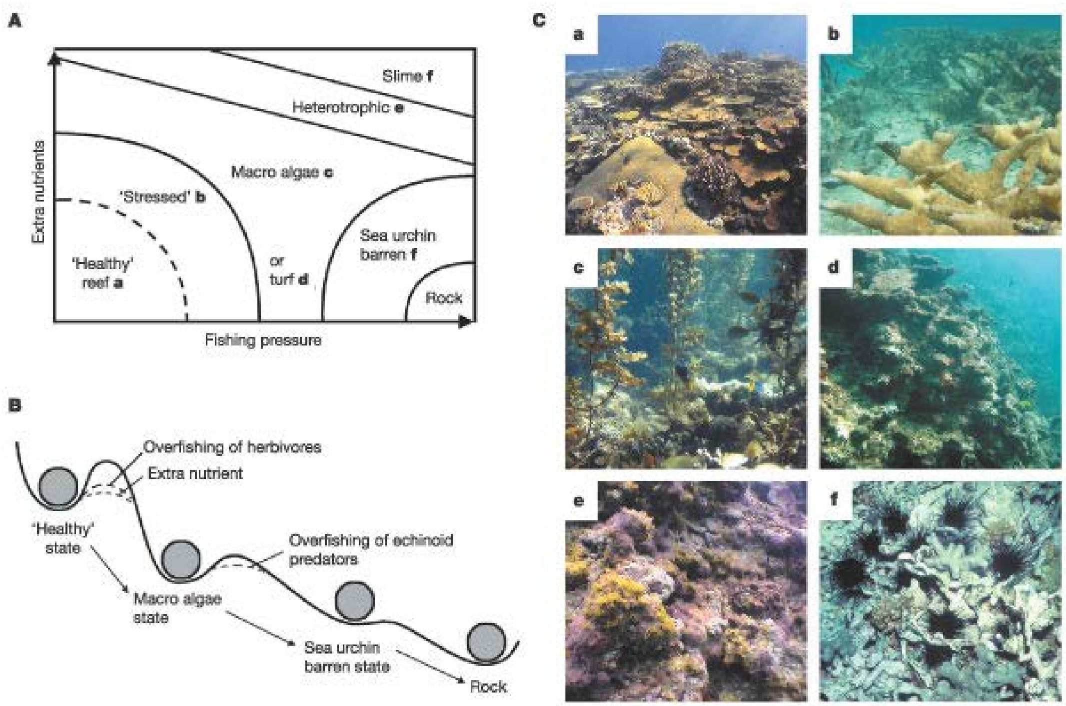
- Genome-wide single nucleotide polymorphism data on populations of *Pocillopora damicronis*
- Muiron Islands cluster together with Pilbara samples
- But southern Ningaloo (Gnaraloo)) more connected with Shark Bay

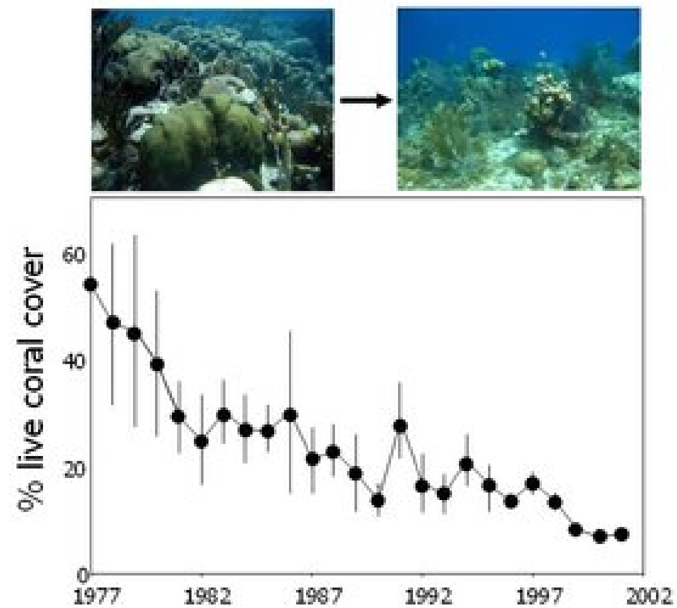


Thomas et al. 2017

Coral Reefs – Resilience

(Bellwood et al. 2004)





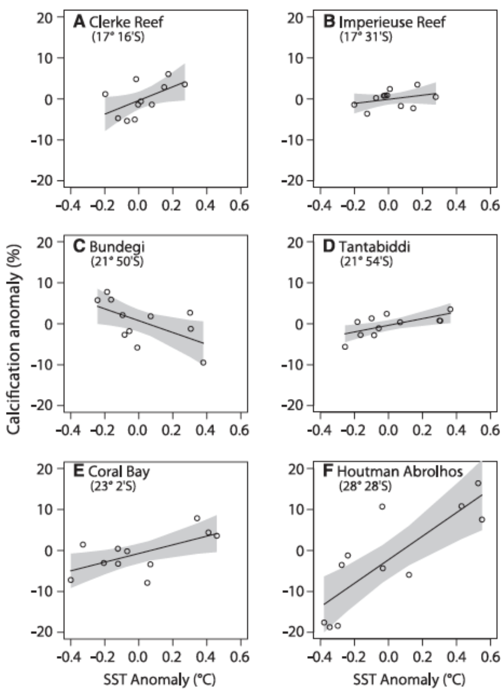
Coral loss in the Caribbean
Encyclopedia of Earth

Coral Reef Resilience

Growth of Western Australian Corals in the Anthropocene

Timothy F. Cooper,[1]* Rebecca A. O'Leary,[1] Janice M. Lough[2]

Fig. 3. Relationships between decadal SST and calcification (cal) anomalies (anom.) for (A) Clerke Reef (change in cal anom. is 7.5%; range of SST anom., –0.20 to 0.27; n = 5 cores), (B) Imperieuse Reef (cal anom., 2.4%; SST anom., –0.20 to 0.28; n = 4), (C) Bundegi (cal anom., –8.6%; SST anom., –0.39 to 0.38; n = 4), (D) Tantabiddi (cal anom., 4.9%; SST anom., –0.29 to 0.36; n = 7), (E) Coral Bay (cal anom., 8.7%; SST anom., –0.40 to 0.46; n = 4), and (F) Houtman Abrolhos Islands (cal anom., 23.5%; SST anom., –3.8 to 0.55; n = 3). Raw data are shown as open circles, solid line is the model fit to the data, and gray area is 95% confidence interval.



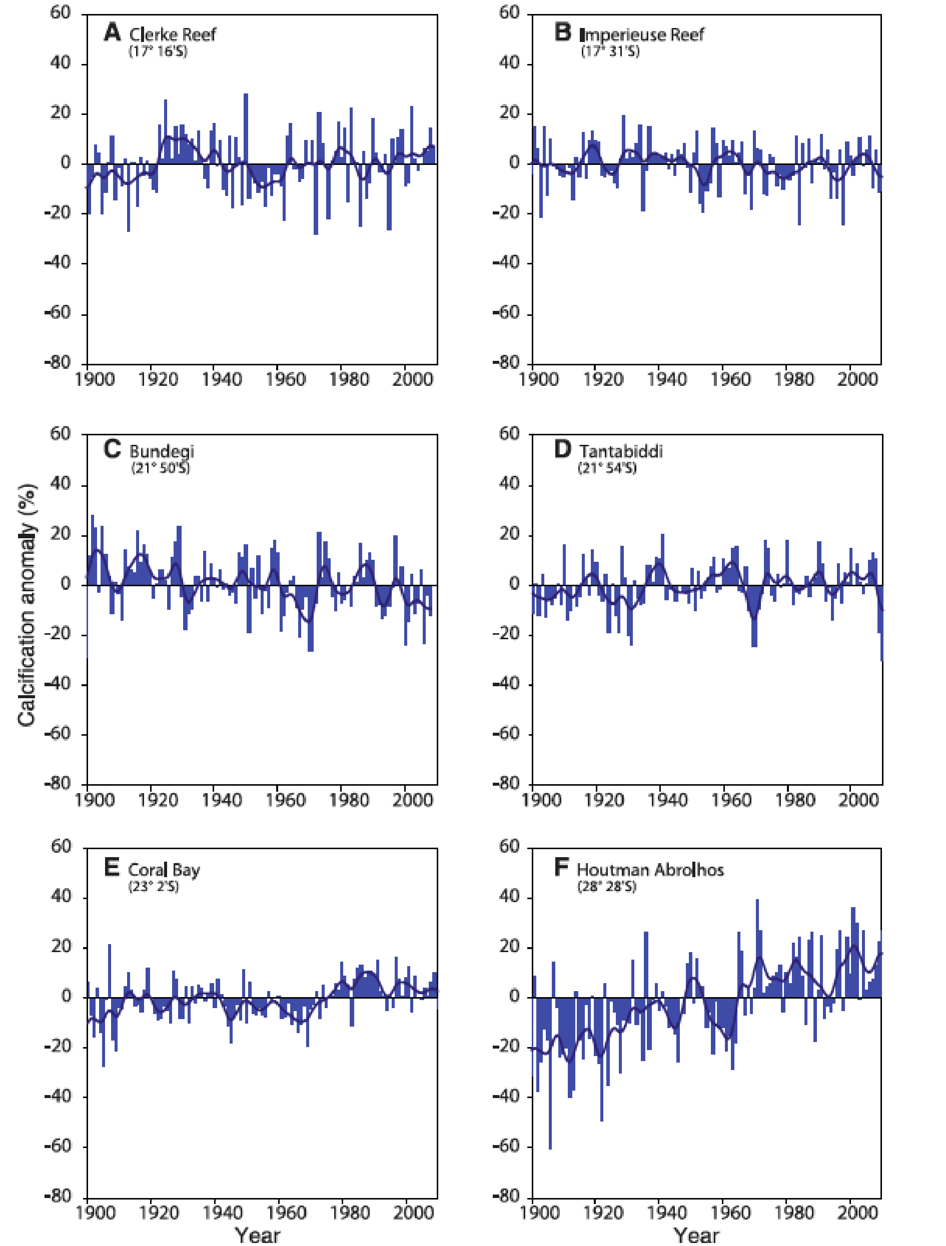


Fig. 4. Average annual calcification anomalies, 1900–2010, for (A) Clerke Reef, (B) Imperieuse Reef, (C) Bundegi, (D) Tantabiddi, (E) Coral Bay, and (F) Houtman Abrolhos Islands. Solid line is the 10-year Gaussian filter.

Effect of Extreme Events – Ningaloo Niño

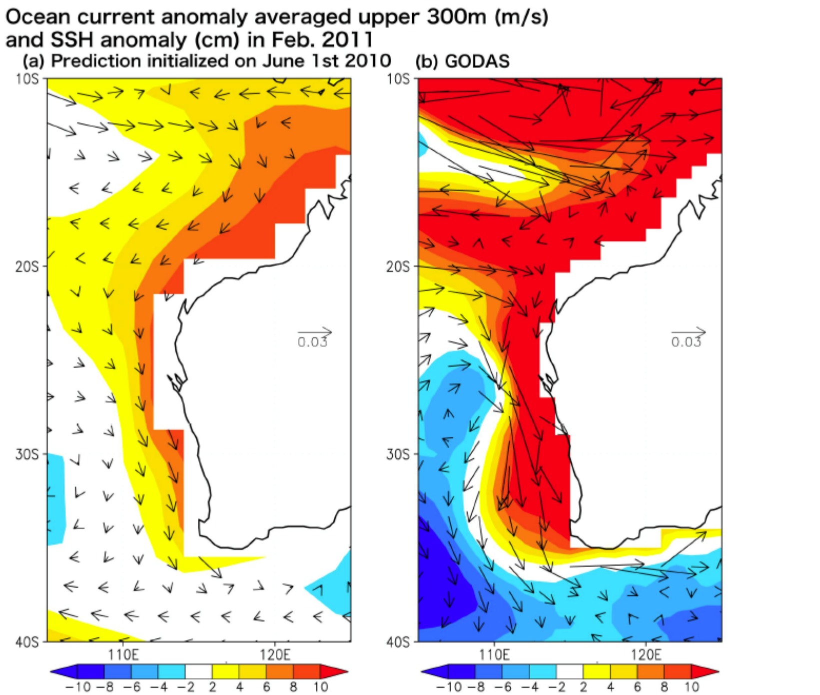
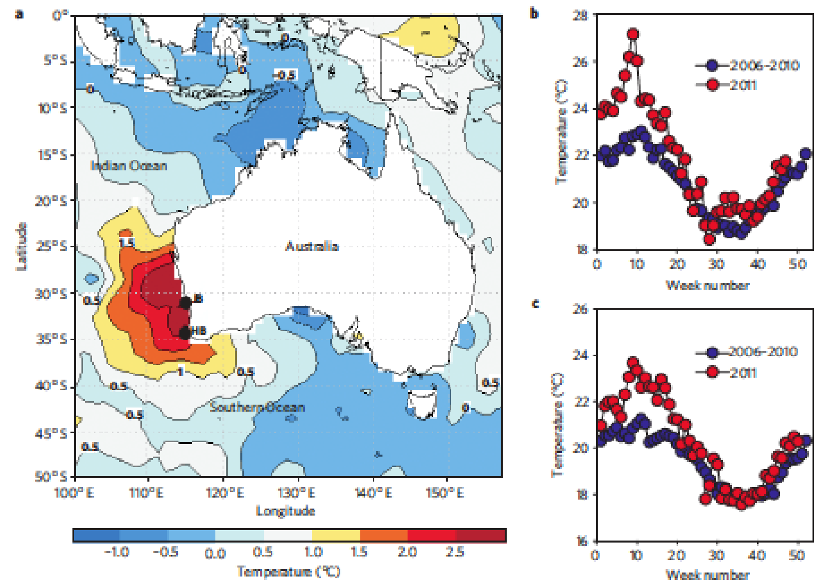


Figure 6 | (a) Ocean current anomalies averaged above a depth of 300 m (vector; m s^{-1}) and sea surface height anomalies (shaded; cm) in February 2011 for (a) the SINTEX-F1 prediction initialized on June 1st, 2010 and (b) the assimilation data of GODAS. The GrADS software was used for this figure.



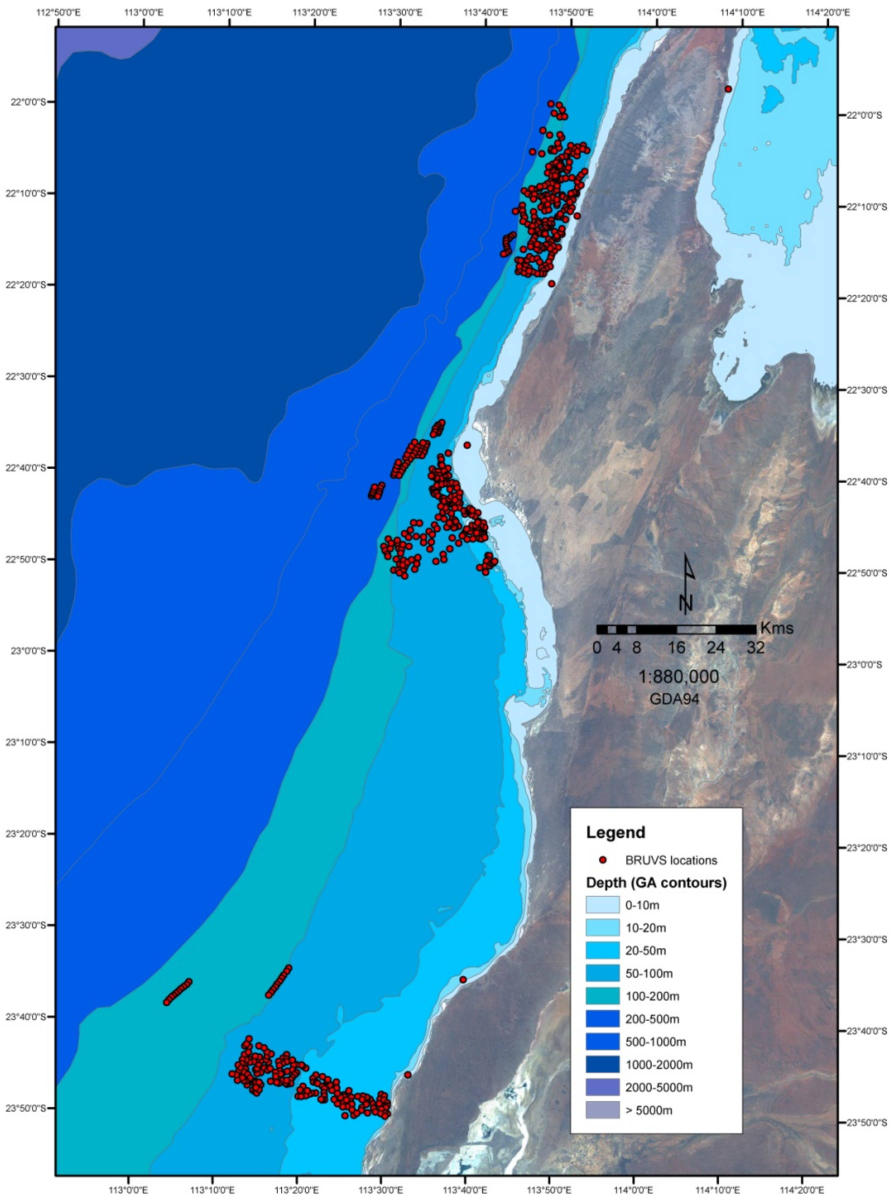
The 2011 heat wave in the southeast Indian Ocean. a, Blended sea surface temperature anomaly map for March 2011 (relative to a 1971–2000 indicating a warming anomaly of >2.5 °C along the warm temperate western coast of Australia. The Jurien Bay (JB) and Hamelin Bay (HB) study e also shown. **b,c,** Weekly temperature anomalies during 2011 (relative to means of the preceding five years) generated from *in situ* ents at ~10m depth at the sites where community data were collected: Jurien Bay (**b**) and Hamelin Bay (**c**).

Wernberg et al 2013

Feng et al. 2013

Coral Reef Fish

- Two vignettes of Industry and State Funded Research
  - **Broadscale Distribution**:
    - **Cross Shelf fish Biodiversity** (WAMSI: CSIRO): Euan Harvey, Ben Fitzpatrick, Mike Cappo, Stephen Newman, Ben Radford, Andrew Heyward, Russ Babcock
  - **MPAs and effectiveness of reserves:**
    - **Benchmarks and thresholds** (PMCP:Gorgon/Barrow Net Conservation Benefits): Mat Vanderklift, Russ Babcock, Damian Thomson, Mick Haywood, Rich Pillans, Cindy Bessey, Margaret Miller



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Depth and Rugosity from Multibeam

Towed video

BRUVs imagery classified

656 samples

365 species

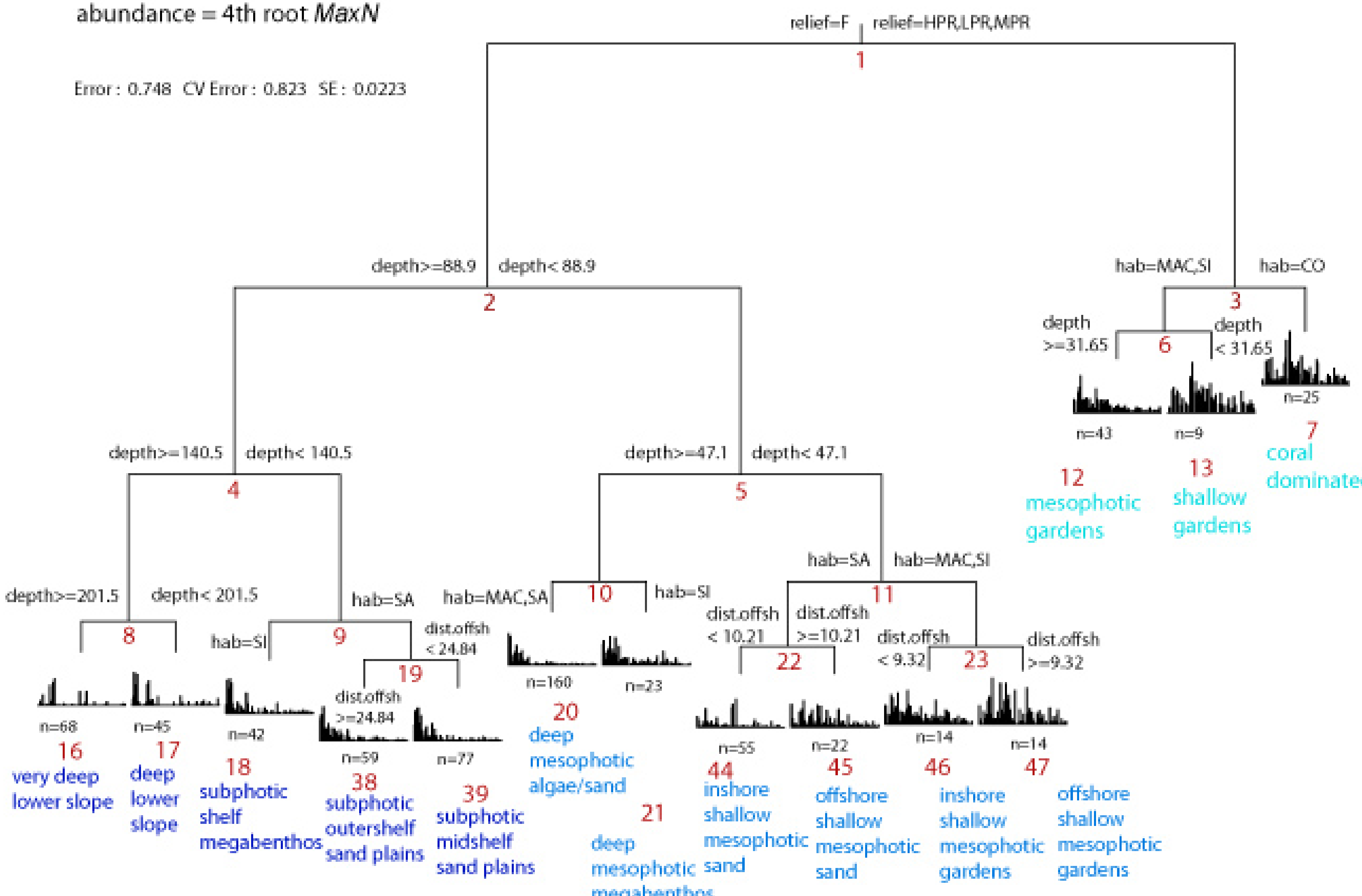
26,088 fish

Cross shelf pattern

126 species with prevalence >= 9 stations

abundance ~ (depth+habitats+seafloor relief+distance offshore) ,

abundance = 4th root *MaxN*



Cross shelf distributions

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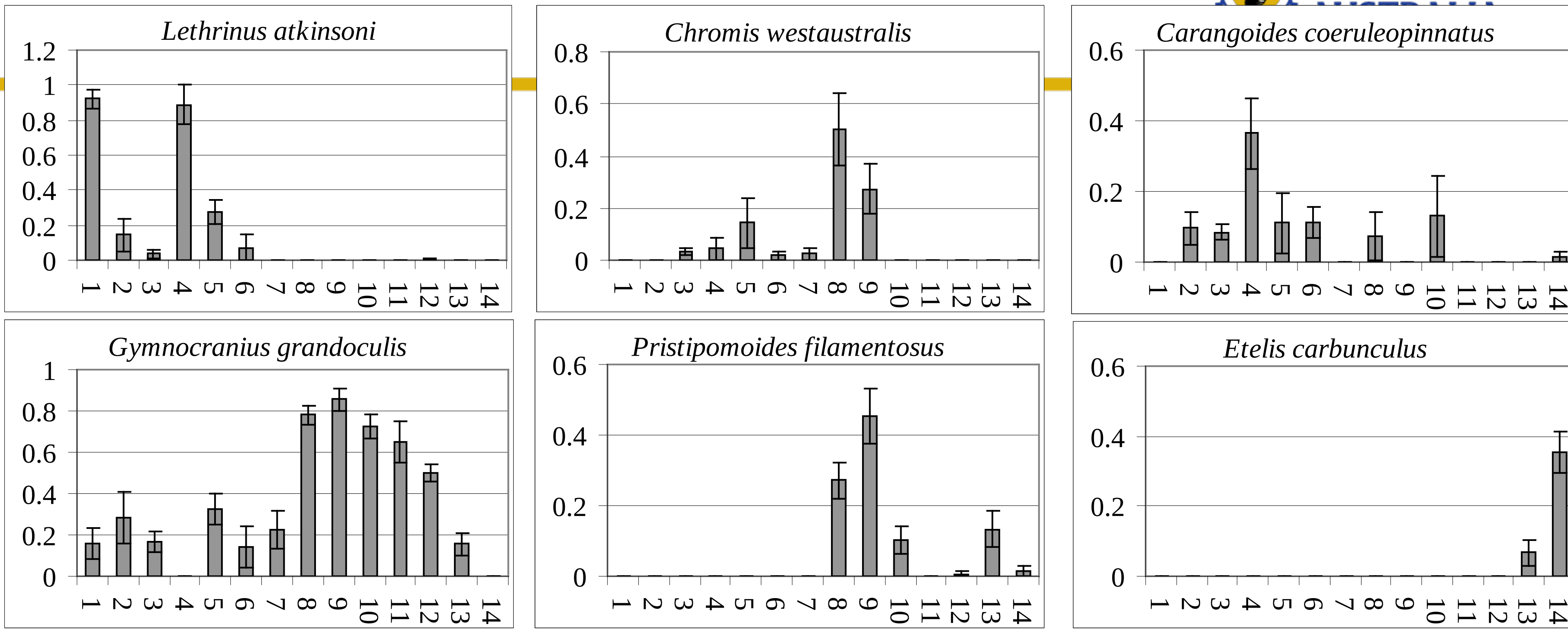
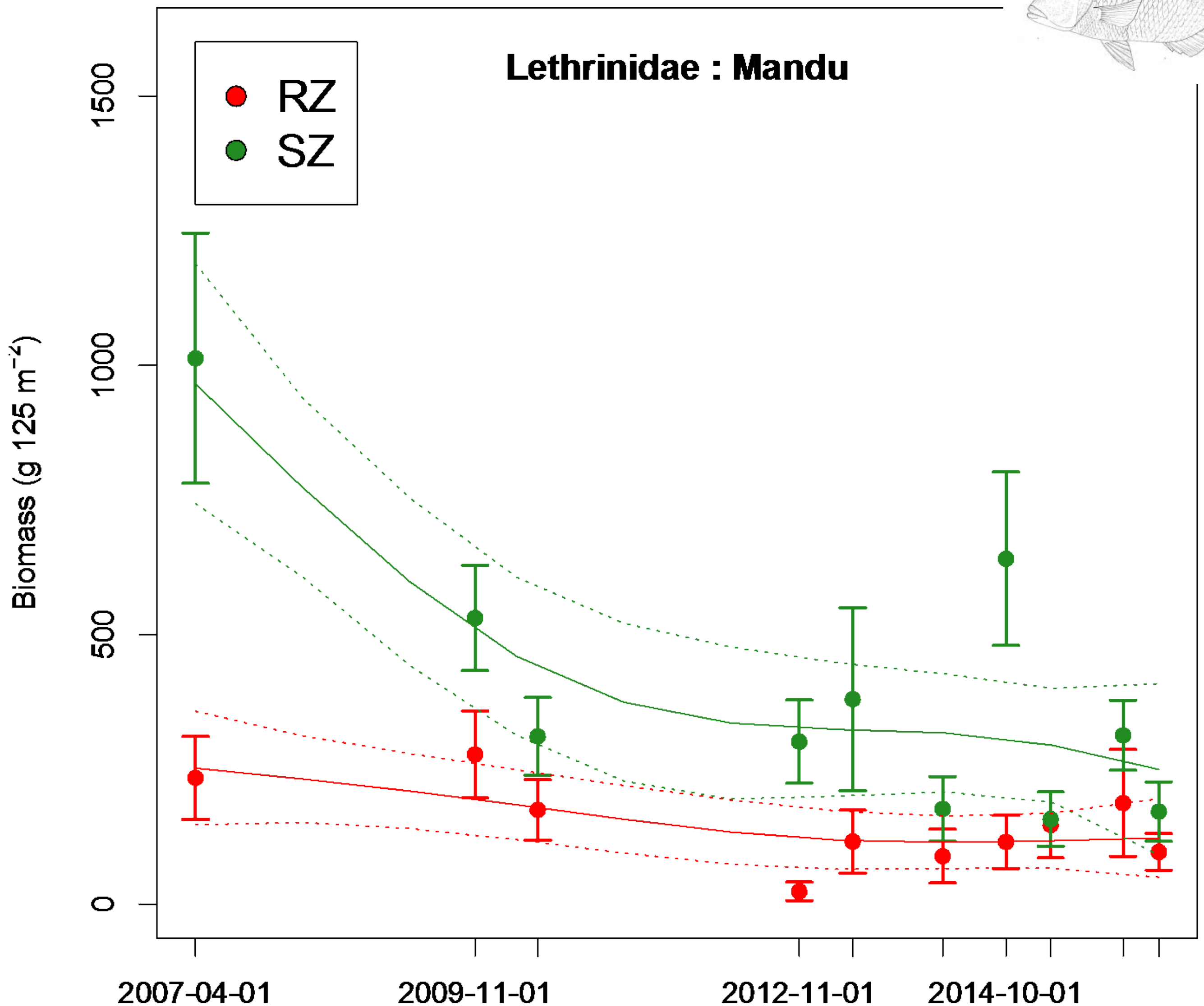
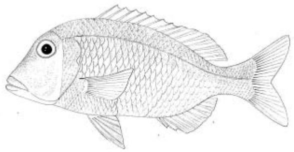


Shallow ⟷ Deep

1 = Coral dominated
2 = inshore shallow mesophotic gardens
3 = inshore shallow mesophotic sand
4 = shallow gardens
5 = mesophotic gardens
6 = offshore shallow mesophotic gardens
7 = offshore shallow mesophotic sand
8 = subphotic midshelf sand plains
9 = subphotic shelf megabenthos
10 = subphotic outershelf sand plains
11= deep mesophotic megabenthos
12 = deep mesophotic algae/sand
13 = deep lower slope
14 = very deep lower slope

Vanderklift (CSIRO): Long term assessment of effectiveness of Sanctuary Zones





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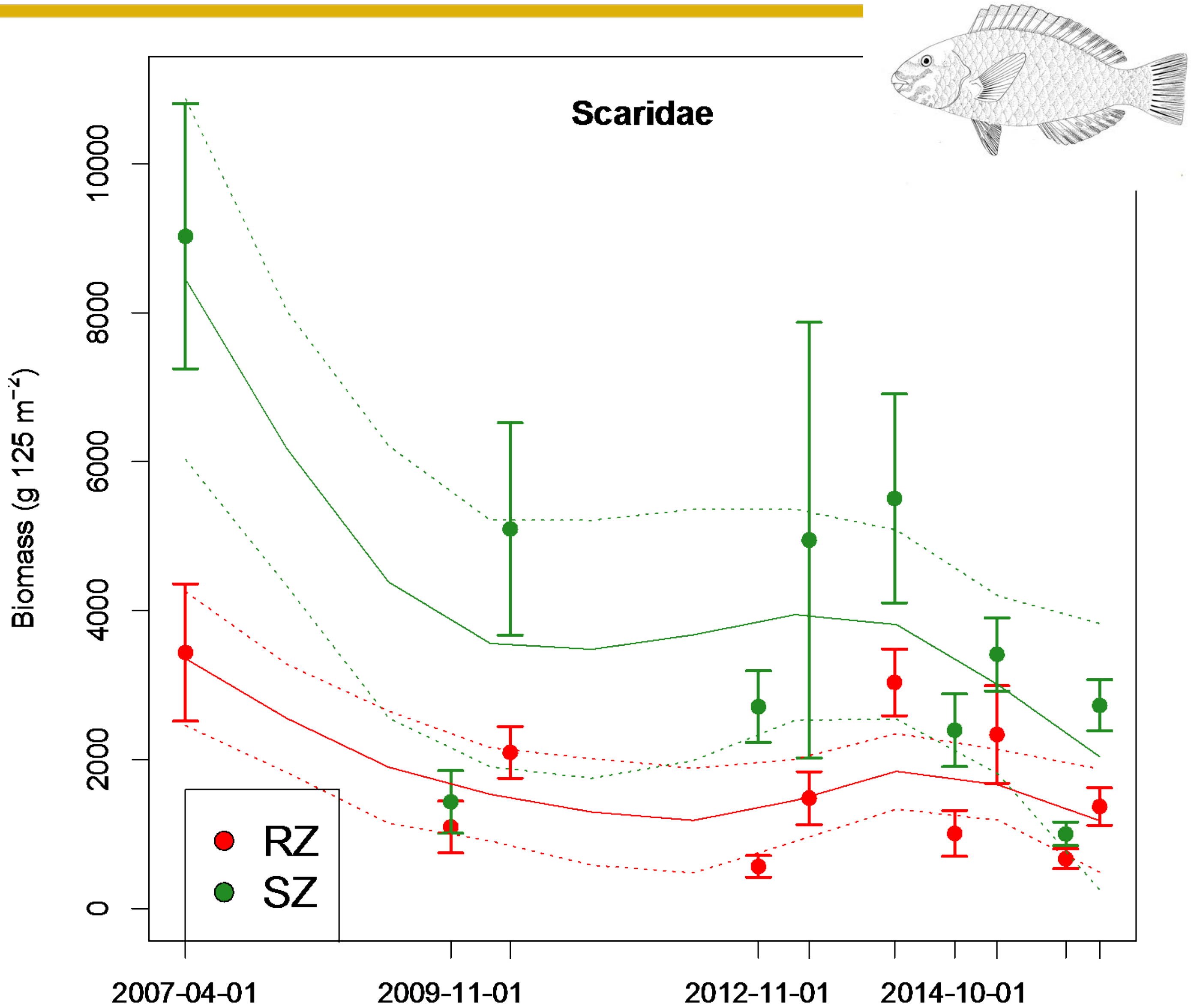

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Biology and stock status of inshore demersal scalefish indicator species in the Gascoyne Coast Bioregion

R. Marriott, G. Jackson, R. Lenanton, C. Telfer, E. Lai, P. Stephenson, C. Bruce, D. Adams and J. Norriss

Government of **Western Australia**
Department of **Fisheries**

National Research **FLAGSHIPS**
Wealth from Oceans

CSIRO

An Evaluation of Management Strategies for Line Fishing in the Ningaloo Marine Park

L. Richard Little
Olivier Thébaud
Fabio Boschetti
A. David McDonald
Ross Marriott
Brent Wise
Rod Lenanton

Viability trade-offs in the evaluation of strategies to manage recreational fishing in a marine park

Olivier Thébaud[a,b,d,*], Nick Ellis[a,b], L. Richard Little[c,b], Luc Doyen[e], Ross J. Marriott[f]

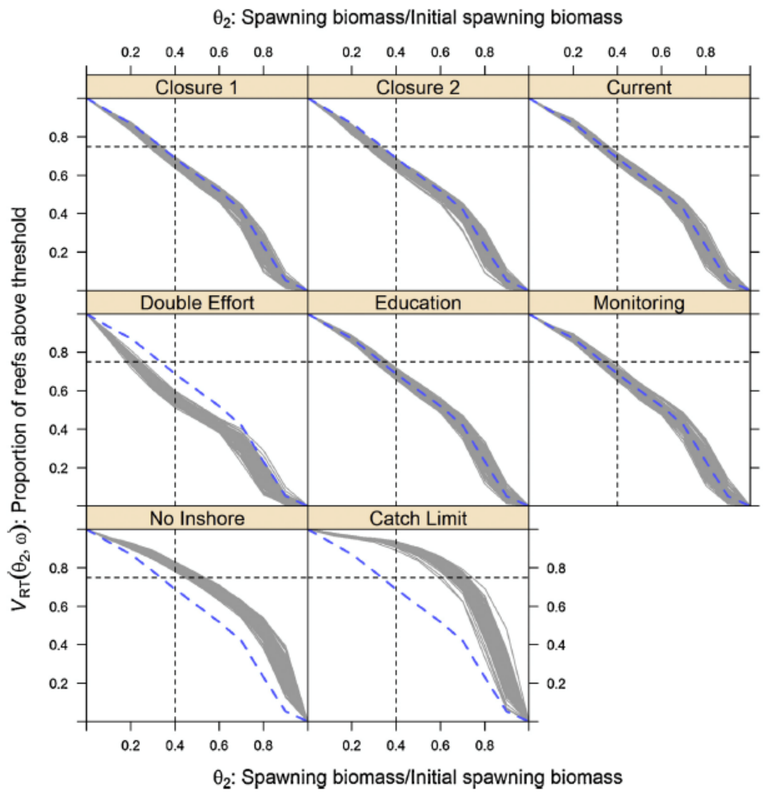

Fig. 2. Curves of $V_{RT}(\theta_2, \omega)$ vs θ_2 over 100 replicates ω (*gray lines*) for each strategy considering indicator I_2. The aggregation functions are f_T = last and g_R = mean. For the *Current* strategy the mean relationship ($\overline{V}(\theta_2)$) over all replicates is shown (*dashed blue line*). This line is duplicated in the panels for the other strategies so that they can be compared. The vertical and horizontal dashed lines correspond to the nominal target (40% of initial spawning biomass) and tolerance (75% of reefs) set during stakeholder consultation (Table 2). According to this definition of viability, only the *Catch Limit* and *No Inshore* simulated strategies are viable. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Marine Megafauna

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Sharks

Restricted movements and mangrove dependency of the nervous shark *Carcharhinus cautus* in nearshore coastal waters

L. Escalle*†, C. W. Speed‡, M. G. Meekan‡, W. T. White§, R. C. Babcock||, R. D. Pillans|| and C. Huveneers¶**

Density of reef sharks estimated by applying an agent-based model to video surveys

Mathew A. Vanderklift[1,*], Fabio Boschetti[1], Clovis Roubertie[1], Richard D. Pillans[2], Michael D. E. Haywoo…

Reef shark movements relative to a coastal marine protected area

C.W. Speed[a,b,*], M.G. Meekan[a], I.C. Field[c], C.R. McMahon[b,d], R.G. Harcourt[c,d], J.D. Stevens[e], R.C. Babcock[f], R.D. Pillans[f], C.J.A. Bradshaw[g,h]

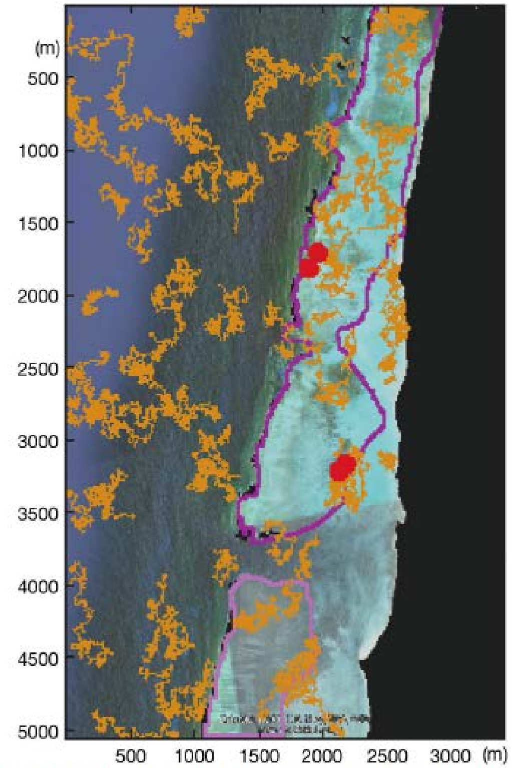

Fig. 1. An example of the movement patterns reproduced by the model, showing 40 movement tracks (orange lines), for k_{dir} = 0 (where k_{dir} is the form of the path an individual travels and 0 = fully random), plotted over the study area. Magenta boundaries show the reef flat habitat. Black represents land and reef crest (barriers to movement). Red dots indicate where cameras were located in field surveys

Contrasting patterns of residency and space use of coastal sharks within a communal shark nursery

Beverly Z.L. Oh, Michele Thums Russ C. Babcock, Jessica J. Meeuwig , Richard D. Pillans, Conrad Speed, Mark G. MeekanB. MFR 2016

UWA Neuroecology Group: Research in Ningaloo

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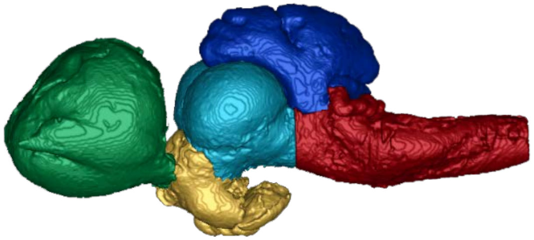
- Hearing and the impacts of anthropogenic noise on the behaviour sharks, turtles and sea snakes
- Chemoreception (taste and smell) in sharks
- Sleep in sharks
- Vision in sharks and shark mitigating wetsuits
- Shark mitigation research with respect to how light, odors, sound and electromagnetic fields may be used to deter sharks – Personal and beach-based deterrents – developing novel and testing existing deterrents
- Colour vision on the reef



Understanding how animals perceive and process their sensory world under different environmental conditions leads to sustainable conservation of biodiversity.

Social-Ecological Context

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Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Enhancing science in coastal management through understanding its role in the decision making network

Geoffrey J. Syme [a,*], Peta Dzidic [b], Jeffrey M. Dambacher [c]

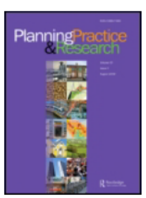
Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Enhancing the knowledge–governance interface: Coasts, climate and collaboration

Beverley Clarke [a], Laura Stocker [b,*], Brian Coffey [c], Peat Leith [d], Nick Harvey [e], Claudia Baldwin [f], Tom Baxter [g], Gonni Bruekers [b], Chiara Danese Galano [b], Meg Good [h], Marcus Haward [i], Carolyn Hofmeester [b], Debora Martins De Freitas [j], Taryn Mumford [e], Melissa Nursey-Bray [e], Lorne Kriwoken [k], Jenny Shaw [b], Janette Shaw [l], Tim Smith [m], Dana Thomsen [m], David Wood [n], Toni Cannard [o]



Routledge
Taylor & Francis Group

Planning Practice & Research

ISSN: 0269-7459 (Print) 1360-0583 (Online) Journal homepage: http://rsa.tandfonline.com/loi/cppr20

Regional Planning and Resilient Futures: Destination Modelling and Tourism Development—The Case of the Ningaloo Coastal Region in Western Australia

Tod Jones , Prof John Glasson , Prof David Wood & Prof Elizabeth A. Fulton

The Future

- Collaborations between researchers, community, industry and government to address coral reef resilience across the NW of Western Australia
  - e.g. BHP Billiton – CSIRO strategic partnership with WA Universities to maintain monitoring and to grow process understanding of Ningaloo.
- Vigilance and ability to act on threats
  - Climate variability
  - Extreme Oceanographic Events
- Resilience of Ningaloo Reef under changing pressures a social-ecological context
- Understanding the value of deep reefs
- Detailed collection of population dynamics of iconic fauna
  - Turtles, Sharks, Whales, Whale Sharks
- Management and policy frameworks for maintaining and growing the tourism and recreational fishing experience but maintaing ecological resilience of the reef