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## The marine heat wave off Western Australia during the summer of 2010/11 – 2 years on

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# **The marine heat wave off Western Australia during the summer of 2010/11 – 2 years on**

Nick Caputi, Gary Jackson and Alan Pearce



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## 1.0 Executive Summary

This second workshop on the 'Marine heat wave - 2 years on' was held on 11 March 2013 about two years after the original event in the summer of 2010/11. The first workshop focused on the oceanographic conditions associated with the event as well as the short-term effects such as fish kill and southerly range extension of a number of tropical fish species. The second workshop concentrated on the oceanographic conditions since the workshop and the longer-term (2 years) effect on fisheries and the marine environment. The key findings identified were:

- The February/March 2011 heat wave with sea surface temperatures (SST) in some areas of the mid-west and Gascoyne reaching 4-5°C above average was a result of a record-strength Leeuwin Current for that time of year during an intense La Niña period, as well as anomalously high air-sea heat flux into the ocean.
- The heat wave effect was felt throughout the water column to depths of 100 m.
- The unusual intensification of the Leeuwin Current was forced remotely by prolonged easterly wind anomalies in the equatorial western Pacific, and by the reduction of southerly winds off south-western Australia that oppose the alongshore current.
- SSTs were higher than normal by at least 2°C during the last three summers in Exmouth Gulf, Shark Bay, and Abrolhos Is. Shark Bay and Abrolhos experienced record high SST during February 2011 (~4°C above normal). SST anomalies in Exmouth Gulf during early 2013 matched or exceeded those of early 2011 (~3°C above normal).
- There have been recent extremes in abundance of brown tiger prawns in Exmouth Gulf with one of the highest recruitments recorded in 2011 followed by the lowest in 2012.
- A survey in Shark Bay in November 2011 showed that abundance of 0+ and 1+ aged scallops and blue swimmer crabs were very low and both fisheries were effectively closed for 2012. The Abrolhos Is. scallop fishery also experienced a similar situation to Shark Bay.
- Finfish recruitment surveys along the west and south coasts during 2011 and 2012 indicated a marked elevation in recruitment by the warm temperate silver bream on the west coast, and a marked decline of the cool temperate yellow-eye mullet on both the west and south coasts. Australian herring recruitment in 2011 was also relatively low. There have been reports of increased abundance of tropical species such as Spanish mackerel, the tropical rabbitfish, smudgespot spinefoot, and sand bass, in the lower west and south coast.
- In Jurien Bay, community structure of temperate seaweeds, sessile invertebrates and reef fishes was significantly affected by the warming event with a substantial reduction in the cover of canopy-forming seaweeds (e.g. kelp *Ecklonia radiata*), including the 100 km range contraction of *Scytothalia dorycarpa*. An increase in abundance of reef fishes with a warm-affinity (*Chaetodon assarius*, *Labracinus lineatus* and *Parma occidentalis*) was observed. Preliminary data from 2012 suggest that these reef fish communities are returning towards the pre-perturbed state, but there is little sign of recovery of canopy seaweeds and biogenic habitat structure.
- Surveys of Damselfishes *Abudefduf sexfasciatus* and *A. vaigiensis* at Rottnest Is. have shown record recruitment in early 2011 and a large settlement in 2012. There were also first sightings of seven tropical fish species, well south of their normal ranges.
- Preliminary analyses suggest a trend of increasing SSTs in the summer and early autumn in Cockburn Sound over the last 10 years and decreasing seagrass shoot densities.

- *Acropora* spp. bleached with high subsequent mortality within areas of Ningaloo Reef and Abrolhos Is. in 2011. The coral cover in some areas within Ningaloo (Bundegi and southern areas of Ningaloo) has continued to decrease.
- Breeding participation and success of Little Penguins on Penguin Is. in 2011 was the lowest observed in 20 years. High SSTs in April and May were correlated with poorer breeding.
- Some tropical crab species, *Scylla serrata*, *Charybdis feriata*, and *C. natatory* were found in the temperate Swan River as well as new records from WA waters of *C. granulata* and *C. annulata*.
- Mass mortalities of *Haliotis roei* occurred in the northern reaches of the species distribution. As the dominant biomass on west coast rocky shores, the ecological impacts on affected areas are highly significant. At present the gaps left by the abalone haven't been taken over by another species except for slight increases in turfing algae.
- Heat stress attributed to the marine heat wave, caused the defoliation, flowering collapse and seed abortion of seagrass meadows in Shark Bay.

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## 2.0 Introduction

A second workshop on the 'Marine heat wave - 2 years on' was held on 11 March 2013 at the Western Australian Fisheries and Marine Research Laboratories, Hillarys, about two years after the unprecedented marine heat wave event in the summer of 2010/11. About 80 scientists and stakeholders attended and 16 presentations were made at the workshop (Appendix 1 and presentation summaries in Section 3).

The first heat wave workshop was held on 5 May 2011 about two months after the peak of the heat wave event in February/March (Pearce *et al.*, 2011). This first workshop focused on the oceanographic conditions associated with the event as well as the short-term (1-2 month) effects observed such as fish kills and southerly range extension of a number of tropical fish species.

The second workshop had three major sessions: (a) an examination of environmental factors that may have caused the heat wave and the oceanographic conditions in the two years since the original event; (b) the longer-term (2 years) effect on fisheries such as the poor recruitment and adult mortality of blue swimmer crabs and scallops in Shark Bay; and (c) the effect on the marine environment such as seagrass/algae habitat, coral communities and range extension of tropical species. The scientific interest in this extreme heat wave event can be gauged by the 14 papers that have already been published on the cause and effect of the marine heat wave in the two years since the event (Appendix 3) with many more still being prepared.

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## **3.0 Presentation summaries**

### **3.1 Management implications of climate change effects on fisheries in WA: an example of an extreme event by N. Caputi**

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This presentation focused on how the marine heat wave during the summer of 2010/11 provided an opportunity of a case study of extreme climate events in this project. The event affected the marine environment and number of fisheries that required a re-assessment of the stocks and significant fisheries management interventions, including closures. From an oceanographic perspective the key question was whether the marine heat wave could be viewed as a rare event that was unlikely to reoccur in the near future or is it likely to become more common as the climate changes. From a fisheries perspective there were short-term (1-2 mo.) and longer-term (6-24 mo.) effects that have been identified in the two years since the heat wave. The short-term effects were fish kills in the mid-west and Abrolhos regions with the 99% mortality of Roei abalone in the Kalbarri region being most significant. There were also short-term (and some longer-term) range extensions of a number of tropical species. However the longer-term effects have been very significant on the recruitment and adult survival of a number of important fisheries for short-lived species such as crabs and scallops in Shark Bay and scallops at the Abrolhos Is. These fisheries were shut during 2012 due to low abundance. The effect on long-lived species may not be observed for a number of years due to the delay between spawning and recruitment into fisheries. An important aspect of this biological effect on fisheries was whether there has been a direct water temperature effect on the spawning and/or larval phase or an impact on the habitat such as seagrass that may take time to recover. The current research focus was on an early assessment of the status of fishery stocks and establishing a monitoring regime to assess the recovery of these stocks. An important aspect of research was the measurement of pre-recruit abundance of scallops that allowed the early detection of the downturn in abundance and early management intervention. The key management focus is the protection and recovery of the spawning stock of these stocks as fisheries can collapse when there is heavy fishing pressure on stocks that are affected by poor recruitment as a result of environmental conditions.



### **3.2 Regional temperature variability along the Western Australian continental shelf over the past decade by A. Pearce**

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During the February/March 2011 heat wave, water temperatures in coastal waters along the mid-west coast exceeded 5°C above the long-term average for that time of year. This has been attributed to both a very strong Leeuwin Current (anomalously high coastal sealevels) during an intense La Niña period and anomalously high air-sea heat flux entering the ocean. Effects on some marine species were devastating (with massive mortality in some areas) while there were also unusual sightings of tropical species, including some iconic megafauna, well south of their normal ranges.

There were reports of unusually warm water during the summer of 2011/12 as well, and early measurements are suggesting that 2013 temperatures are also above average.

#### **Larger-scale indices**

Traditional indices of environmental conditions off the west coast are the Southern Oscillation Index (SOI -- a measure of the atmospheric pressure gradient between the Pacific and Indian Oceans, and used as an index of El Niño/Southern Oscillation (ENSO) events), Fremantle sealevel (FMSL, a proxy for the strength of the south-flowing Leeuwin Current) and sea-surface temperatures (SSTs) in the south-eastern Indian Ocean. Monthly anomalies of FMSL have been derived by linear detrending of the gradual sealevel rise over the past century and subtraction of the long-term mean annual cycle, and SST anomalies off the Abrolhos Islands were calculated by subtracting the mean annual cycle from the Reynolds SST dataset. The monthly SOI, FMSL anomaly and SST anomaly were all smoothed by a 3-point moving average to reduce small-scale variability and clarify the major features.

These 3 parameters are closely related, with La Niña events (high SOI) generally being associated with a strong Leeuwin Current (high sea level) and higher water temperatures (more warm water advected southwards). The February/March 2011 heat wave was a result of a record-strength Leeuwin Current for that time of year during an intense La Niña period, in conjunction with an anomalously high air-sea heat flux into the ocean.

Over the past decade, the highest SSTs were all associated with La Niña events and correspondingly strong Leeuwin Currents in 2008, 2011 and 2012 (**Figure 3.2.1**). At this early stage, 2013 is shaping up to be warmer than normal, although the SOI is at neutral levels.

It is interesting that the SOI peaked during relatively brief La Niña conditions over the summers of 2006, 2008, 2009, 2011 and 2012 (**Figure 3.2.1**) whereas in earlier decades this pattern was not evident. With the exception of 2006, each of these was associated with a stronger summer Leeuwin Current. Water temperatures were anomalously high in the summers of 2006/7, 2008, 2010, 2011, 2012 and perhaps 2013 - not all of these were associated with a stronger Leeuwin Current, suggesting that higher air-sea heat flux entering the ocean also contributed to raising surface water temperatures in 2006/7 and 2010.

## **Local water temperatures**

Hourly temperature logger measurements have been obtained from a number of locations over the past decade (albeit with some data gaps). Daily and monthly averages have been derived from the hourly temperatures at Rat Island, Dongara, Rottnest Island (a much shorter time-series), Warnbro Sound and Busselton Jetty to represent coastal and outer shelf conditions along the west coast.

The monthly temperatures clearly show the anomalously high peaks at all the selected sites in early 2011, 2012 and 2013. The daily temperatures rose and fell by  $\sim 2^{\circ}\text{C}$  every few days and displayed some alongshore and cross-shelf variability, but all peaked over a couple of days at the end of February 2011. These short-term temperature “spikes” may have severely affected already stressed animals and resulted in some of the observed mortality.

Daily temperatures derived from the Integrated Marine Observing System (IMOS) 100 m mooring off Two Rocks reveal that at the peak of the 2011 heat wave the high temperatures were experienced down to the seabed, i.e. the water column was effectively isothermal down to at least 100 m.

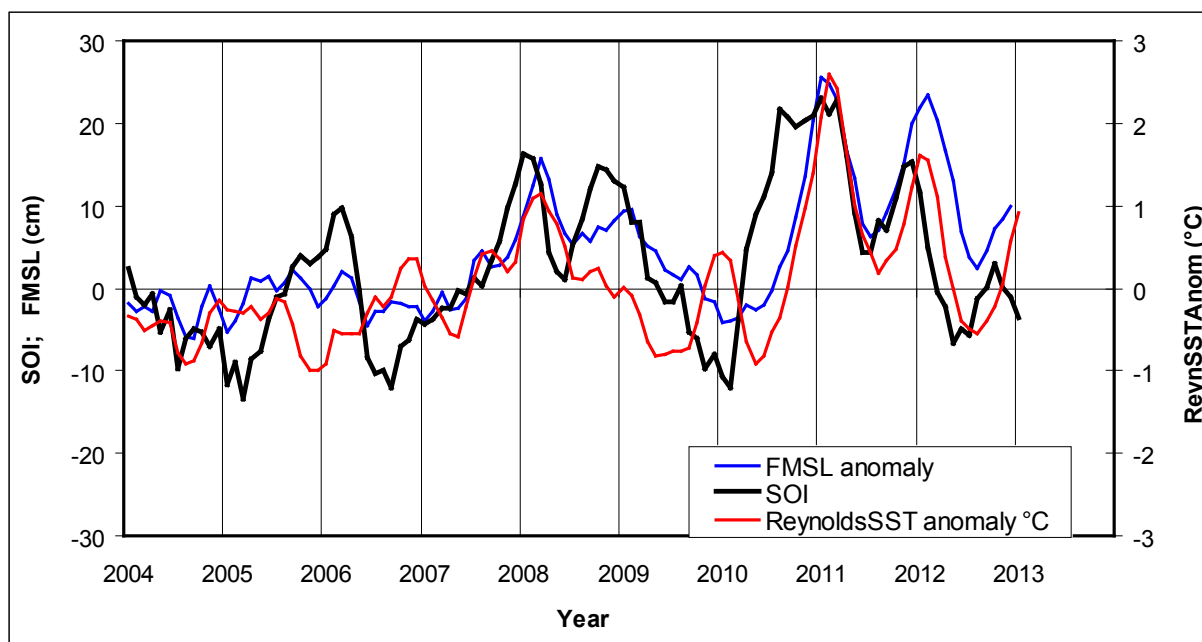
## **Some conclusions**

The larger-scale (Reynolds), local (nearshore Tloggers) and IMOS 100m station temperatures all show the February/March 2011 peak to be the highest on record. The summer of 2012 was almost as warm; summer 2013 is still evolving, and also appears to be anomalously warm although the temperatures are not as high as in the previous 2 summers.

Relationships between the water temperature, the Leeuwin Current and air-sea heat fluxes over the past decade need to be further explored.

## **Acknowledgements**

Water temperature data were kindly provided by Ken Suber (CSIRO -- Reynolds SSTs), Mark Rossbach (Department of Fisheries for coastal temperature loggers), Alex Hoschke (Rottnest loggers) and Sophie Teede (Busselton Jetty Environment and Conservation Association, Busselton loggers).



**Figure 3.2.1.** Monthly mean values of the Southern Oscillation Index (SOI -- black line), the detrended Fremantle sea level anomaly (blue) and the Reynolds SST anomaly for the block at the Abrolhos Islands (red) over the past decade. The values have been smoothed by a 3-month moving average to reduce smaller-scale variability.

### 3.3 La Niña forces unprecedented Leeuwin Current warming in 2011 by M. Feng

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Ocean circulation off the Western Australia coast in the southeast Indian Ocean is dominated by the poleward-flowing Leeuwin Current. Interannual and decadal variability of the Leeuwin Current is to a large extent driven by tropical Pacific climate variability, such that the current is stronger during La Niña events and weaker during El Niño events. Interannual variability of ocean temperature off the Western Australia coast is mostly forced by the Leeuwin Current heat advection and the buffering role of local air-sea heat flux. Unprecedented warm sea surface temperature (SST) anomalies were observed off the west coast of Australia in February–March 2011. Peak SST during a 2-week period were 5°C warmer than normal, causing widespread coral bleaching and fish kills. Understanding the climatic drivers of this extreme event, which we dub “Ningaloo Niño”, is crucial for predicting similar events under the influence of global warming. In this study we use observational data and numerical models to demonstrate that the extreme warming was mostly driven by an unseasonable surge of the poleward-flowing Leeuwin Current in austral summer, which transported anomalously warm water southward along the coast. The unusual intensification of the Leeuwin Current was forced remotely by oceanic and atmospheric teleconnections associated with the extraordinary 2010-2011 La Niña. The surge of the Leeuwin Current was not only forced by the prolonged easterly wind anomalies in the equatorial western Pacific, but also was furthermore impelled by the reduction of the southerly winds in February 2011 that oppose the alongshore current. The amplitude of

the warming was boosted by both multi-decadal trends of the Pacific climate toward more La Niña-like conditions and intraseasonal variations in the Indian Ocean.

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### **3.4 Sea surface temperature variability along the Gascoyne and mid-west coast of Western Australia 2010-2013 by Y. Hetzel**

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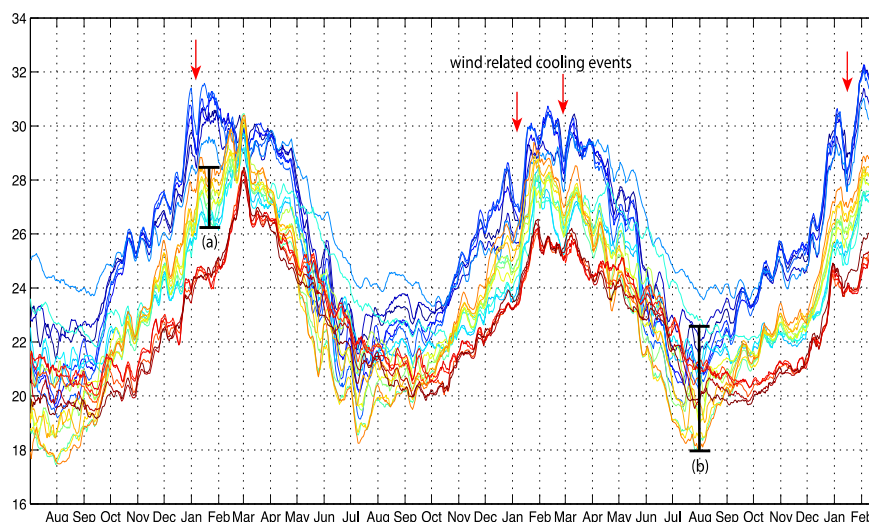
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The extremely high summer sea surface temperatures (SSTs) experienced along the mid-west coast of Western Australia from 2010/11-2012/13 have negatively impacted seagrass habitat and many marine species, including the poor recruitment and adult mortality of commercially fished scallops in Shark Bay and the Abrolhos Islands. The ecological effects of the ‘marine heat wave’ have varied within and between the three major fishing grounds of Exmouth Gulf, Shark Bay, and the Abrolhos Islands. Whilst the regional (100’s of km) SST patterns related to the ‘heat wave’ have been well described (Pearce and Feng, 2013), the finer scale (10’s of km) variability is less well known. The present analysis focused on SST variability over the past three years at this finer scale (1-30 km) with the aim of identifying areas in Exmouth Gulf, Shark Bay, and the Abrolhos Islands more and less likely to experience high temperatures.

The lack of continuous *in situ* measurements of SST in the region necessitated the use of satellite-derived ‘blended’ or ‘optimum interpolation (OI)’ SSTs that combine multiple satellite sensor, ship and buoy measurements to create a global gap-free dataset. The NOAA OIv2 data provided continuous daily SST data from 1982- February 2013 at ¼ degree (~28 km) resolution. The length of the time series allowed for calculation of monthly mean anomalies. The NASA JPL blended G1SST dataset consisted of 1 km grid spacing but was limited to July 2010 to present. When compared to available temperature logger data from Shark Bay and Rat Island in the Abrolhos, the satellite SST data captured the major trends with agreement within 1-2°C. Differences were attributed to the depth of the loggers and location in shallow water where diurnal heating effects are important. Overall, the satellite-derived data provides an invaluable tool to monitor temperatures along the West Australian coast where *in situ* measurements are sparse.

In each of the three fishing areas analysed, SSTs were higher than normal during the last three summers with winter temperatures near average or slightly below average. Shark Bay and the Abrolhos Islands experienced record high temperatures during February 2011 (~4°C above

normal), with both 2012 and 2013 February SSTs approximately 2°C above average (**Figure 3.4.1**). Shark Bay experienced the largest deviation from mean temperatures that is probably related to its enclosed geography and shallow depths. Temperature anomalies in the Abrolhos area were slightly moderated when compared to Shark Bay due to its offshore location and the influences of the Capes and Leeuwin Currents. In contrast, SST anomalies in Exmouth Gulf during early 2013 matched or exceeded those of early 2011 (~3°C above normal), whilst the summer SST during February 2012 peaked at only ~1°C above normal.



**Figure 3.4.1.** Smoothed (6 day) sea surface temperature time series extracted from the 1 km G1SST dataset for fisheries survey sites in Exmouth Gulf (blues), Shark Bay (yellows), and the Abrolhos Islands (reds). Red arrows indicate cooling events due to strong southerly winds and enhancement of the Capes and Ningaloo Currents. Summer temperatures within Shark Bay vary by approximately 2°C (a) depending on location and > 4°C in winter (b).

Shark Bay and Exmouth Gulf had the largest spatial and seasonal variability in temperatures due to the influence of the continental land mass and shallow depths as compared to the Abrolhos Islands. In Exmouth Gulf and Shark Bay, horizontal temperature gradients from the outer to inner regions exist throughout the year, reversing with the seasons. Heat loss to the atmosphere during winter causes these shallow bays to become cooler (~4°C; **Figure 3.4.1** – indicated at time b) than offshore (Leeuwin Current) waters, whilst in summer the inner regions are warmer (~2°C; **Figure 3.4.1**– indicated at time a). SST gradients are at a minimum during spring (Oct-Nov) and autumn (Apr-May) as the gradients reverse. The focus here is on the summer regime as this was the season when the high anomalous temperatures occurred that may have affected the habitat and/or caused mortality of scallops, crabs, and other species.

Cooling related to the enhancement of the Capes and Ningaloo Currents by strong southerly wind events ( $>10 \text{ m s}^{-1}$ ) during summer provided critical relief from rising temperatures, with the effects most obvious in Shark Bay and to a lesser extent in Exmouth Gulf and the Abrolhos Islands. The Capes and Ningaloo Currents are wind-driven northward flowing inshore currents associated with upwelling of cooler waters onto the continental shelf. When strong along-shelf (southerly) winds blow, these currents are enhanced and intrude into the western regions of Shark Bay and northwest Exmouth Gulf, causing SSTs to drop 1-2°C in the outer areas of the bays (**Figure 3.4.1**; red arrows). In Exmouth Gulf, the area near the tip of the Northwest Cape is most affected. In Shark Bay, the cooler water intrudes through the Naturaliste Channel (western entrance) and exits out the northern entrance when the event is relatively strong. SSTs near

Naturaliste Channel were consistently cooler than other areas of the bay due to this flushing mechanism. This was also the site of the main concentration of surviving scallops since the mortality event in 2011 suggesting that the intruding Capes Current may have provided a 'safe haven' during periods of elevated temperatures. Unfortunately, peak temperatures during recent years usually occurred during sustained periods of relaxed winds when air-ocean heat fluxes could not be compensated by advection of cooler water into the bays. Furthermore, winds in the region were weaker and more northerly during strong La Niña conditions. Wind records from Carnarvon indicated that during 2010/11 the mean November-March southerly wind component was  $\sim 2 \text{ m s}^{-1}$  lower than the long-term mean. Although this was just one of the factors contributing to the high SSTs experienced during the 'marine heat wave' it highlights the importance of the wind in controlling water temperatures in these shallow regions.

This analysis of sea surface temperatures in Exmouth Gulf, Shark Bay, and the Abrolhos Islands has shown that there can be differences in SSTs between areas separated by 10's of kilometres. We have identified the inner regions of Shark Bay and Exmouth Gulf to be more susceptible to extreme temperatures, with areas near the entrances providing some respite from heating due to cooling from the intrusion of Capes and Ningaloo Current water.

### **Acknowledgements**

Charitha Pattiaratchi and Sarath Wijeratne provided helpful feedback on the upwelling effects of the Capes and Ningaloo Currents as well as ROMS 3D circulation model results, and Alan Pearce also contributed through useful discussion of the physical processes in the region. Mervi Kangas and Nick Caputi also gave valuable insight into the links between SSTs and ecological impacts. One kilometre GISST data were produced by the NASA JPL ROMS (Regional Ocean Modeling System) group (<http://ocean.jpl.nasa.gov/SST/>). OIv2 data were obtained from NOAA\_OI\_SST\_V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at <http://www.esrl.noaa.gov/psd/>.

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## **3.5 Impacts of marine heat wave and flooding events on invertebrate fisheries in the Gascoyne region and the Abrolhos Islands by M. Kangas**

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The marine heat wave event in late 2010 to early 2011 had a significant impact on the invertebrate fisheries in the Gascoyne (Shark Bay and Exmouth Gulf) and Mid-West regions (Abrolhos Islands). Several flood events in Shark Bay with both the Gascoyne and Wooramel Rivers flowing during the same period added to these impacts. These impacts are still being felt in a number of fisheries including scallops in Shark Bay and Abrolhos, blue swimmer crabs in Shark Bay and prawns in Shark Bay and Exmouth Gulf.

## **Exmouth Gulf prawn fishery**

The Exmouth Gulf prawn fishery is the second largest prawn fishery in Western Australia (WA). It is based primarily on the brown tiger prawn *Penaeus esculentus* and the western king prawn *Penaeus latisulcatus*. In the early 1980s very low landings were attributed to recruitment overfishing and management strategies were put in place to protect the spawning stock and the landings improved over 3-4 years. Cyclones have also had a major impact, particularly on brown tiger prawns over the history of the fishery. In 1975 very high landings were recorded, attributed to positive cyclone effects whilst in 2000 very low landings were recorded and a recruitment failure was detected – attributed to a severe cyclone that went through the middle of Exmouth Gulf in 1999 and caused significant physical damage to inshore nursery habitats. A fairly strong correlation has been observed with percentage of seagrass/algal cover and brown tiger prawn landings during the recovery of the structured habitats in the inshore areas between 2000 and 2004 (post cyclone).

The heat wave event may have contributed to the recent extremes in abundance of brown tiger prawns in Exmouth Gulf. In 2011, the brown tiger prawn recruitment and landings were one of the highest recorded which led to a very high spawning stock abundance. However in 2012, the lowest recruitment was observed resulting in the lowest catch. This in turn resulted in a low spawning stock in 2012 although at levels that have historically resulted in moderate recruitment.

The hypotheses under investigation are that:

- The 2010/11 warmer summer temperatures may have been beneficial for recruitment in 2011.
- The warmer summer temperatures (which also occurred in the summer of 2012/13) may have had a direct negative effect on the spawning (timing/success) or transport/survival of larvae in the spring of 2011 leading to poor recruitment in 2012. This may be a short-term (1 year) effect as the spawning stock is not significantly affected.
- The warmer temperatures may have led to the loss of structured habitat (seagrass and/or algae) in the nursery areas that may have contributed to the poor recruitment. This may be a long-term (3-4 year) effect based on previous experience with loss of structured habitat.
- There was some other undetected perturbation in the region.

## **Shark Bay prawn fishery**

The Shark Bay prawn fishery is the largest prawn fishery in WA, targeting the western king prawn and the brown tiger prawn. Each species exhibits annual variability in landings but in the early 1980s this fishery also experienced recruitment overfishing of brown tiger prawns. Since 2000, higher recruitment of both species has occurred during strong La Niña/Leeuwin Current years with strong recruitment strength observed in 2011. This led to good catches and this may have been due to improved catchability, growth and survival of prawns due to the warmer water temperatures, and the turbidity effects of the flooding events.

There were no obvious negative effects of the 2010/11 heat wave on the recruitment of key prawn species in 2011 or 2012. However there was an apparent shift in the distribution of the brown tiger prawns in the eastern part of the bay which is regarded as the key tiger prawn spawning area, with very low spawning stock abundance recorded for 2012 in this area. However commercial catch rates of brown tiger prawn were quite high just south of the tiger prawn spawning area indicating that prawns may not have migrated into the historically known

spawning area in 2012. This may be a result of the direct effects of the heat wave and/or flooding events or the effects of these environmental conditions on the seagrass habitat.

### **Shark Bay scallop fishery**

The Shark Bay scallop fishery is generally the largest scallop fishery in WA but stock levels since 2011 appear to have been significantly impacted upon by the heat wave. An annual pre-season fishery-independent survey has been conducted in November since the 1980s and provides an indication of the residual adult scallop stock and new recruits. This abundance index allows for a catch prediction the following fishing season. The catch was well below the prediction for 2011 and this may have been attributed to poor growth and mortality of scallops during late 2010 and 2011. Scallop fishing was fairly limited in 2011 and stopped in May at a catch rate level that should have ensured some carryover of stock for the following season. However by August, prawn fishers commented that there were very few scallops on the trawl grounds. The annual pre-season survey in November 2011 confirmed the anecdotal comments with very low recruit abundance and extremely low residual abundance throughout the bay. Due to the very low abundance the scallop fishery was closed for the 2012 season.

Strong La Niña conditions as in 2011 (with strong Leeuwin Current flow) are always associated with poor scallop larval settlement, so the poor recruitment during the survey was expected, however the poor survival of residual stock was not. We suspect high mortality of adults from thermal stress, reduced growth from the stress and possibly some change in food availability. The November 2012 pre-season survey again indicated very low recruitment and almost no residual scallops in Shark Bay which means an extremely low spawning stock. The Shark Bay scallop fishery will remain closed for the 2013 season.

### **Abrolhos Islands and Mid-West scallop fishery**

The Abrolhos Islands and mid-West trawl fishery has also experienced high variability in annual settlement and resultant scallop catches but as with the Shark Bay scallop fishery, the 2011 fishing season produced significantly less scallop meat than had been predicted from the annual pre-season survey. In 2011 and 2012 the pre-season scallop survey indicated low abundances with almost no scallops found in 2012, so the fishery was closed for 2012 and will not be open for the 2013 season.

### **Shark Bay blue swimmer crabs**

In late 2011, blue swimmer crab (*Portunus armatus*) stocks in Shark Bay were found to be at historically low levels due to an apparent recruitment failure and mortality of adult stock. This was largely attributed to the unprecedented set of environmental conditions that were experienced in Shark Bay during late 2010 - early 2011 (2 flooding events and associated raised turbidity in December 2010 and February 2011 and the marine heat wave in early 2011) which affected a number of fish stocks in the Gascoyne region. The low stocks were confirmed by a fishery-independent trawl survey conducted in November 2011 and by the very low commercial crab trap catch rates experienced at that time (significantly less than 1.0 kg/traplift). High catch rates reported by trawlers early in the 2011 season were attributed to the flushing of crabs onto trawl grounds during the flood events, with catch rates declining significantly by August 2011. Very limited crab fishing/retention took place between December 2011 and April 2012 and since May 2012 both the trap and trawl industry sectors have imposed voluntary non-retention of crabs in Shark Bay. Fishery-independent trawl surveys as well as trap surveys aboard a leased commercial vessel were undertaken throughout 2012 to monitor the recovery, with stock levels remaining low. The fishery will remain closed until significant and long-term recovery is evident.



### **3.6 The effect of the 2011 marine heat wave on Roe's abalone (*Haliotis roei*) stocks in Western Australia by A. Hart**

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Following the catastrophic mortality of *Haliotis roei* caused by the 2010/11 marine heat wave (Pearce *et al.*, 2011), a complete closure of the Area 8 fishery was legislated, and monitoring and stock recovery programmes in Kalbarri and Perth were implemented. Mortality rates were location-specific, but in the major part of the Kalbarri fishery, north of the Murchison River, survival rates were estimated to be 0.01% or less. Higher survival was estimated at Port Gregory (5-10%), and Lucky Bay (80-90%). In the Perth fishery no major mortalities were recorded, however evidence suggests a temporary stunting growth effect in mature age classes that has now ceased, but resulted in a 30% drop in numbers of the legal size-class (61-70 mm) transitioning from the sub-legal cohort (51-60 mm). In response to the mortality in the Kalbarri region, the Department of Fisheries obtained a funding grant from the Australian Seafood CRC entitled "Recovering a collapsed abalone stock through translocation". To date, five founder populations sourced from the nearest surviving population at Lucky Bay have been set-up in the Kalbarri region. Future monitoring will determine whether this has been successful in initiating recruitment.

### **3.7 Assessing the effects of the 2010/11 marine heat wave on finfish and associated fisheries by G. Jackson**

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The extent to which long-term Department of Fisheries (DoF) finfish monitoring databases can help clarify the manner in which finfish species (principally key exploited species) were affected by the 2010/11 marine heat wave has been investigated.

Available databases include those pertaining to i) CAES (catch and effort statistics from commercial fisheries for edible species, and the Marine Aquarium Fish [MAF] fishery), ii) Charter/Tour Operators, iii) recreational fishing surveys (West Coast boat-based creel surveys, and the phone-diary based 'iSurvey'), iv) nearshore finfish annual recruitment surveys (from 1996 to present), v) Research Angler Programme (RAP) logbooks, and vi) records from the Busselton Jetty Underwater Observation Facility. Although not interrogated during the current investigation, databases from annual angling competitions (e.g. Swanfish, Kalbarri Offshore Angling Club estuary fishing competition, Marmion Angling Club Bluewater Classic) may also contribute useful information.

Anecdotal reports from the wider community formed a significant part of the evidence presented at the initial marine heat wave workshop (Pearce *et al.*, 2011). These, together with ongoing reports are currently held on Departmental TRIM files. In the future it is expected that the national interactive web-based community project 'Redmap' ([www.redmap.org.au](http://www.redmap.org.au), launched in

December 2012) will capture an increasing proportion of such reports. An up-to-date summary of such information provided since the heat wave is held in the TRIM system, and presented in Appendix 2.

Events such as the 2010/11 marine heat wave add an additional short-term impact to the underlying longer-term environmental changes that are influencing the abundance and distribution of marine species off the Western Australian coast. Elevated sea surface temperature (SST) appears to be the main environmental influence. However the strength and timing of peak Leeuwin Current (LC) flows is also very important. SST can influence the spatial and temporal extent of breeding, and survival of recruits, while the LC influences the dispersal of recruits.

Historically the peak LC flows (as indicated by Fremantle Sea Level [FSL]) were experienced during the winter months, i.e. May and June. However the timing of recent strong LC flows, experienced during La Niña years, were atypical, with peak flows being experienced progressively earlier in the year. Peak flows during 1999 and 2000 commenced in April, one month earlier than “normal”. In 2008 they commenced a further month earlier in March, while the peak flows in the most recent two years (2011 & 2012) occurred even earlier, in January, and extended through to June. Such shifts in the timing and magnitude of LC flows have the potential to generate a change in the composition of the suite of tropical species transported south.

Strong LC can influence the distribution of large juveniles and adults, and can also transport larvae and small juveniles to regions south of their normal range. While detailed accounts of how different species have been affected by the heat wave are still being investigated, some interesting preliminary results are presented below.

The capture of displaced larger juveniles and adults is immediately identifiable in catches of fishers. Catches by commercial operators are recorded in CAES returns, and those of anglers in creel survey results and RAP records. A good example of a displaced species is Spanish mackerel (*Scomberomorus commerson*). This tropical species is a regular visitor to waters off Perth during the warmer months (late summer/autumn). However, data from the 2011 boat-based recreational fishing survey revealed that during the heat wave, Spanish mackerel were captured well south of Perth, and on occasions, as far east as Albany on the south coast.

Records of the capture of large mobile species such as sharks have the potential to provide further evidence of the impact of the heat wave on the finfish community of the west coast of Western Australia. Commercial fishers operating in both the Gascoyne Coast Bioregion and northern regions of the West Coast Bioregion report greater levels of interaction with tropical shark species. Species-specific shark catch records in CAES over a 30-year period have revealed that distributional shifts in catches of indicative species may be related to long-term changes in SST.

Typically, the newly settled recruits of tropical species only survive for several months post-recruitment (during the warmer months). However, available evidence suggests that a number of these tropical recruits have survived throughout the cooler winter months. Examples include a tropical rabbitfish, smudgespot spinefoot (*Siganus canaliculatus*), that was first reported from the waters of Cockburn Sound in the summer of 2011, and has persisted in that environment to become a target species for commercial fishers, and a regular capture for recreational fishers (**Figure 3.7.1**). Another northern species, sand bass (*Psammoperca waigiensis*), has regularly been caught since 2011/12 in commercial haul net catches off Fremantle. In Perth nearshore waters, small juveniles (70-150 mm total length, TL) of common dart (*Trachinotus botla*) were first recorded in finfish recruitment surveys in September 2011, have persisted and are now regularly taken by recreational anglers (at lengths of around 300 mm TL) along much of the

lower west coast shoreline (**Figure 3.7.1**). In past years this species was occasionally recorded as far south as Perth, but it has never been as abundant as it is at present. Another more tropical species, the black-spotted dart (*Trachinotus bailloni*) for which there is no previous record of captures off metropolitan beaches, was also captured along the metropolitan shoreline in April 2012. Small threadfin salmon (*Polydactylus plebieus*) (120-185 mm TL) were first recorded by shore-based recreational fishers at Dongara, Quinns Rocks and Preston Beach in March/April 2012. Individuals evidently survived over the winter months, with the species captured at Pinnaroo Point in finfish recruitment surveys in September 2012, and more recently by a recreational angler at Esperance on the south coast.



**Figure 3.7.1:** Examples of tropical species resident in Perth nearshore waters following the 2010-11 marine heat wave event, (Left) smudgespot spinefoot (*Siganus canaliculatus*) and (Right) common dart (*Trachinotus botla*) (Photos: Chris Dowling).

The MAF harvests post-settled recruits of numerous finfish species and has provided various examples of how the heat wave influenced recruitment and survival of target species. MAF data indicate a marked increase in the abundance of the sub-tropical western butterflyfish (*Chaetodon assarius*) in Perth waters during 2011. Unusually, catches were also recorded as far south as Geographe Bay. MAF data also indicate that the common weedy seadragon (*Phyllopteryx taeniolatus*), a temperate species, has been less abundant and captured further south off the lower west coast since the heat wave.

Finfish recruitment surveys in the West Coast and South Coast Bioregions indicate changes in the location and rate of recruitment by various nearshore temperate species. Surveys during 2011 and 2012 indicated a marked elevation in recruitment by the warm temperate silver bream (*Rhabdosargus sarba*) on the west coast, and a marked decline in recruitment of the cool temperate yellow-eye mullet (*Aldrichetta forsteri*) on both the west and south coasts. Future commercial and recreational catch records should reveal whether these recruitment trends eventually flow through into fishery catches.

Recruitment surveys also revealed that Australian herring (*Arripis georgianus*) recruitment in 2011 was relatively low following the heat wave. Although similarly low recruitment has been observed in other years, RAP logbook catch rates indicated that the abundance of maturing herring from the 2011 year class entering the west coast fishery in late 2012 onwards was greatly reduced compared to other year classes.

In future, a more detailed review of the various ongoing DoF databases should reveal whether the southern extensions of northern species eventually result in the establishment of active breeding populations, and result in a more permanent southerly shift in the traditional areas

of higher abundance either within the historical range of these species, or beyond that range. Where a significant range shift is demonstrated, management will need to be reviewed to ensure ongoing sustainability of the stock.

### **3.8 Impacts of the marine heat wave on temperate reef communities by T. Wernberg**

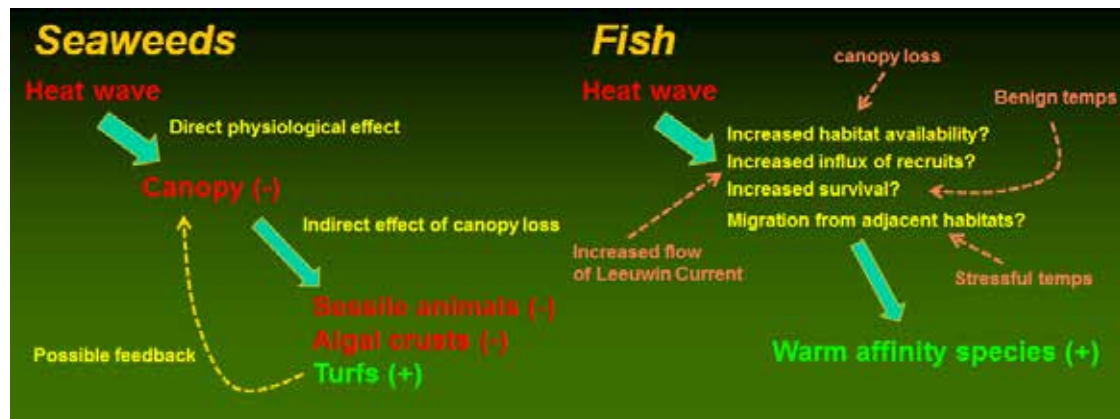
Thomas Wernberg, Dan Smale, Tim Langlois, Scott Bennett, Thibaut de Bettignies, Mads Thomsen and Fernando Tuya

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Heat waves and other extreme events are increasing in frequency and severity as a consequence of climate change, with potentially devastating impacts on marine ecosystems. During the 2011 marine heat wave, temperate reef communities in Western Australia - which are among the most diverse in the world - experienced the highest-magnitude warming event on record. Warming anomalies of 2–4°C persisted for >10 weeks. In Jurien Bay, a warm-temperate location, community structure of temperate seaweeds, sessile invertebrates and reef fishes were significantly affected by the warming event. For example, we found a substantial reduction in the cover of canopy-forming seaweeds (e.g., the kelp *Ecklonia radiata*), including the local extirpation and 100 km range contraction of *Scytothalia dorycarpa* (a prominent fucoid), and an increase in the abundance of reef fishes with a warm-water affinity (e.g., *Chaetodon assarius*, *Labracinus lineatus* and *Parma occidentalis*). Consequently, there was a shift in community structure towards a habitat state with less structural complexity and more turf algae, and a relative ‘tropicalisation’ of fish assemblages. Subsequent ecophysiological experiments on *S. dorycarpa* suggested that the decimation of canopy-forming seaweeds was caused by thermal stress at high temperatures, which ultimately caused cascading indirect effects on smaller algae and benthic invertebrates. A number of mechanisms could explain the changes in fish communities, including increased habitat availability, recruitment, survival and migration. Preliminary data from 2012 (2 years post-heat wave) suggest that fish communities are now returning towards the pre-perturbed state, but there is little sign of recovery of canopy seaweeds and biogenic habitat structure. Interestingly, the heat wave did not cause the same level of disturbance farther south, at the cooler Hamelin Bay, suggesting temperate communities in Jurien Bay are closer to an absolute thermal threshold of sudden change. In conclusion, the extreme heat wave was a major disturbance to temperate reef communities in south-western WA. The rates and trajectories of community recovery are unknown, but we will continue to monitor key reefs. Clearly, marine heat waves are key drivers of biodiversity patterns and the frequency and intensity of such episodes will have major implications for species distributions and ecosystem structure in Western Australia and globally.



**Figure 3.8.1.** The impacts of the marine heat wave on temperate reef communities were complex. The heat wave had direct physiological effects on canopy-forming seaweeds which decreased in cover. This, in turn, had indirect negative effects on sessile animals (sponges, ascidians) and encrusting algae which rely on canopy cover to prevent overgrowth, but positive indirect effects on small foliose and filamentous turf-forming algae. Canopy recovery has likely been suppressed by the turf cover through limiting canopy recruitment. For reef fishes, four different mechanisms can explain the observed patterns. Loss of canopy algae could have increased the available habitat as many species (e.g., *P. occidentalis*) prefer canopy free patches. At the same time, the increased flow of the Leeuwin Current and the elevated temperatures could have caused an increased delivery of fish recruits from lower latitudes and a higher survival. It is also possible that fish from shallower reefs shifted deeper as habitat was released, although this seems less likely as many juvenile and sub-adult individuals were observed.

### Key papers

- Smale, D., Wernberg, T. (2012). Ecological observations associated with an anomalous warming event at the Houtman Abrolhos Islands, Western Australia. *Coral Reefs* **31**: 441-441.
- Smale, D., Wernberg, T. (2013). Extreme climatic event drives range contraction of a habitat-forming species. *Proceedings of the Royal Society B* **280**: 20122829.
- Wernberg, T., Smale, D. A., Tuya, F., Thomsen, M. S., Langlois, T. J., de Bettignies, T., Bennett, S., Rousseaux, C. S. (2013). An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. *Nature Climate Change* **3**: 78-82.

## 3.9 How heat waves can change fish distributions in southwest Australia by T. Langlois

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Southwestern Australia has been described as an old, climatically buffered and infertile seascape (OCBIS) because of the geological and oceanographic stability of the region for the last 60 million years (Langlois *et al.*, 2012). The southward flowing Leeuwin Current has acted to warm the region and suppresses upwelling and productivity during the winter. The relatively stable and low nutrient environment has led to a high diversity and endemic species in marine habitats of southwestern Australia and many of these species have a unimodal distribution along the coast. This creates a system where changes in species distribution should be relatively easy to detect.

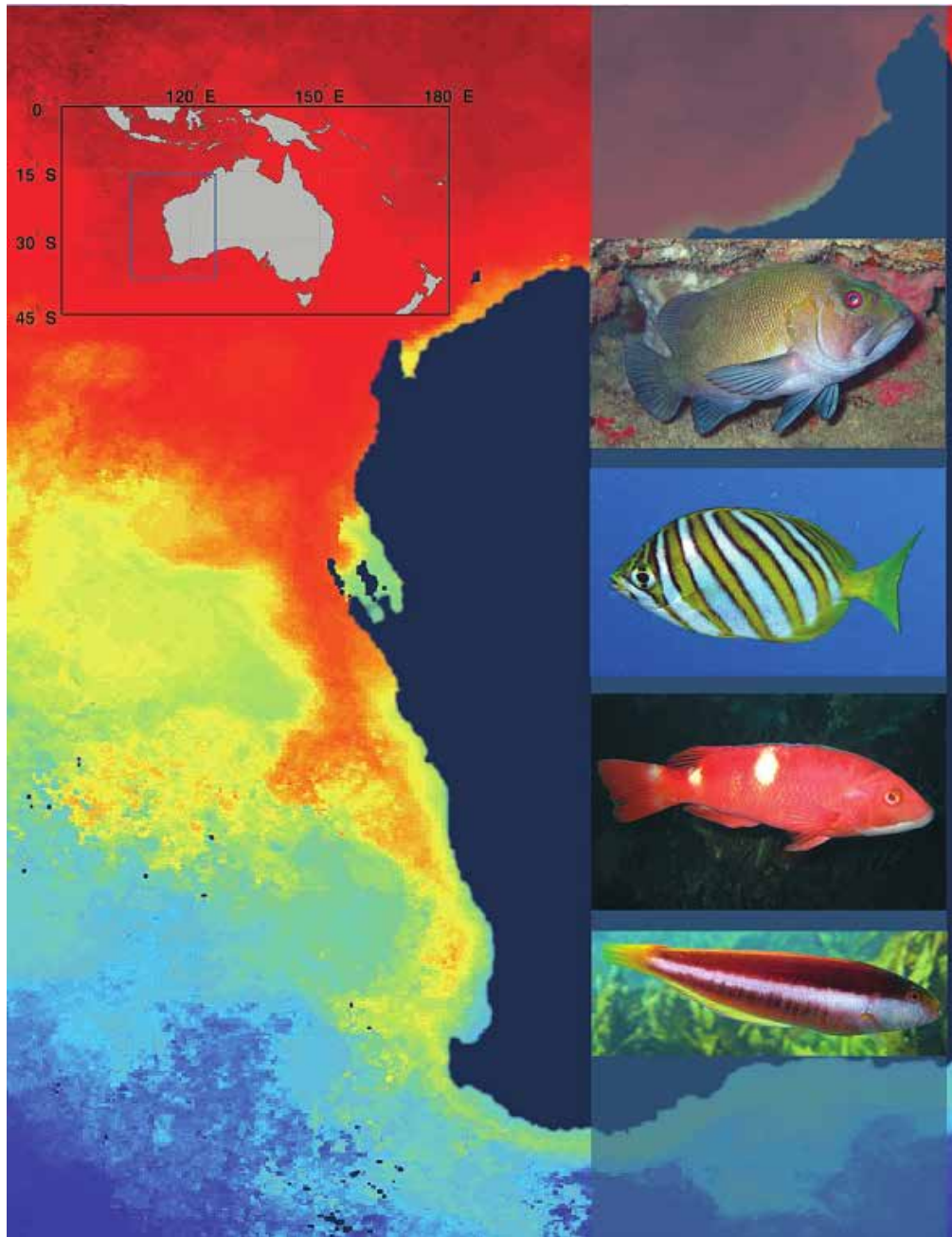
After the marine heat waves of 2011-13 changes in the distribution of many marine species have been observed. Monitoring studies conducted in Jurien Bay revealed an increase in the abundance of reef fishes with a warm-affinity (e.g., *Chaetodon assarius*, *Labracinus lineatus* and *Parma occidentalis*) after the initial heat wave (Wernberg *et al.*, 2013). Interestingly, the heat wave did not cause the same level of disturbance further south, at the cooler Hamelin Bay, suggesting temperate communities in Jurien Bay are closer to an absolute thermal threshold of sudden change.

A broader benchmark study of fish assemblages along the southwestern Australian coast was conducted from 2007 to 2010. The recently completed monitoring of the proposed Nagari Capes Marine Park, Houtman-Abrolhos Islands and Perth metropolitan waters will allow us to further assess what changes have occurred. The most important question to answer for the future will be have we seen a permanent shift in fish distributions, the start of a trend or will these species return to their previous distributions.

### Key papers

Langlois, T. J., *et al.* (2012). Consistent abundance distributions of marine fishes in an old, climatically buffered, infertile seascape. *Global Ecology and Biogeography*, **21**: 886-897.

Wernberg, T., *et al.* (2013). An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. *Nature Climate Change*, **3**(1): 78-82.



**Figure 3.9.1.** The Western Australian coast with the Leeuwin Current flowing south along the coast. Four of the species discussed are shown.



### 3.10 Indicators of heat stress to seagrasses by G. Kendrick

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In summer 2011, the west coast of Australia was affected by a marine heat wave that elevated sea temperatures 2–4°C higher than normal over several weeks, resulting in coral bleaching, macroalgal mortalities, and fish kills over much of the coast. This study reports on effects to seagrasses in Shark Bay. The temperate species, *Amphibolis antarctica* and *Posidonia australis* are the dominant seagrasses, although they are towards the northern limits of their geographical distribution. Tropical species of the genera *Cymodocea*, *Halodule* and *Halophila* are minor components. We present evidence from 3 separate research programs that indicate the heat wave impacted both *A. antarctica* and *P. australis* over a broad spatial extent and in different ways.

Defoliation of *A. antarctica* meadows was observed baywide but was more extreme in areas of high turbidity driven either by detrital pools or by particulates in floodwaters from the Wooramel River that year. *A. antarctica* was susceptible to decreases in light availability when combined with higher temperatures, presumably due to increased respiratory demand with no ability to increase photosynthesis to meet this. The small, tropical seagrass species, *H. uninervis*, was not significantly affected by the flood. *H. uninervis* is adapted to higher water temperatures than *A. antarctica*. In addition, the high seed production and dormancy in the sediments in this seagrass would be well suited to increases in frequency and intensity of disturbance events like riverine flooding.

An analysis of *A. antarctica* biomass with distance from the Wooramel delta indicated that leaf biomass declined with distance. Leaf biomass obtained in March, two months after the combined effects of high water temperatures and flooding, declined logarithmically. The log linear model was highly significant with an  $r^2$  of 0.96 ( $\log(\text{Leaf\_biomass}) = 0.291 \times \text{Wooramel distance}$ ) (**Figure 3.10.1**). A highly significant linear model was obtained for September, 8 months after combined effects of high water temperatures and flooding, with an  $r^2$  of 0.89 ( $\text{Leaf\_biomass} = 6.29 \times \text{Wooramel distance}$ ) (**Figure 3.10.1**).

Similarly, an independent study of the L'Haridon Bight, Monkey Mia and Peron Peninsula meadows indicated wide-scale defoliation of *A. antarctica* and death of meadows 1 year after the extreme water temperature event of 2011. Burkholder *et al.* (2012) surveyed the entire Shark Bay between 2007 and 2009. A smaller number of sites were then sampled in 2012.



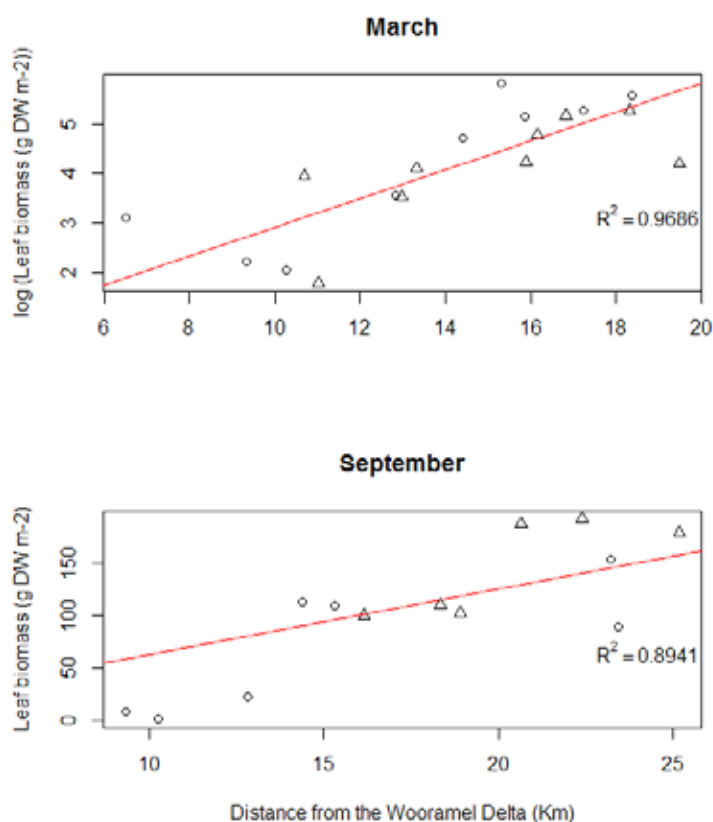
Percent cover of *A. antarctica* from 3 x 0.6 x 0.6 m quadrats per site declined from median values of 65% to less than 10% in L'Haridon Bight (31 sites), 80% to <10% in sites at Monkey Mia (42 sites), 65% to <5% on the eastern Peron Peninsula (20 sites), and 65% to 25% on the eastern Peron Peninsula including Denham (20 sites).

The extent and intensity of defoliation and plant mortality from the Wooramel Bank and Faure Sill and from eastern and western shores of Peron Peninsula suggest defoliation after higher than usual water temperatures was a bay-wide phenomenon. The greatest effects were seen in shallow areas nearshore, in turbid waters and in high salinities. Our evidence is correlative and further experimentation is required to further understand the cause-effect pathway. How a loss of a major foundation species across such a wide region in Shark Bay will affect seagrass dependent marine organisms is unknown.

*Posidonia australis* do not show defoliation at any sites across the bay, but 100% seed abortion was observed from flowering in the Western Bay in 2011. Successful reproduction has not been observed since. Flowers developed pericarp (fruit) but these were all empty, containing aborted embryos (**Figure 3.10.2**). This effect was also observed at Guichenault Point on the eastern Peron Peninsula in 2012.

## References

Burkholder, D. A., Fourqurean, J. W., and Heithaus, M. R. (2013). Spatial pattern in seagrass stoichiometry indicates both N-limited and P-limited regions of an iconic P-limited subtropical bay. *Marine Ecology Progress Series*, **472**: 101–115.



**Figure 3.10.1.** Leaf biomass (g DW m<sup>-2</sup>) as a function of the distance from the Wooramel Delta. Circles denote sites located South while triangles indicate sites located North of the Wooramel.



**Figure 3.10.2.** Longitudinal sections through pericarps (fruits), showing a hollow section (white arrow) where embryos should be found, and a much reduced aborted embryo (black arrow) from Useless Loop, 2012.

### **3.11 Department of Environment and Conservation monitoring the effects of the 2010/2011 marine heat wave on coral communities; Two years on by S. Field**

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In the summer of 2010-11, unprecedented levels of coral bleaching induced by anomalous elevated seawater temperature events were recorded across 12° of latitude and 1200 kilometres of coastline in Western Australia (Moore *et al.*, 2012). A collaborative study, involving state and federal government agencies, universities, industry and community groups, showed coral mortality, as a result of significant bleaching and storminess, occurred only in isolated areas of the state and was not as severe as predicted given the severity and extent of bleaching that occurred. Preliminary results in 2010/11 detected that *Acropora* spp. bleached with high subsequent mortality within areas of the Ningaloo Reef and the Houtman Abrolhos Islands but did not suffer the same levels of mortality within reefs inside the Montebello Barrow Islands marine protected areas. In addition, coral mortality was not only taxa and location specific within regions, but also partially due to increased storminess generated by the anomalously warm water.

Subsequent systematic monitoring at sites within the Department of Environment and Conservation (DEC) managed marine parks using fixed transects in 2011 and 2012 showed coral cover in some areas within the Ningaloo Reef continued to decrease (e.g. Bundegi and southern areas of Ningaloo) or have remained stable (e.g. Northern Ningaloo). Coral cover within other regions such as the Montebello and Barrow Islands Marine Protected Areas also remained at levels similar to those prior to bleaching in 2011. There were also regional differences in the coral taxa affected. At Ningaloo Reef and the Houtman Abrolhos Islands *Acropora* spp. were most affected in 2011, but at the Montebello and Barrow Islands there was extensive bleaching of *Echinopora* spp., *Montipora* spp., and *Galaxea* spp. although only some of those colonies subsequently died. The detection of differential bleaching and subsequent loss of coral for particular taxa across locations and regions may not only be driven by the differing physiological characteristics of colonies within the same taxon, but also differences in heat-stress, local oceanographic characteristics, and the community structure of affected areas.

Understanding the spatial and temporal variation of coral responses to heat stress within marine protected areas and the broader marine environment aids in identifying areas that are resilient or susceptible to bleaching, enabling informed management decisions about spatial protection of reefs. Continued monitoring and research is required to elucidate coral reef dynamics and the variable responses of corals to the pressures that affect them. To achieve this goal on a State-wide basis, it is essential to continue to work collaboratively with a range of government and non-government agencies and community groups for the development of standard recording methodologies and provide the capacity required to record coral bleaching events and their impacts in real time.

## References

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### **3.12 Heat Wave 2011 – Cockburn Sound context: brief look at historical temperatures and insights to habitat impacts since by T. Rose**

By Sarah Macey, Tom Rose and Geoff Botting

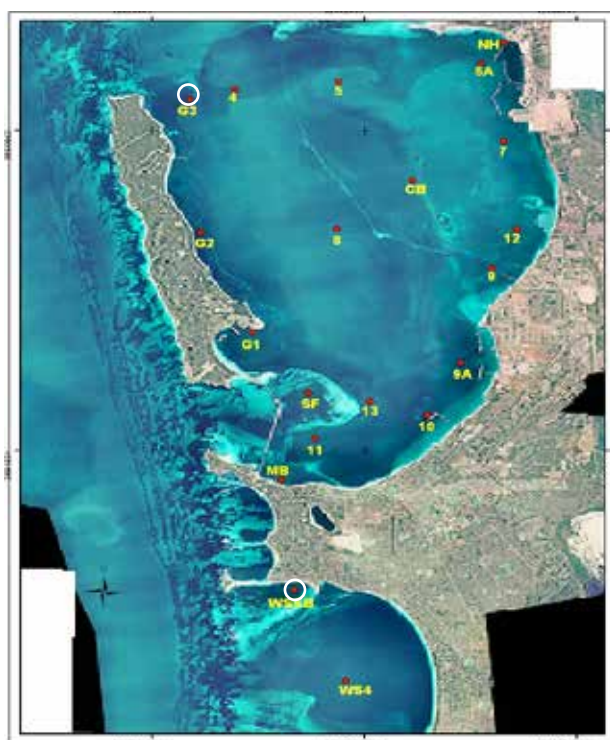
Cockburn Sound Management Council, PO Box 5161, Rockingham Beach, WA, 6969

[Tom.Rose@dec.wa.gov.au](mailto:Tom.Rose@dec.wa.gov.au)

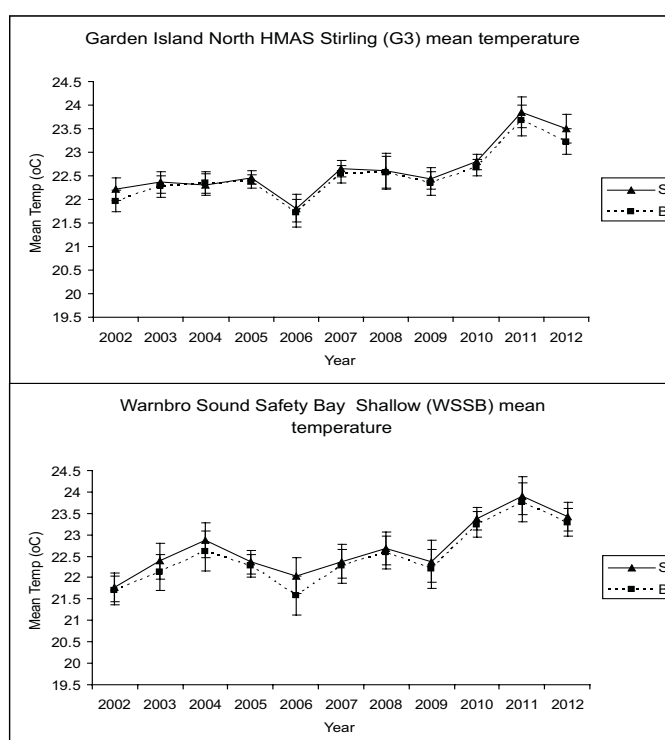
In the summer of 2011, Cockburn Sound experienced a significant marine heat wave, with sea temperature anomalies ranging from +2 to over +4°C recorded at numerous locations in the Sound as well as in nearby Warnbro Sound (Rose *et al.*, 2012). This event was fuelled by one of the strongest La Niña events on record and subsequently a strong Leeuwin Current that fed warm tropical waters down the coast which combined with warm local air temperatures. Together they influenced Cockburn Sound and nearby coastal embayments. Not only were sea temperatures high but lower dissolved oxygen was also recorded. Before and after 2011 the Cockburn Sound Management Council (CSMC) has also observed a general trend of declining seagrass shoot densities at a number of sites in Cockburn and Warnbro Sound.

Preliminary analyses suggest a trend of increasing sea temperatures and decreasing shoot densities over time. Although less clear there may also be a general trend of decreasing dissolved oxygen levels at several deep sites. These preliminary observations were based on surface and

bottom waters temperatures and dissolved oxygen levels between 1985 and 2012 measured from two sites in Cockburn Sound, one off Garden Island and a shallow reference site at Warnbro Sound. Similarly seagrass shoot density was compared at Garden Island and Warnbro Sound. Data though is presented between 2002 and 2012, between December and April only.



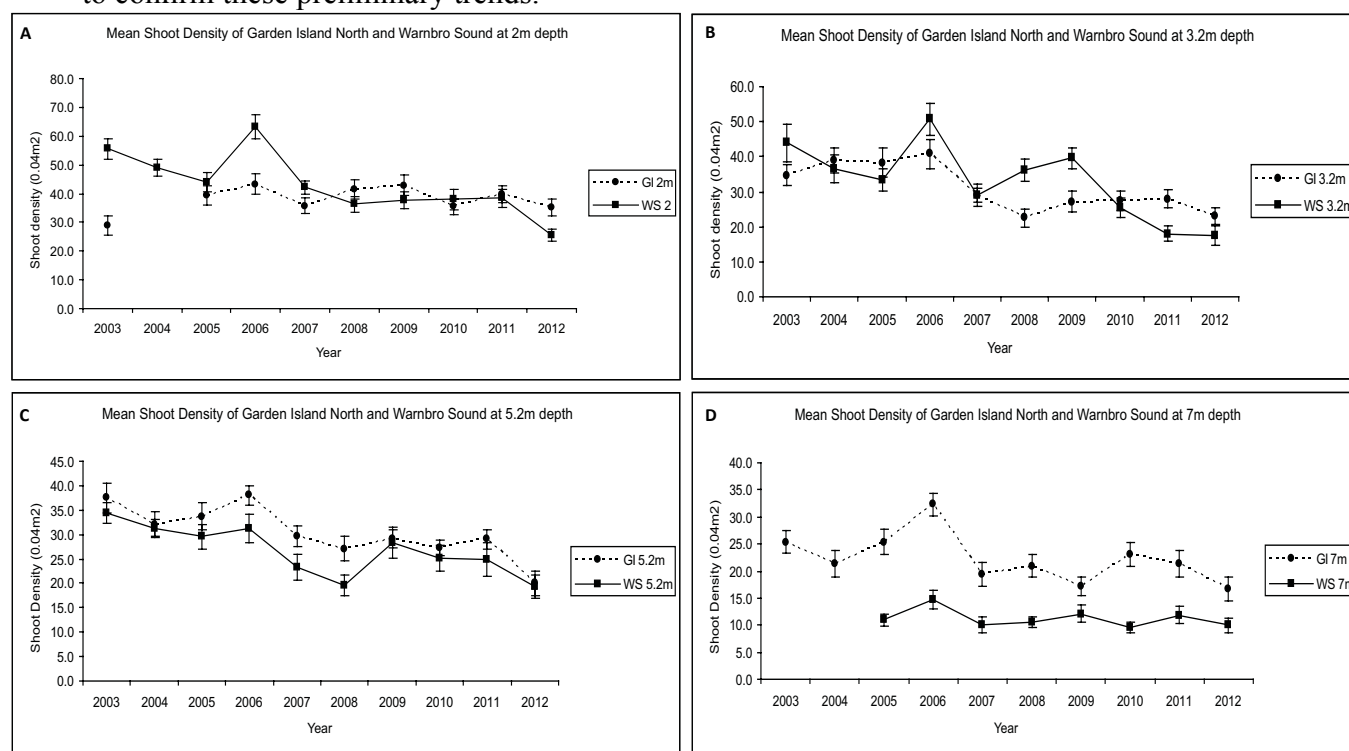
**Figure 3.12.1.** Map of sample sites within Cockburn Sound (key sites) circled)



**Figure 3.12.2.** Mean temperatures at surface (S) and bottom (B) depths at Warnbro Sound and Garden Island North

Initial analyses indicate that there is a steady and gradual trend of rising sea temperatures for both surface and bottom waters throughout the study period. In particular, there is a continual rise in summer and early autumn temperatures after the 2011 marine heat wave event. This increase in sea surface temperatures appears to correlate with a decrease in the seagrass shoot density at a number of sites within the Cockburn and Warnbro Sound area. Increased water temperatures have been observed to negatively influence seagrass growth, and although local temperate seagrasses are generally well adapted to fluctuations in summer temperatures, extreme high temperatures have been shown to increase mortality and reduce growth in seagrass meadows (Holmer *et al.*, 2011).

Evidence suggests that photosynthetic activity of temperate and tropical seagrasses are affected by heat shock. Important enzymes are thermally inhibited and cells redirect their energy towards defensive strategies. Heat shock in seagrasses can also reduce chlorophyll levels, reduce light (energy) absorption in chloroplasts for photosynthesis, and affect the levels of protective enzymes such as ascorbate peroxidase and superoxide dismutase. These proteins protect against oxidative stress (Massa *et al.*, 2011). Although there does seem to be a link between decreasing seagrass shoot density and increasing water temperatures, more statistical analyses are needed to confirm these preliminary trends.



**Figure 3.12.3.** Mean seagrass shoot density (per 0.04m²) of Garden Island North and Warnbro Sound at A) 2m B) 3.2m C) 5.2m and D) 7m

Despite the increased frequency of warmer sea temperatures and declining dissolved oxygen at several deep sites there has been no increase in reports of animal fatalities (e.g. fish, squid and starfish kill incidents), disease, marine pests, seagrass die-off or poor water quality including algal blooms. There is a lot of variability in the results and the influence of advective environmental factors such as wind and currents are likely to help dissipate or remove heat content from many of Cockburn and Warnbro Sounds' shallow and deep water habitats. Increased variability is also influenced by bathymetry which may also affect local advective processes. Finally, physical forces like erosion and/or sand burial may also play a role in the shallows of Warnbro Sound

particularly if storminess is increasing. Despite these factors, long term temperature rises can be expected to increase the frequency of adverse and debilitating conditions for warm temperate adapted organisms and their environment.

With the expected increase of events like this related to climate change, the question remains as to what long term impacts will occur in Cockburn and Warnbro Sound temperate seagrass meadows and other important environmental assets like local faviid and plesiastred coral and kelp habitats. This makes utilisation of more thorough statistical analyses critical to confirm the CSMC's preliminary observation of trends.

## References

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## Acknowledgements

Special thanks to Dan Smale for his initial 2011 assistance with analyses and interpretation and the Cockburn Sound Management Council and their water quality contractors (MAFRL Murdoch University) who have collected data used in this preliminary analysis.

### 3.13 Record-breaking temperatures and tropical fish recruitment at Rottnest Island by A. Pearce

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<sup>2</sup> Curtin University, GPO Box U1987, Perth, Western Australia 6845

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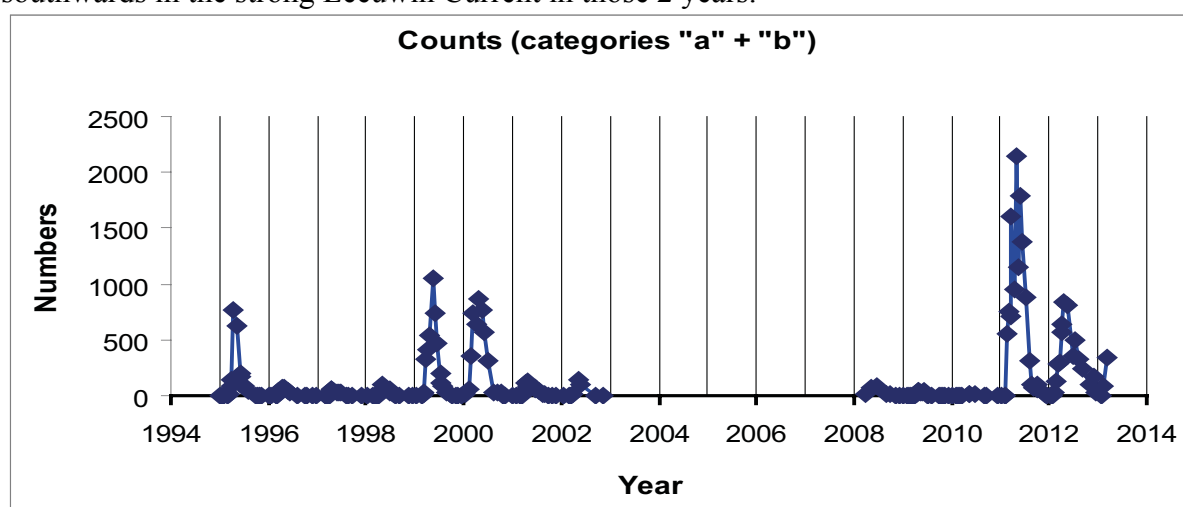
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Visual surveys of larval, juvenile and adult fish have been undertaken at Rottnest Island since 1977, but from 1995 more extensive observations at Parker Point have included a range of size categories as well as surface temperature measurements between Fremantle and Parker Point. Two of the more common and highly visible species have been the Damsel fish *Abudefduf sexfasciatus* (Scissortail Sergeant) and *A. vaigiensis* (Indo-Pacific Sergeant).

Both species are known to breed at the Abrolhos Islands, but no breeding behaviour has ever been witnessed at Rottnest Island. The annual arrival of new recruits (larvae and early juveniles) each autumn suggests therefore that they have been transported southwards in the Leeuwin Current as there is no local recruitment. The pelagic larval duration is about 3 weeks, and sample calculations and modelling have shown that pelagic particles/larvae can easily be carried well south of Rottnest Island by the current system in that time.

Over the past 2 decades, relatively large pulses of newly-arrived larvae and small juveniles have been observed in some years, typically between February and May, with much smaller numbers over the remainder of the year. Combining the larval and juvenile stages (size categories “a” and “b”) of both *Abudefduf* species into a single recruitment index has shown record recruitment in early 2011 (**Figure 3.13.1**), coincident with the marine heat wave of late February and the strong Leeuwin Current prevailing at the time. The following summer of 2012 also experienced an unusually large settlement, in line with previous high numbers during the La Niña events in 1999 and 2000 when the Leeuwin Current was again very strong. The high recruitment has been attributed to both strong southwards advection in the Leeuwin Current and a higher growth rate (with consequent better survival) due to the higher water temperatures.

Although Rottnest Island was previously the furthest south that *Abudefduf* larvae had been seen, 1 larval *A. sexfasciatus* was sighted at the Busselton Underwater Observatory in late March 2011 and 2 larvae were recorded in March 2012, all 3 having apparently been carried southwards in the strong Leeuwin Current in those 2 years.



**Figure 3.13.1.** Numbers of larval and juvenile damselfish observed at Parker Point between 1994 and 2013. There were no surveys between 2003 and 2007.

Apart from the *Abudefdufs*, the stronger Leeuwin Current flows and warmer temperatures experienced during the 2011 La Niña event were associated with seven new records for the first sightings of tropical fish species at Rottnest Island, well south of their normal ranges (**Table 3.13.1**). There were no “first sightings” in 2012, nor (as yet) in 2013.

**Table 3.13.1.** First sightings of tropical species at Rottnest Island in 2011.

<i>Acanthurus nigrofuscus</i>	Brown Surgeonfish
<i>Chaetodon speculum</i>	Oval-spot Butterflyfish
<i>Dascyllus trimaculatus</i>	Three-spot Dascyllus
<i>Hemigymnus melapterus</i>	Thicklip Wrasse
<i>Lutjanus bohar</i>	Red Bass
<i>Scarus frenatus</i>	Six-banded Parrotfish
<i>Scarus prasiognathus</i>	Dusky Parrotfish



### **3.14 Impact of the marine heat wave on Little Penguins: Change in diet and the lowest breeding success since records began in 1986 by B. Cannell**

Belinda Cannell<sup>1</sup>, Lynda Chambers<sup>2</sup>, Mike Bunce<sup>1</sup>, Daithi Murray<sup>1</sup>, Stuart Bradley<sup>1</sup> and Ron Wooller<sup>1</sup>

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The largest colony of Little Penguins in Western Australia is located on Penguin Island, 50 km south of Perth, and the breeding performance of a nestbox subpopulation has been monitored for over 20 years. From our long term data set, high SSTs in April and May are correlated with poorer breeding. In the summer of 2010 and throughout 2011, the waters along the south-western coast of Western Australia were impacted by a record strength Leeuwin Current and above average sea surface temperatures. In 2011, the penguins breeding participation and success were the lowest observed since monitoring began. Less than a third of the average number of eggs was laid and only 10% of these resulted in successful fledglings. In addition, four times the average number of penguins was found dead from August-December 2011. The dead penguins were found on Penguin Island and along the coast, up to 400 km south of the colony. Necropsies revealed that many of the penguins had died from starvation. Whitebait, the major constituent of their diet in previous years, was absent in 2011. It is likely that the anomalous oceanographic conditions impacted the presence of the whitebait in the local coastal waters. However the construction of a boat ramp adjacent to the major whitebait nursery in 2010 may have also played a role. These data highlight the ability to use penguins as sentinels of climate change but also the difficulty in decoupling environmental and anthropogenic causes of change.

### **3.15 Biosecurity, crabs and the marine heat wave by M. Hourston**

M. Hourston

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The Department of Fisheries is the lead agency in Western Australia for marine biosecurity and the Department's pest monitoring efforts are linked to the federal initiative, "The National System for the Prevention and Management of Marine Pest Incursions".

One of the most recent pest incursions has been *Charybdis japonica*, the Asian Paddle Crab, which was found in the Swan River Estuary by members of the public in late 2012. These detections sparked delimiting and response activities by the Department which included a large public awareness campaign. The public awareness campaign was a success resulting in the capture of two more *C. japonica*. An extra bonus from the public awareness campaign was reports of several species of crab that were locally rare or had not been known from the region previously.



These species (not currently listed as pests) included *Scylla serrata*, *C. feriata*, *C. natator*, *C. granulata*, and *C. annulata*. The first three of these species are typically tropical, and specimens were found in the temperate Swan River Estuary. The latter two species are widespread elsewhere in the world but are new records from Western Australian waters.

From these detections, two trends have been observable:

- Native species with typically tropical distributions were found far south of their ‘normal’ recorded range. This could be attributable to the higher temperature regime experienced during the heat wave.
- Non-native species with a wide thermal tolerance were found in Australia. This may be attributable to a larval transport event, also linked to the heat wave and the associated unusually strong Leeuwin Current.

In terms of marine biosecurity we must remain adaptable in the light of changing environmental regimes. Events like the current marine heat wave will change the types of pest species that we need to look for, however, the methods and protocols already in place are already sufficient to effectively monitor for them. With the increased stress on natural systems and the potentially increased inoculation pressures of non-native species, the marine heat wave has the potential to increase the likelihood of marine pest incursions dramatically.

### **3.16 Range extensions - Redmap by G. Jackson**

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At the first marine heat wave workshop there was strong support for increasing community involvement in monitoring change in Western Australia’s marine environment through collection of observational data (e.g. from commercial and recreational fishers, divers and beach walkers) through Redmap. Redmap (Range Extension Database and Mapping project, [www.redmap.org.au](http://www.redmap.org.au)) is an online database and mapping resource that allows members of the public to submit observational data (including photographs) of marine species occurring outside their known distribution (i.e. species that may be undergoing range shifts). Following a successful 3-year pilot in Tasmania, the project has now scaled-up to an Australian-wide long-term biodiversity monitoring system designed to be a low-cost, citizen science based approach to assess changing marine species distributions. Australia has over 3.5 million fishers and divers - many equipped with consumer electronics and the capacity to record verifiable observations. However, one challenge to the adoption of such datasets is the perception of bias or low quality. In addition to extracting geo-tag information from photographs (validating location), species identifications are verified by a large national panel of expert scientists using a semi-automated validation workflow. This initiative has the potential to generate large amounts of valuable quality data, engage communities in climate science and raise awareness of ocean warming and its consequences. The Department of Fisheries represents WA on the Redmap National steering committee.



Figure 3.16.1. Image of the Redmap website

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## 4.0 Overview of findings

A second workshop on the 'Marine heat wave - 2 years on' was held on 11 March 2013 about two years after the original event in the summer of 2010/11. This workshop concentrated on the oceanographic conditions since the workshop and the longer-term (2 years) effect on fisheries and the marine environment. The key findings identified were:

- The February/March 2011 heat wave with sea surface temperatures (SST) in some areas of the mid-west and Gascoyne reaching 4-5°C above average was a result of a record-strength Leeuwin Current for that time of year during an intense La Niña period, as well as anomalously high air-sea heat flux into the ocean.
- The unusual intensification of the Leeuwin Current associated with the extraordinary 2010/11 La Niña was forced remotely by the prolonged easterly wind anomalies in the equatorial western Pacific, and by the reduction of the southerly winds in February 2011 that oppose the alongshore current.
- A stronger summer Leeuwin Current was evident in 2008, 2009, 2011-2013 with most years being associated with anomalously high SST (2007, 2008, 2010-2013).
- SSTs were higher than normal during the last three summers in the three major fishing grounds of Exmouth Gulf, Shark Bay, and Abrolhos Is with winter temperatures near average or slightly below average. Shark Bay and Abrolhos experienced record high SST during February 2011 (~4°C above normal), with both 2012 and 2013 February SSTs approximately 2°C above average. SST anomalies in Exmouth Gulf during early 2013 matched or exceeded those of early 2011 (~3°C above normal).
- During the first heat wave event in 2010/11 there were a number of fish kill events recorded in the mid-west and Abrolhos Is. in late February and early March at a time when there were relatively calm conditions recorded that may have resulted in deoxygenation of the waters. There have not been any recorded fish kills associated with the following two anomalous summer water temperatures.
- The heat wave event may have contributed to the recent extremes in abundance of brown tiger prawns in Exmouth Gulf with recruitment being one of the highest recorded in 2011 followed by the lowest in 2012 despite a very good spawning stock in the previous year.
- King and tiger prawn catches in Shark Bay were within historic ranges, however there was an apparent shift in the distribution of the brown tiger prawns near their spawning area with a very low spawning stock in 2012. However catch rates were quite high just south of the spawning area indicating that the migration may have been affected by the effects of the heat wave and/or flooding events on the prawns or the seagrass habitat.
- The scallop catch in Shark Bay was well below prediction for 2011, possibly due to poor growth and mortality during the heat wave of 2010/11. Scallop fishing stopped in May 2011 at a reasonable catch rate. However a survey in November 2011 found extremely low abundance. The fishery was closed for 2012 and the November 2012 survey again indicated very low abundance and the fishery will remain closed for 2013. The Abrolhos Is. scallop fishery also experienced a similar situation to Shark Bay.
- In late 2011, blue swimmer crab (*Portunus armatus*) stocks in Shark Bay were at historically low levels due to low recruitment and mortality of adult stock. This was attributed to the unprecedented environmental conditions during late 2010-early 2011 (2 flooding events and marine heat wave). A survey in November 2011 and very low commercial crab trap catch

rates confirmed the low abundance and there has been no commercial retention of crabs since April 2012.

- Finfish recruitment surveys in the west and south coast during 2011 and 2012 indicated a marked elevation in recruitment by the warm temperate silver bream (*Rhabdosargus sarba*) on the west coast, and a marked decline in recruitment of the cool temperate yellow-eye mullet (*Aldrichetta forsteri*) on both the west and south coasts. Australian herring (*Arripis georgianus*) recruitment in 2011 was also relatively low.
- There have been many reports of increased abundance of tropical species such as Spanish mackerel (*Scomberomorus commerson*), smudgespot spinefoot (*Siganus canaliculatus*), and sand bass (*Psammoperca waigiensis*), in the lower west and south coast since the heat wave.
- In Jurien Bay, community structure of temperate seaweeds, sessile invertebrates and reef fishes were significantly affected by the warming event with a substantial reduction in the cover of canopy-forming seaweeds (e.g. kelp *Ecklonia radiata*), including the 100 km range contraction of *Scytothalia dorycarpa*.
- An increase in abundance of reef fishes with a warm-affinity (*Chaetodon assarius*, *Labracinus lineatus* and *Parma occidentalis*) was observed in Jurien Bay after the heat wave. However the effect was not observed further south, at the cooler Hamelin Bay, suggesting temperate communities in Jurien are closer to an absolute thermal threshold of sudden change. Preliminary data from 2012 suggest that fish communities are returning towards the pre-perturbed state, but there is little sign of recovery of canopy seaweeds and biogenic habitat structure.
- Surveys of Damselfishes *Abudefduf sexfasciatus* and *A. vaigiensis* at Rottnest Is. since 1995 have shown record recruitment in early 2011, coincident with the marine heat wave and strong Leeuwin Current. The summer of 2012 also experienced an unusually large settlement, in line with previous high numbers during the La Niña events in 1999 and 2000 associated with strong Leeuwin Currents. There were also seven first sightings of tropical fish species in 2011 at Rottnest, well south of their normal ranges.
- Preliminary analyses suggest a trend of increasing SSTs in the summer and early autumn in Cockburn Sound over the last 10 years and decreasing seagrass shoot densities.
- *Acropora* spp. bleached with high subsequent mortality within areas of Ningaloo Reef and Abrolhos Is. Subsequent monitoring showed coral cover in some areas within Ningaloo (Bundegi and southern areas of Ningaloo) continued to decrease.
- Breeding participation and success of Little Penguins on Penguin Is. in 2011 was the lowest observed in 20 years. High SSTs in April and May are correlated with poorer breeding.
- Some tropical crab species, *Scylla serrata*, *Charybdis feriata* and *C. natatory* were found in the temperate Swan River as well as new records from WA waters of *C. granulata* and *C. annulata*.
- Range extensions of tropical species in the lower west coast have persisted in the last two years but not to the same extent as observed at the peak of the heat wave in 2010/11.
- The tropical mud crab species has been reported in 2012 in the lower west coast and this may reflect the transport of mud crab larvae further south by the strong Leeuwin Current. A similar situation happened about 2 years after the very strong Leeuwin Current in 1999/2000.

Some key issues identified as requiring further research during the workshop were:

- Whether the three summers of 2010/11 to 2012/13 that showed above average water temperatures off Western Australia are part of a long-term trend. Previous research has indicated that long-term (30-50 year) water temperature increases off WA were mainly concentrated on the autumn/winter period with little or no long-term increases in spring/summer (Caputi *et al.*, 2009).
- Understanding the effects of the 3 years of above average water temperature on prawns in Exmouth, scallops and blue swimmer crabs in Shark Bay, and scallops in Abrolhos Is. that may have been significantly affected by the initial heat wave event of 2010/11.
- The possible effect on the recruitment and adult populations of finfish fisheries needs to be assessed as data becomes available on the age structure of key indicator species such as pink snapper.
- The effect of the heat wave and subsequent environmental conditions on the seagrass/algal habitats, coral and the fish community will require ongoing monitoring to assess their recovery.
- Redmap provides a mechanism for long-term monitoring of the range extension of tropical species that have been observed since the heat wave in 2010/11.

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## **5.0 Acknowledgements**

We would like to thank all the presenters for their enthusiastic support of the workshop and providing abstracts for this report. We also acknowledge the 80 participants in the workshop for attending and also making a considerable contribution to the discussion on the day. Finally we thank Jenny Moore for her organization of the workshop and contribution in collating and editing the report and Dr Stephen Leporati for reviewing the report.

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## **6.0 References**

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## 7.0 Appendices

### Appendix 1. Workshop Program

Time	Agenda	Speaker
9.00am	<b>Introduction</b>	
	<i>a. Objective</i>	<b>Rick Fletcher</b>
	<i>b. FRDC Climate change project: example of an extreme event</i>	<b>Nick Caputi</b>
9.20am	<b>Oceanography</b>	
	<i>a. Regional temperature variability along the WA continental shelf over the past decade</i>	<b>Alan Pearce</b>
	<i>b. La Niña forces unprecedented Leeuwin Current warming in 2011</i>	<b>Ming Feng</b>
	<i>c. Spatial variability and trends in sea surface temperatures in the Gascoyne region of Western Australia 2010-2013</i>	<b>Yasha Hetzel</b>
	<i>d. Discussion</i>	
10.30am	<b>Morning Tea</b>	
11.00am	<b>Effect on fisheries</b>	
	<i>a. Effect of heat wave on blue swimmer crabs, prawns and scallops in the Gascoyne and mid-west</i>	<b>Mervi Kangas &amp; Danielle Johnston</b>
	<i>b. Marine heat wave impacts on abalone Roei stocks</i>	<b>Anthony Hart</b>
	<i>c. Assessing the effects of the 2010/11 marine heat wave on finfish fisheries</i>	<b>Gary Jackson</b>
	<i>d. Discussion</i>	
12.30pm	<b>Lunch</b>	
1.30pm	<b>Effect on marine community</b>	
	<i>a. Impacts of the marine heat wave on reef communities</i>	<b>Thomas Wernberg</b>
	<i>b. "Recovery" in fish assemblages after the heat wave</i>	<b>Tim Langlois</b>
	<i>c. Defoliation, flowering collapse and seed abortion in Shark Bay: indicators of heat stress to seagrasses during the 2011 marine heat wave</i>	<b>Gary Kendrick</b>
	<i>d. Effects of the 2010/2011 marine heat wave on coral communities: Two years on</i>	<b>Stuart Field</b>
	<i>e. The heat wave 2011 in context of Cockburn Sound: a brief look at historical temperatures and habitat impacts including seagrass</i>	<b>Tom Rose</b>
3.10pm	<b>Afternoon Tea</b>	
3.30pm	<i>f. Record-breaking temperatures and tropical fish recruitment at Rottnest Island</i>	<b>Alan Pearce</b>
	<i>g. Impact of marine heat wave on Little Penguins: Change in diet and lowest breeding success since records began in 1986</i>	<b>Belinda Cannell</b>
	<i>h. Occurrence of marine pest <i>Charybdis japonica</i> and range extension of native <i>Portunids</i> due to the marine heat wave</i>	<b>Mat Hourston</b>
	<i>i. Range extensions – Redmap</i>	<b>Gary Jackson &amp; Mike Burgess</b>
	<i>j. Discussion</i>	
4.30 pm	<b>General Discussion</b>	<b>Nick Caputi</b>
5.00 pm	<b>Close</b>	

## Appendix 2. Records of observations since the 2010/11 marine heat wave

These reports were provided by members of the public and scientific and fishing communities during the period immediately following the marine heat wave up to the second marine heat wave workshop (in May 2013). The information is intended to complement that reported in Appendix 3 in Fisheries Research Report 222 (Pearce *et al.* 2011). The information is housed in Department of Fisheries TRIM File RS 224/11-02.

<b>Extension of adult distribution:</b>			
<b>Area/Locality</b>	<b>Date</b>	<b>Observation</b>	<b>Observer</b>
East of Albany	15/07/2011	Blue marlin ( <i>Makaira mazara</i> ) (approx 4 m long) washed ashore	Tim Leary
Cockburn Sound	Feb 2012	Two NW blowfish (Silver toadfish <i>Lagocephalus sceleratus</i> ) caught from boat off Woodmans Point	Suzanne Ward
Off Mindarie	2/02/2012	Barracuda ( <i>Sphyraena barracuda</i> ) (104 cm TL) caught boat fishing for mackerel	Neil Sumner
Off Ledge Point	Apr-12	Boat angler caught pennant fish ( <i>Alectis ciliaris</i> )	Mike Roennfeldt
Ocean Beach, Denmark	14/04/2012	Black marlin ( <i>Makaira indica</i> ) (3215 mm TL) washed ashore	Tim Leary
Rottneest Island	during 2012	Upward of 20 dead green turtles ( <i>Chelonia mydas</i> ) washed ashore.	West Australian. 18 February 2013
<b>Arrival of new recruits:</b>			
<b>Area/Locality</b>	<b>Date</b>	<b>Observation</b>	<b>Observer</b>
Pinnaroo Point	30/09/2011	Capture of juvenile dart ( <i>Trachinotus botla</i> ) in Recruitment Survey beach seine hauls	Chris Dowling
Cockburn Sound	Oct-11	Capture of several coral crabs ( <i>Charybdis cruciata</i> )	Dave Harris
Swan River, East Perth	Oct-11	Dead mud crab ( <i>Scylla sp.</i> ) reported	Dave Harris
Murchison Estuary	13/10/2011	Kalbarri Offshore Angling Club kids fishing Comp. Species caught include estuary cod ( <i>Epinephelus coioides</i> ), mores perch ( <i>Lutjanus russelli</i> ), black-spotted dart ( <i>Trachinotus baillinii</i> ), common dart ( <i>Trachinotus bolta</i> ), western striped grunter ( <i>Pelates quadrilineatus</i> ), northern threadfin ( <i>Polydactylus plebius</i> ), northern flathead ( <i>Platycephalus arenarius</i> ), mud crab ( <i>Scylla sp.</i> )	Chris Dowling
Off Fremantle	20/12/2011	Juvenile cobia ( <i>Rachycentron canadus</i> ) (280 mm TL) caught boat fishing around Stragglers	Mike Roennfeldt
Nearshore beaches off Perth metro area (including Warnbro Sound.	2011 onwards	Moon crabs ( <i>Ashtoret lunaris</i> ) taken in Recruitment Survey beach seine hauls, and by shore - based commercial net fishers	Chris Dowling
Swan River, Mosmans	25/02/2012	Coral crab ( <i>Charybdis cruciata</i> ) caught whilst crabbing	Chris Dowling
Swan River	26/02/2012	Swanfish – painted lizardfish/grinner ( <i>Trachinocephalus canadus</i> )	Josh Brown
Cockburn Sound	Dec 2011/ Feb 2012	Spinefoot (Rabbitfish) ( <i>Siganus canaliculatus</i> ), and sandbass ( <i>Psammoperca waigiensis</i> ) in commercial catches	Frank Iianni

Dongara	5/03/2012	One juvenile threadfin salmon ( <i>Polydactylus plebeius</i> ) approx. 10-12 cm TL, and many dart ( <i>Trachinotus</i> sp.) caught from beach	Ray Masini
Dongara	6-9 Apr 2012	Two juvenile threadfin ( <i>Polydactylus plebeius</i> ) (approx. 50-60 mm TL) caught from shore	Keith Shadbolt
Cockburn Sound	10/04/2012	800 kg of spinefoot ( <i>Siganus canaliculatus</i> ) commercially caught with <i>P. sexlineatus</i> , and sand bass ( <i>Psammoperca waigiensis</i> ) regularly caught during the summer of 2011/12	Chris Dowling
Pinnaroo Point	12/04/2012	Juvenile dart ( <i>Trachinotus bolta</i> & <i>T. baillonii</i> ) (15-30 cm TL) caught by beach seine	Chris Dowling
Off Jurien Bay	Jan-13	24 lionfish ( <i>Pterio</i> spp) and some yellowtail seahorses ( <i>Hippocampus</i> sp.) in RL pots in 36 m depth	Kevin Brewer
Marmion Beach	Mar-13	Dart ( <i>Trachinotus bolta</i> ) caught by shore-based angler	Mike Roennfeldt
Rottneest Island	17/03/2013	Grass emperor ( <i>Lethrinus laticaudis</i> ) caught by boat angler	Chris Dowling
Swan River - under Fremantle Traffic Bridge	Apr-13	Twelve spinefoot ( <i>Siganus canaliculatus</i> ) caught by angler	Chris Dowling
Cockburn Sound - Coogee Jetty	May-13	Angler caught Rankin cod ( <i>Epinephelus multinotatus</i> )	Mike Roennfeldt

**Observations from Aquarium Fish fishers:**

Area/Locality	Date	Observation	Observer
Off Perth Metro	2011 post-heat wave	Explosion of seahorse ( <i>Hippocampus angustus</i> ) population; absence of sea dragons ( <i>Phyllopteryx taeniolatus</i> ); initially, butterflyfish ( <i>Chaetodon</i> sp) all but gone	Ben Mitchell
Off Perth Metro	2011 post-heat wave	Western butterfly ( <i>Chaetodon assarius</i> ) - good recruitment post – heat wave; cleaner shrimps ( <i>Stenopus hispidus</i> ) gone	Steven Marns
South of Perth Metro	2011/12	Evidence of tropicals overwintering soapfish ( <i>Diploprion bifasciatum</i> ) & yellowtail angel ( <i>Chaetodon topluspersonifer</i> )	Steven Marns
Geographe Bay	Mar-11	Starry triggerfish ( <i>Abalistes stellatus</i> ) caught diving	Derek Dufall
Off Perth Metro	Dec-11	Yellow emperor ( <i>Lethrinus atkinsoni</i> ) caught diving	Steven Marns
Off Exmouth	Mar-12	Regal angelfish ( <i>Pygoplites diacanthus</i> ) caught diving	Derek Dufall



### **Appendix 3. Some of the publications on the 2010/2011 heat wave**

- Abdo, D. A., L. M. Bellchambers & S. N. Evans (2012). Turning up the heat: increasing temperature and coral bleaching at the high latitude coral reefs of the Houtman Abrolhos islands. PLoS ONE 7(8): e43878. doi:10.1371/journal.pone.0043878, 11pp.
- Bureau of Meteorology, 2012. Record-breaking *La Niña* events: An analysis of the *La Niña* life cycle and the impacts and significance of the 2010–11 and 2011–12 *La Niña* events in Australia. <http://www.bom.gov.au/climate/enso/history/ln-2010-12/?ref=ad>.
- Cannell, B. L., L. E. Chambers, R. D. Wooller & J. S. Bradley (2012). Poorer breeding by little penguins near Perth, Western Australia is correlated with above average sea surface temperatures and a stronger Leeuwin Current. Marine and Freshwater Research 63, 914–925. <http://dx.doi.org/10.1071/MF12139>.
- Depczynski M., J. P. Gilmour, T. Ridgway, H. Barnes, A. J. Heyward, T. H. Holmes, J. A. Y. Moore, B. T. Radford, D. P. Thomson, P. Tinklet, & S. K. Wilson (2013). Bleaching, coral mortality and subsequent survivorship on a West Australian fringing reef. Coral Reefs 32, 233-238.
- Feng, M., M. J. McPhaden, S.-P. Xie & J. Hafner (2013). La Niña forces unprecedented Leeuwin Current warming in 2011. Scientific Reports 3: 1277DOI:10.1038/srep01277
- McDonald, J. I. (2012). Detection of the tropical mussel species *Perna viridis* in temperate Western Australia: possible association between spawning and a marine heat pulse. Aquatic Invasions 7(4), 483-490. doi.org/10.3391/ai2012.7.4.005.
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- Pearce, A., R. Lenanton, G. Jackson, J. Moore, M. Feng, & D. Gaughan (2011). The “marine heat wave” off Western Australia during the summer of 2010/11. Research Report 222, Department of Fisheries, Western Australia, 36 pp.
- Pearce, A. F. & M. Feng (2013). The rise and fall of the “marine heat wave” off Western Australia during the summer of 2010/2011. Journal of Marine Systems 111-112, 139-156. doi.org/10.1016/j.jmarsys.2012.10.009.
- Rose, T. H., D. A. Smale & G. Botting (2012). The 2011 marine heat wave off southwest Australia. Ocean Science Discussions 9, 1691–1703, 2012. doi:10.5194/osd-9-1691-2012.
- Smale, D. A. & T. Wernberg (2011). Ecological observations associated with an anomalous warming event at the Houtman Abrolhos Islands, Western Australia. Coral Reefs (2012) 31:441. DOI 10.1007/s00338-012-0873-4
- Smale, D. & Wernberg, T. (2013). Extreme climatic event drives range contraction of a habitat-forming species. Proceedings of the Royal Society B 280:20122829
- Thomson, D. P., D. Bearham & F. Graham (2011). High latitude, deeper water coral bleaching at Rottnest Island, Western Australia. Coral Reefs, doi:10.1007/s00338-011-0811-x.
- Wernberg, T., D. A. Smale, F. Tuya, M. S. Thomsen, T. J. Langlois, T. de Bettognies, S. Bennett & C. S. Rousseaux (2012). An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. Nature Clim. Change 3, 78-82, doi:10.1038/nclimate1627.