Fisheries Research Report No. 222, 2011

The "marine heat wave" off Western Australia during the summer of 2010/11

A. Pearce, R. Lenanton, G. Jackson, J. Moore[1], M. Feng[2] and D. Gaughan

[1] Department of Environment and Conservation
[2] CSIRO

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

Department of
Environment and Conservation

Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH, Western Australia 6920

Fish for the future

Correct citation:

Pearce, A., Lenanton, R., Jackson, G., Moore, J., Feng, M. and Gaughan, D. 2011. The "marine heat wave" off Western Australia during the summer of 2010/11. Fisheries Research Report No. 222. Department of Fisheries, Western Australia. 40pp.

Enquiries:

WA Fisheries and Marine Research Laboratories, PO Box 20, North Beach, WA 6920
Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: www.fish.wa.gov.au
ABN: 55 689 794 771

A complete list of Fisheries Research Reports is available online at **www.fish.wa.gov.au**

ISSN: 1035 - 4549 ISBN: 978-1-921845-25-3

Contents

1.0 Executive Summary

* Water temperatures off the south-western coast of Western Australia rose to unprecedented levels during February and March 2011, and this warming event has been termed a "marine heat wave". While surface temperatures were more than 3°C above the long-term monthly average over an extended area in February 2011, the temperature in some localised areas in coastal waters exceeded the long-term monthly average by 5°C for periods of a day or two in late February/early March.

* A scientific Workshop was organised on Thursday 5 May, 2011 to review the oceanic processes and biological/fisheries consequences of the heat wave and to provide a means for capturing much of the anecdotal information.

* This heat wave, which coincided with an extremely strong *La Niña* event and a record strength Leeuwin Current, is viewed as a major temperature anomaly superimposed on the underlying long-term ocean-warming trend.

* While sudden changes in water temperature have been recorded in waters off the Western Australian coast in the past, there have been no previous records of such strongly elevated temperatures.

* Biological effects reported to date include fish and invertebrate deaths, extensions and contractions in species distributions, variations in recruitment and growth-rates, impacts on trophic relationships and community structure, and variations in catch rates of exploited species.

* As such, the elevated water temperatures were viewed as resulting either in mortality or in a variety of "sub-lethal" effects, both of which can have either short or long-term implications.

* These observed and expected biological consequences are based primarily on anecdotal information collected during or directly after the passage of the heat wave. However, as results from ongoing research and monitoring programs become available, a more comprehensive and considered view of the effects will be forthcoming in the form of peer-reviewed journal papers.

* While widespread mortality of fish and invertebrates were reported, none were shown to be attributable to disease.

* It appears that the incursions of large volumes of silt-laden water from river outflows into the adjacent coastal waters of the mid-west coast between Dongara and NW Cape following the passage of the tropical cyclone Bianca in late January are also likely to have contributed to the mortality experienced by the marine biota of that region.

* While the nature of the impacts will to a large extent dictate the type and degree of management response, most of the fishery responses identified in this report are currently covered in the ongoing monitoring and assessment protocols in place in the Department of Fisheries, noting that in particular, the response to mortality events is a well co-ordinated, interdepartmental process.

* The two most urgent "Fisheries Management" actions are (a) the need to review the management (and future monitoring) arrangements for Area 8 of the Roe's abalone fishery, and (b) to determine the consequences of any additional mortality of the 2010 rock lobster puerulus settlement.

2.0 Introduction

Towards the end of 2010, evidence began to emerge of unusually warm waters flooding southwards along the Western Australian coastline. By February 2011 it was clear that a significant warming event was taking place, with widespread reports of fish kills and of tropical species being found further south than their normal range. Both large-scale satellite-derived sea-surface temperatures and local temperature logger measurements (**Figure 1**) showed that temperatures were >3°C above the normal summer averages in some regions. The term "marine heat wave" was coined to describe the unprecedented nature of the spatially and temporally extensive event. It was associated with an extremely strong *La Niña* and a record strong Leeuwin Current for this time of year.

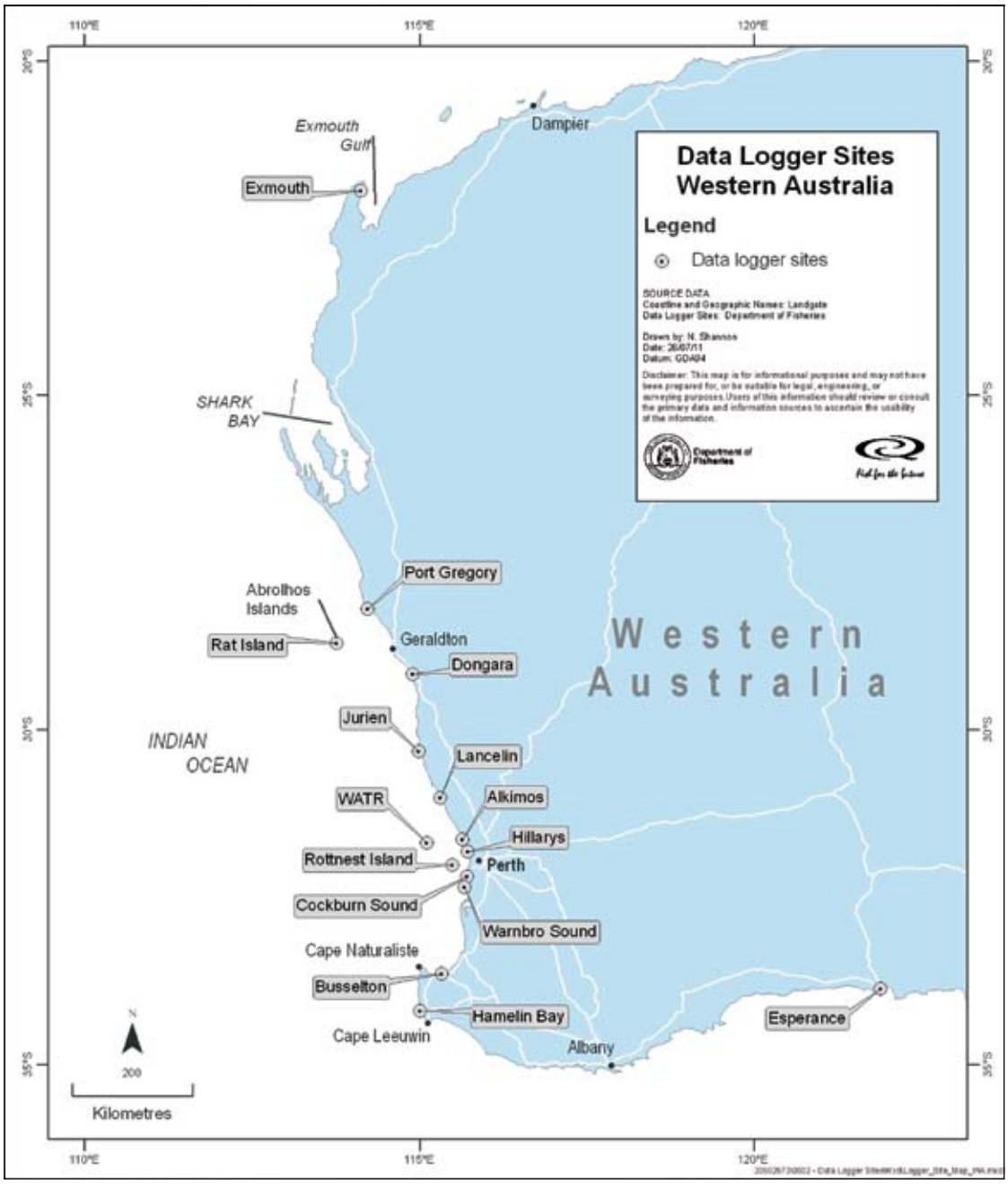

Figure 1. Chart showing the places mentioned in the text and the positions of the temperature measurements (circled).

Because of the important implications for the marine ecology and commercial and recreational fisheries off Western Australia, a workshop was held on the 5th May 2011 at the Western Australian Fisheries and Marine Research Laboratories, Hillarys, to review the oceanographic, ecological and fisheries consequences of the marine heat wave.

2.1 Workshop Objectives

The objectives of the workshop were to:

1. Review the oceanographic and meteorological information associated with the heat wave.
2. Examine the consequences for the marine flora and fauna (both vertebrate and invertebrate species).
3. Bring researchers together to determine if there were synergies in research activities associated with the heat wave and to consider whether there is sufficient information for a series of linked journal publications.

Following the distribution of a notice through the Australian Marine Sciences Association (AMSA) and Department of Fisheries email lists, as well as some personal invitations, offers of presentations were received and a program prepared (**Appendix 1**). The program was split into two sessions dealing with (a) the oceanography and large-scale biological consequences and (b) more localised/regional observations or anecdotal accounts. About 80 people attended the workshop (**Appendix 2**) including representatives from national and State government agencies, universities, and stakeholders, demonstrating a wide interest in the event.

2.2 Workshop outcomes/reports

In the summing-up session of the workshop (and including subsequent discussions), it was agreed to pursue the following "outputs" from the workshop:

a) A brief summary of the workshop in a few pages (mainly the "abstracts") to be emailed within a fortnight to the workshop participants and any other interested parties.

b) A Fisheries Research Report with more detail on the oceanographic and biological observations as well as the implications for management and further research (this report).

c) A poster to be submitted to the AMSA Conference in Fremantle in July 2011.

In addition, it was agreed that there was sufficient information and interest in the preparation of some peer-reviewed journal publications:

a) An overall paper based on the analysis and interpretation of the oceanographic information and a brief summary of the biological observations/consequences, planned for submission by about September.

b) A potential series of journal papers by different authors and groups including (but not necessarily restricted to) the workshop presenters.

2.3 Scope of this report

The production of this Fisheries Research Report was one of the agreed outcomes of the Workshop. The objectives of the report were to summarise the presentations (including more detailed analyses of the oceanographic information) to document issues raised in the discussion, and to examine the potential management implications including both short-term effects (such as variations in stock abundance) and longer-term impacts (such as range contractions of breeding stock). The biological effects reported to date were based primarily on the detailed anecdotal observations reported during the passage of the heat wave. However, as results from ongoing research and monitoring programs become available, a more comprehensive and considered account of the effects will be forthcoming, and it is planned that these will form the basis for a series of scientific papers in peer-reviewed journals during coming months. This report is designed to provide a formal basis for follow-up between potential collaborators on scientific papers to ensure the published results are synergistic and capture as much of the detail as possible, perhaps including some aspects that would not merit publication on their own.

Priorities for further monitoring and research are also discussed, highlighting the importance of appropriately targeted monitoring. It is worth pointing out that the detailed analysis of the warm water anomalies has only been possible because of the extensive network of high-quality temperature monitoring sites along the coast and at the offshore islands. In addition, shelf and offshore temperature monitoring stations have recently been established along the Two Rocks shelf and in the Perth Canyon by the Australian Integrated Marine Observing System (IMOS), as well as water quality measurements at three Western Australian National Reference Stations (Ningaloo, Rottnest Island and Esperance). With support from the WA State Government, IMOS has now extended its shelf-monitoring program to the North West Shelf and Kimberley coast, and these new observations will be used to complement the BlueLink modelling efforts by CSIRO and the Bureau of Meteorology to further the understanding the mechanism(s) and regional context of the heat wave.

3.0 Presentation summaries

In this section, summaries of all the presentations have been provided by the authors and are reproduced here as a record of the workshop proceedings. The first presentation, dealing with the physical oceanography of the warming, has been expanded to summarise the oceanographic observations, focussing on the spatial and temporal extent of the elevated water temperatures.

3.1 The Leeuwin Current and ocean temperatures off Western Australia in summer 2011

Alan Pearce (Department of Fisheries and Curtin University) and Ming Feng (CSIRO)
alan.pearce@fish.wa.gov.au; ming.feng@csiro.au

The elevated temperatures, which peaked along the Western Australian coast in February/March this year, have been well captured by temperature records from many sources, covering a wide range of spatial and temporal scales (**Figure 1**). This "marine heat wave" was associated with one of the strongest *La Niña* events ever recorded and with record high summer sea levels along the WA coast (implying very strong southward transport of the Leeuwin Current).

On the regional scale, monthly satellite-derived sea surface temperatures (SSTs) showed warming of > 2°C above normal developing north-west of Exmouth in November 2010, then migrating southward and towards the coast in December. By January 2011 (**Figure 2a**), the warm patch had extended southward to Shark Bay and now included a small area with temperatures > 3°C above average. The southward extension continued into February (**Figure 2b**) when this > 2°C water covered a large area extending from Ningaloo to the Capes region and to almost 1,000 km offshore, and there was a central "core" > 3°C along the midwest coast and out to 200 km offshore -- this represented the peak of the heat wave. These summer temperatures were the highest since the satellite records began three decades ago. By March, the > 2°C patch had continued drifting southward and was weakening, beginning to break up in April and by May had effectively disappeared.

Fortuitously, sea surface temperature was recorded during a voyage of the RV "Whale Song" from Cape Town to Fremantle in January and February, clearly showing the rise in temperature into and across the Leeuwin Current/eddy region (Rob MacAulay pers.comm.)

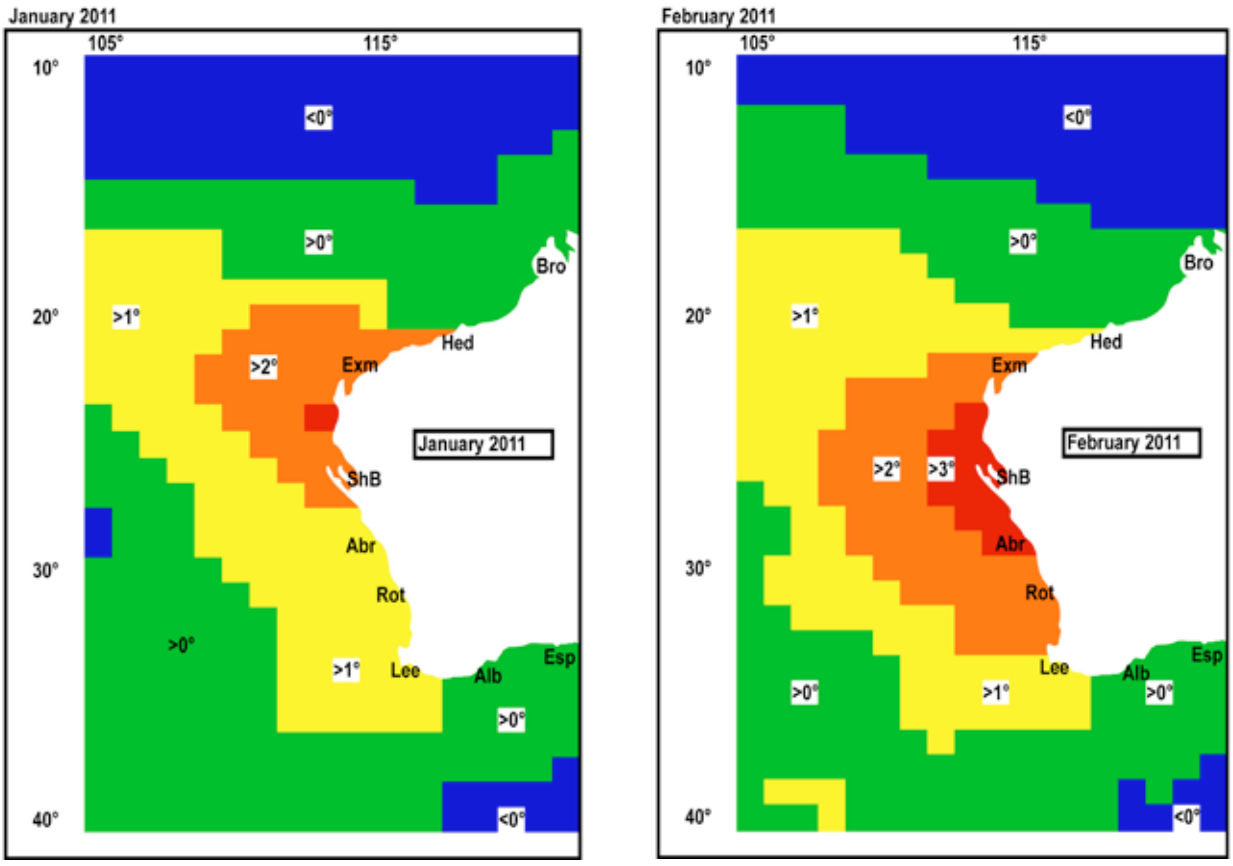

Figure 2. Monthly SST anomalies in the south-eastern Indian Ocean in (a) January and (b) February 2011 (at the peak of the heat wave) derived from the Reynolds SST dataset. Each colou ed block, wh ch is nominally 100 km * 100 km square, represents the difference between the monthly SST for that block and the long-term average for the month; the colour codes are: red >3°C anomaly; orange 2-3°C; yellow 1-2°C; green 0-1°C; blue <0°C.

On a more local scale, hourly temperatures from a number of nearshore sites along the coast and at the Abrolhos Islands have complemented the larger-scale measurements by providing more detail of the structure and evolution of the event in coastal waters. Temperature loggers have been used at many of the Department of Fisheries puerulus collector sites along the coast since 2001, and those measurements have been supplemented by loggers at Exmouth (the Curtin University Piercam installation), the Abrolhos Islands (Pelsaert Pearls/Cardno; FRDC project 2007/216), Lancelin (Friends of Lancelin Island), Rottnest Island (Curtin University; CSIRO), Cockburn Sound (Department of Fisheries), Busselton Jetty (Busselton Jetty Environment and Conservation Association) and Hamelin Bay (University of Western Australia). Hourly temperatures are also available from the Seaframe weather recording sites at Hillarys and Esperance (National Tidal Centre -- Bureau of Meteorology) and the Integrated Marine Observing System (IMOS) moorings off Two Rocks (CSIRO).

From these hourly measurements, daily-averaged temperatures have been derived from all available locations, and these confirm that the warm waters penetrated across the continental shelf into the coastal and nearshore region (**Table 1**). While the temporal evolution of the warming event was variable between sites (see Pearce & Feng, in preparation), the heat wave tended to peak over just a day or two at most sites, the bulk of these extreme temperatures

peaking over the 3-day period 27 February to 1 March all along the coast and the offshore islands (**Table 1**). The implications of this synchronism in terms of the relative contributions of the Leeuwin Current, oceanic eddies and the air-sea heat flux are being examined by Pearce & Feng (in preparation), as the geographic scale of the event suggests this was not solely a Leeuwin Current phenomenon.

To place these regional observations in a broader-scale perspective, monthly values of the Southern Oscillation Index (SOI, a measure of the intensity and phase of the *El Nino*/Southern Oscillation (ENSO) cycle) and of Fremantle sea level (an index of the strength of the Leeuwin Current – Pearce & Phillips, 1988; Feng *et al*. 2003) have been analysed. *La Niña* events can be defined by elevated values of the SOI. Previous (recent) *La Niña* events occurred over an extended period from May 1998 to March 2001, from June 2007 to February 2008 and from August 2008 to April 2009 (Bureau of Meteorology website: http://www.bom.gov.au/climate/enso/lnlist/), but the 2010-2011 event was one of the strongest over the past century. Likewise, Fremantle sea level anomalies (the difference between the monthly mean sea level and the long-term mean for that month) were at record highs over the period of the heat wave, indicating a very strong Leeuwin Current for this time of year.

Further, satellite altimeter sea levels suggested that the anomalous high Fremantle sea level originated from the equatorial western Pacific, with a stronger than normal Indonesian Throughflow transporting very warm Pacific Ocean waters into the southeast Indian Ocean. These in turn fed into the strong Leeuwin Current. The strong *La Niña* condition was superimposed on a decadal strengthening of the Throughflow and the Leeuwin Current which has been identified over the past 2 decades -- these relationships are being examined in more detail by Pearce & Feng (in preparation).

Table 1. The peak daily temperatures (and dates) recorded at the monitoring sites along the Western Australian coast. For those sites where there were 5 years or more of available data, the temperature anomaly from the long-term monthly mean for February/March has been included. The "WATR" entries refer to the Integrated Marine Observing System (IMOS) temperature moorings in water depths of nominally 50 m, 100 m and 150 m off Two Rocks, the shallowest measurements being at a nominal depth of 25 m.

Site	Date of peak temp. (2011)	Temp.°C	Anomaly (mean)	Source
Exmouth Gulf	24 Jan	31.2°		A. Hoschke
Port Gregory	28 Feb	28.9°	4.7° (24.2°)	M. Rossbach
Abrolhos Is. (Rat)	1 Mar	28.7°	5.0° (23.7°)	M. Rossbach
Abrolhos Is. (Rat)	1 Mar	28.6°		FRDC
Abrolhos Is. (Pelsaert)	28 Feb	28.7°		J. Buckee
Dongara	26 Feb	29.4°	4.9° (24.5°)	M. Rossbach
Jurien Bay	27 Feb	28.3°	5.5° (22.8°)	M. Rossbach
Alkimos	28 Feb	27.1°	3.7° (23.4°)	M. Rossbach
Lancelin	27 Feb	27.5°	4.2° (23.3°)	K. Marrs Ekamper
WATR50 (25 m)	28 Feb	25.4°		IMOS mooring
WATR100 (25 m)	6 Mar	25.6°		IMOS mooring
WATR150 (25 m)	27 Feb	26.6°		IMOS mooring

Site	Date of peak temp. (2011)	Temp.°C	Anomaly (mean)	Source
Hillarys Marina	28 Feb	26.9°	3.1° (23.8°)	Bur. Meteorology
Hillarys	28 Feb	26.5°		M. Rossbach
Rottnest (Parker)	1 Mar	25.7°		A. Hoschke
Rottnest (Parker)	28 Feb	26.3°		A. Pearce
Rottnest (south)	28 Feb	26.2°		A. Hoschke
Rottnest (west)	28 Feb	26.1°		D. Thomson
Cockburn Sound	1 Mar	26.2°		C. Marsh
Warnbro Sound	1 Mar	26.6°	3.3° (23.3°)	M. Rossbach
Busselton Jetty	28 Feb	25.6°	3.8° (21.8°)	A. Micha
Hamelin Bay	5 Mar	24.1°		T. Wernberg
Albany Waverider	12 Mar	23.2°		S. Moyes
Esperance Jetty	28 Feb	22.3°	1.7° (20.6°)	Bur. Meteorology

3.2 Dead fish - simmered or chilled?

Brian Jones (Department of Fisheries)
brian.jones@agric.wa.gov.au

On or about 27th Febuary 2011, an unusually warm eddy moved south in the Leeuwin Current bringing 30 degree water south to the vicinity of Moore River. The resulting spike in water temperatures (an increase of 2-3 degrees over a few days), also associated with calm still conditions, caused large fish kills at the Abrolhos Islands and along the coast from Green Head to Moore River. Dead fish continued to wash ashore over the next week, resulting in more reports, which were investigated by the interdepartmental State Fish Kill response program. Most of the fish received by the laboratory were already rotten, consistent with washing ashore after death. The large number of species affected was inconsistent with a causal pathogen. Based on a water sample collected in the vicinity of the dead fish on 4th March 2011, no algae (dinoflagellates and raphidophytes) typically causative for fish-kills were identified.

It is well established in the literature that sudden changes in temperature are lethal to fish (Sylvester 1972, Kim et al, 2001), these sudden temperature changes often being associated with current eddies and upwellings. For example, a significant, internationally reported fish kill off Dirk Hartog Island in 1937 was attributed to an influx of unusually cold water, reported at the time as "coldest on record" (Anon 1937 a,b; Lenanton *et al*., in preparation, a).

3.3 *Unprecedented bleaching of Western Australian reef corals*

James Moore[1], L. Bellchambers[2], M. Depczynski[3], S. Evans[2], S. Field[1], K. Friedman[1], J. Gilmour[3], D. Holley[1], T. Holmes[1], R. Middlebrook[1], T. Ridgway[3], H. Taylor[1], D. Thomson[4], P. Tinkler[3], S. Wilson[1]

[1] Department of Environment and Conservation (DEC), [2] WA Department of Fisheries (DoF), [3] Australian Institute of Marine Science (AIMS), [4] Commonwealth Scientific and Industrial Research Organisation (CSIRO)

james.moore@dec.wa.gov.au

Coral bleaching events are usually caused by long periods (usually 4 to 8 weeks) of warmer than average summer sea surface temperatures. As such, the mass of warm water that recently pooled off the Western Australia (WA) coastline, coinciding with unusually strong *La Niña* conditions, resulted in what we believe to be the first WA regional scale coral bleaching event. Accumulated thermal stress over the Austral summer affected corals to at least Rottnest Island in the south and the Montebello and Barrow Islands (MBI) in the north, with reports extending as far north as Cygnet Bay in the Kimberley. The onset of the bleaching event was observed at Ningaloo Reef and the MBI in the middle of January 2011, and extended southwards to Shark Bay, the Houtman Abrolhos Islands (HAI), Jurien Bay and eventually in waters surrounding Rottnest Island during March 2011 as the anomalously warm water moved southwards. Given the large spatial extent of the summer 2011 coral bleaching event, a meeting was convened in the middle of March between the DEC, DoF, AIMS, and CSIRO (the four agencies charged with research and monitoring of areas of significant coral habitat in WA) to coordinate a response to the assessment and documentation of the event.

Presently, the group is prioritising data to be included in the analysis for the publication based on criteria detailed in **Table 2**, which documents the data that are presently available and surveys that are planned to assess recovery and mortality of corals in the regions identified as having significant coral habitat. Preliminary examination of available data has highlighted that the MBI, Ningaloo Reef and the HAI regions will form the basis of the publication with supplementary support from regions with less replication or data resolution such as Rottnest Island and Shark Bay. It is anticipated that this data will be included in a publication planned for submission in the last quarter of this year (Moore et al., in preparation). Given the spatial extent of this event, and the prevailing institutional jurisdictions, we will be working closely as a group in the coming months to synthesise and standardise the available data into a concise and comprehensive account of this anomalous and significant event for WA coral reefs.

Table 2. Criteria for prioritising of sites for inclusion in 2011 WA coral bleaching publication.

	Kimberley	Dampier	Montebellos	Ningaloo	Shark Bay	Abrolhos	Perth	Geographe
Institution	**UWA?**	**Rio Tinto**	**DEC**	**AIMS/CSIRO/ DEC**	**DEC**	**Fisheries**	**CSIRO**	**?**
SST	✓	✓	✓	✓	✓	✓	✓	✓
In *situ temp*	×	✓	✓	✓	✓	✓	✓	Busselton
Site depth < 10m	?	?	✓	✓	✓	✓	✓	?
Backreef/ sheltered sites	?	?	✓	✓	✓	✓	✓	?
% coral cover	?	?	✓	✓	✓	✓	✓	?
Min. 5% total coral cover	?	?	✓	✓	✓	✓	✓	?
Transect ≥ 25m	?	?	✓	✓	✓	✓	✓	?
Before data	?	?	Apr 10	Jan 10	May 10	Feb 10	Mar 10	?
During data	?	?	Feb 11	Feb 11	?	Mar 11	Mar 11	?
Post data planned	?	?	May 11	Aug 11	Jun 11?	May-Jun 11	?	?

Yellow shading indicates regions with highest resolution and replication of data.

3.4 Unusual biological events coinciding with warm ocean conditions along the south-west coast of WA

Kim Smith, Noel Chambers & Gary Jackson (Department of Fisheries)
kim.smith@fish.wa.gov.au

In 2011, commercial fishers, recreational fishers and the public reported many unusual biological events along the lower west and south coasts of WA, coinciding with very warm coastal waters. Many species (fish and invertebrates) reportedly underwent "range extensions" (i.e. not necessarily permanent extensions in the true sense of the term), moving southwards along the west coast and/or eastward along the south coast. Mackerel were the mostly commonly reported species (see **Appendix 3**). Sightings commenced in February and were ongoing at the time of writing (May). Sightings coincided with the progressive extension of the heat wave into each region. Abnormal fish behaviour was also reported, particularly on the south coast. For example, Australian salmon displayed higher rates of feeding and a change in their preferred prey. Abnormal fish behaviour and warm water also resulted in lower catch rates in some commercial fisheries, unusual species composition in catches and poor condition of landed fish.

On the west coast, fish kills were reported during early/mid March (Lenanton et al., in preparation, b). Numerous events occurred on the mid-west coast, with one event also reported in Shark Bay. Many species of fish and invertebrates were affected. Some events involved very high densities of dead fish. Most dead fish were observed on beaches, with a few also reported floating in coastal waters. Kills were numerically dominated by sedentary species (eg. wrasse, cobbler, leatherjacket, eel, various invertebrates), although more mobile species were also affected (eg. whiting, herring, mullet). Large volumes of dead seagrass and macroalgae were reported on beaches or floating nearby. Discoloured water and a benthic layer of "slime" (suggesting a phytoplankton bloom) were also reported. On the south coast, hundreds of beached elongate sunfish were observed around Albany, commencing in early May. In 2008, another strong Leeuwin Current also resulted in sunfish strandings and range extensions along the south coast (Smith et al., 2010).

3.5 Lobster and abalone mortalities

Simon de Lestang, Anthony M. Hart (Department of Fisheries)
simon.delestang@fish.wa.gov.au; anthony.hart@fish.wa.gov.au

The marine heat wave documented on the Western Australian coast during the 2010/11 summer was associated with substantial reports of fish mortalities and related environmental phenomena. In the case of rock lobster, mortalities were only recorded at 2 locations, the Abrolhos Islands and Leeman; however it was noted that these may have been more widespread but less detectable, as dead lobsters do not float. More significantly, there were widespread reports of unusual lobster behaviour and discoloured water in areas between Wedge Island and Geraldton, which persisted for up to a month. Further investigations on lobster abundance are currently being planned for Seven Mile Beach later in 2011, as data will be available for a before/after comparison.

In the case of Roe's abalone, the effect of the marine heatwave appears to have been more severe, as compared to lobsters, abalone are less able to move to avoid unfavourable conditions. Between early February and early March, Roe's abalone stocks have suffered significant, if not total mortality in areas north of the Murchison River. Commercial fisher surveys between

March and June 2011 have not located a live abalone in this area. A significant spike in SST of between 26 and 30°C in late February appears to have been the trigger, arriving after at least 2 months of elevated water temperatures. Mortalities were also associated with discoloured water, poor visibility and algal blooms. Commercial fishers have voluntarily closed the Area 8 fishery, and policy action to close the recreational fishery was recently initiated.

3.6 Prawn recruitment trends and scallop growth in Shark Bay during 2010/11 - observations after unusually warm sea temperatures and flood events

Errol Sporer and Mervi Kangas (Department of Fisheries)
errol.sporer@fish.wa.gov.au

Recent fishery independent observations in Shark Bay, Exmouth Gulf and the Abrolhos Islands indicate;

- In combination with high turbidity due to flood events in Shark Bay in December 2010 and February 2011, apparent good survival of king (*Penaeus latisulcatus*) and tiger prawn (*Penaeus esculentus*) juveniles has resulted in high recruitment in March/April. The higher water temperatures contributed to increased recruitment of king prawns and catchability. The recruitment index this year is the highest observed since 2001. Commercial catches this season (2011) have been above average compared to recent years for March and April.
- During the annual scallop (*Amusium balloti*) survey conducted in November 2010 in Shark Bay, scallop size was smaller than normally observed during this period, and a repeated survey of a sub-set of sites in February 2011 confirmed reduced growth of scallops as well as the likelihood of an additional settlement of scallops later than normal. This may have been due to the higher water temperatures in Shark Bay relating to reduced growth, possibly due to a variation in food availability, heat stress and changes to the reproductive cycle of scallops.
- Exmouth Gulf recruitment surveys indicate high tiger prawn catches for the 2011 season. Seawater temperatures observed in 2010 were around 26 to 28°C whereas in 2011 the temperatures observed were around 29 to 30°C.
- During prawn recruitment surveys in Exmouth, higher blue swimmer crab (*Portunus pelagicus*) abundances were observed in Exmouth Gulf.
- Increased rainfall because of more frequent cyclonic activity in the northern fisheries was associated with an increase in banana prawns (*Fenneropenaeus merguiensis*).
- In the Abrolhos Islands scallop fishery, variable scallop growth patterns have been observed, not only in 2011, but also in 2009 and 2010. Normal scallop growth was observed in the Southern Group whilst poor growth has been observed in the Wallabi group. Even though scallop settlement was successful in 2010, meat size is relatively small compared to the scallops in the southern region and scallops in this area normally. It is uncertain whether this difference is due to food availability, different oceanographic influences or other factors.

3.7 Observations on the effects of high water temperatures at the Houtman Abrolhos Islands

Scott Evans and Lynda Bellchambers (Department of Fisheries)
scott.evans@fish.wa.gov.au

The Biodiversity and Biosecurity Section of the Department of Fisheries WA has been conducting reef monitoring at the Houtman Abrolhos Islands since 2007. One component of the program is monitoring 10 permanently marked sites using diver operated stereo video. The sites range in depth from 5 to 25 m and are surveyed in February/March each year. Environmental data from *in-situ* temperature and water movement loggers are also collected.

In 2011 the survey period (February-March) coincided with a period of high water temperatures along the Western Australian coast. Preliminary results from the *in-situ* loggers suggest that water temperatures were 3- 4°C warmer than previous years and as of the 3rd of March had not declined. Coral bleaching was observed at the majority of sites with up to 80% of corals bleached at some sites, particularly in the Easter Group.

During the survey period, water clarity and quality were lower than expected, with visibility less than 3 m and fish kills observed throughout the archipelago. A combination of factors may have been responsible for the poor water quality observed, from algal blooms and early coral spawning to low swells and light winds throughout the survey period. Fish mortality appeared indiscriminate ranging from small inshore species to large iconic species such as baldchin groper and breaksea cod. A number of fish were also observed displaying unusual behaviour such as wobbegong sharks on the bottom venting their gills and western rock lobster docile and away from the protection of the reef during the day.

3.8 Detecting ecological impacts of the 2011 heatwave through benthic monitoring

Dan Smale, Thomas Wernberg, Tim Langlois & Gary Kendrick (University of Western Australia)
daniel.smale@uwa.edu.au

A number of benthic monitoring programs are currently underway that have been, or could be, used to detect ecological consequences of the 2011 marine heat wave. As part of the Western Australian Marine Science Institution (WAMSI) and through the Integrated Marine Observing System (IMOS), an autonomous underwater vehicle (AUV) has been deployed to conduct high-resolution sampling of benthic communities at Rottnest Island, Jurien Bay and the Houtman Abrolhos Islands. The AUV captured thousands of stereo-images to sample replicate 25 x 25 m grids of seabed (100% coverage) at 15, 25 and 40 m depth at all locations. Individual images were subsequently 'stitched' together to produce continuous meshes of the seabed that can be monitored through time. The first sampling was completed in April 2010 and most grids were resampled in April 2011. In 2010 no coral bleaching was evident at any location, whereas in 2011 considerable (>20%) coral bleaching was observed at two 15 m sites at the Abrolhos. Further image analysis will be conducted to assess changes in kelp canopy structure and overall benthic assemblage composition.

Over longer time periods (i.e. >5 years) the structure of macroalgae and fish assemblages at key locations has been monitored. These data represent important 'baseline' information on the structure of benthic communities along the West Coast. Repeat surveys will be conducted in 2011 to assess whether the 2011 heat wave has had significant, long-term effects on ecological patterns.

3.9 Enhanced larval fish recruitment at Rottnest Island

Barry Hutchins (WA Museum)
swp@iinet.net.au

I have been investigating the recruitment of tropical reef fishes at Rottnest Island for almost 40 years. Although many sites around the island have been regularly surveyed, most of my effort has been in the lagoon at Parker Point, often referred to as Pocillopora Reef because of the abundance of the tropical coral *Pocillopora damicornis* there. In most years, the recruitment of tropical juvenile fish commences in autumn, and continues through winter. Survivorship into spring is usually low as water temperatures are then approaching the lethal limit for many tropical species. There is normally no recruitment in the summer months. In most years the numbers settling were low, but on several occasions, particularly 1999 and 2000, large numbers of recruits settled. Once again survivorship was low but at a noticeably higher level than in previous years.

Since 2000, the levels of tropical recruitment have been low at the island, especially in 2010 when only low numbers of new recruits were observed. At the beginning of 2011, however, water temperatures started to rise well above the norm, in February reaching almost 27°C in the deeper waters adjacent to Parker Point and almost 28°C in the lagoon. At the same time, a large number of recruits of the tropical damselfishes *Abudefduf sexfasciatus* and *A. vaigiensis* arrived on the reefs of Parker Point. The damselfish numbers quickly approached the record levels of 2000, and by April had surpassed them. The numbers of juveniles on these reefs in May were at the highest levels on record, and new recruits are still settling. At least 6 new records of tropical fishes for Rottnest Island have so far been recorded. The final total could be close to the record level of 14 new records found in 2000 as juveniles of the more secretive species start to emerge from the reefs. To date (May 2011), new recruits of 38 tropical species of reef fishes have been recorded for the Parker Point lagoon.

3.10 Some new visitors to the Busselton Underwater Observatory

Anna Micha (Busselton Jetty Environment and Conservation Association)
uwo@busseltonjetty.com.au

The Busselton Jetty Underwater Observatory is a large viewing chamber located on the ocean floor beneath the "iconic" Busselton Jetty. For the past 5 years, the staff of the Underwater Observatory have collected observations on the marine ecosystem in the form of simple presence/absence twice-daily surveys of the fish visible from the Observatory windows.

In the last few months, the observations have revealed several new species to the area that are more commonly found in the warmer waters of the north. Our surveys have also revealed significant falls in certain species that have been common sightings in the past. The new species to the area include raccoon butterflyfish, reef bannerfish and scissor-tail sergeant majors. Each

of these species appeared at the end of February and has been sighted regularly for at least one month or longer. The species that have dropped in numbers include the short tailed nudibranch that has dropped from a sighting percentage of 74% - 80% in March 2006, 2007 and 2008 to zero sightings in March 2011.

It must be noted that the Busselton Jetty has recently undergone significant restoration, which may influence the habitat of certain species.

4.0 Post-workshop submitted reports

The following are invited written contributions from a number of attendees who made worthwhile oral contributions on the day of the Workshop.

4.1 Observed offshore recreational fishing changes during the 2011 *La Niña* event

Ian Stagles (WA Game Fishing Association)
stagles@westnet.com.au

The early signs for game fishers in the Perth area were the early high Sea Surface Temperatures (SST) around the Fish Aggregating Devices (FADs) deployed around the 200m isobath. These seasonally higher SSTs saw mahi mahi recruit onto the FADs several weeks earlier than normal during *El Nino* events.

Marlin (black and blue) were also sighted several weeks earlier than normal and both the size and mix of species were significantly different to all previous years on record. Prior to 2011, the majority of marlin arriving in Perth waters were blue marlin, averaging 120 to 200 kilos in weight, and this year the vast majority of marlin were blacks ranging from 30 to 70 kilos in weight. In fact very few sizable blue marlin were encountered during the season, which traditionally runs from February to April.

During years of a strong Leeuwin Current other tropical species are occasionally sighted including wahoo. These fish historically have been around 20 kilos, or more, in weight and this year fish as small as 70cm in length were caught.

Further north, at Jurien Bay, local charter operators were encountering numbers of marlin on a regular basis, but again the fish were mainly small blacks.

Exmouth Game Fishing Club hosted the Australian International Billfish Tournament in late March 2011, in which 68 teams competed. As with the Perth marlin fishery, Exmouth competitors mostly encountered black marlin as small as 6 kilos estimated weight, which is very unusual.

The southern regular distribution of marlin species along the West Coast extends as far as Perth waters. Occasionally marlin are captured further south and this year the furthest southerly capture was Busselton.

Bait fish schools, upon which marlin feed, were primarily striped tuna which were evident in good numbers. However, smaller pelagic baitfish such as blue mackerel and pilchards were not commonly seen.

Through to the end of May 2011 the SSTs remained high and no winter run of larger tuna had been sighted.

4.2 A warm seawater event in Cockburn Sound – late February to mid-March, 2011. A note by Cockburn Sound Management Council (CSMC), Western Australia

Tom Rose and Geoffrey Botting (Cockburn Sound Management Council – Department of Environment and Conservation)
Tom.Rose@dec.wa.gov.au ; Geoffrey.Botting@dec.wa.gov.au

Background

Cockburn Sound experienced a warm seawater plume that pulsed through its popular recreational and industrial waters between the end of February and mid-March 2011. For approximately three weeks, elevated water temperatures and generally lower dissolved oxygen conditions compared to usual summer and early autumn conditions were experienced in Cockburn Sound, Owen Anchorage and Warnbro Sound. Analysis of CSMC data revealed a general system wide trend of elevated water temperatures. During this warm water event, temperatures reached a maximum of 27.58ºC in surface waters (0.5 m deep) and 26.62ºC in the bottom waters at a 10 m deep site. In Warnbro Sound maximums of 27.51ºC and 25.28ºC in surface and bottom waters (18 m deep) respectively were reached. Historical CSMC records indicate that ambient bottom water temperatures at these sites (2002-2010) usually range between 21-23.5ºC with surface temperatures one to two degrees warmer.

Dissolved Oxygen (DO) concentrations dipped to a minimum of 3.12 mg/L at one site in the deep southern basin of Cockburn Sound in the middle of the warm water event. The lowest DO concentrations in Warnbro Sound reached 6.39 mg/L during mid March or the last week of the warm water event. The previously lowest recorded bottom DO value for Cockburn Sound was 4.9 mg/L at deeper sites in late February or March in 2003 and 2007, while for Warnbro Sound at site WS4 it was 5.5 mg/L in 2009 during mid February.

The CSMC has little evidence of any detrimental environmental events or incidents that could be directly attributed to this elevated warm water temperature pulse or be ascribed to the impact of lower dissolved oxygen levels in Cockburn and Warnbro Sounds. Reports that were received were not unusual for this time of the year. However, a total of maybe four reports could possibly be related to the warm water conditions that occurred over the three week period. They relate to an algal bloom in northern Cockburn Sound, starfish deaths in Owen Anchorage (x2) and rotten smells at a beach.

Summary and Discussion

When temperatures and dissolved oxygen concentrations during this three week warm water period are compared to median values recorded between 2002 and 2010, it is remarkably clear how extreme this event was compared to "usual" summer and early autumn conditions. Temperatures were two to three degrees warmer than usual and at several sites DO concentrations were about 2 mg/L lower than the norm. More extreme conditions occurred at shallower eastern shelf Cockburn Sound sites although deep southern basin sites were also affected by low DO concentrations. After Week 13, water temperatures and to a certain extent bottom dissolved oxygen conditions quickly returned to median values associated with early autumn.

Interestingly, no extra-ordinary fish kill or biota mortality events occurred during this period. The CSMC do not regularly monitor the relatively numerous but small coral bommies/ outcroppings located on the eastern Kwinana shelf or near northern Garden Island (approx 20-24 coral locations are reported to exist). These small colonies may have experienced adverse conditions causing localised bleaching. Certainly though, no fish kills or extra ordinary reports were made of other marine biota deaths, e.g. starfish.

4.3 Likely impacts of the marine heat wave on Little Penguins along the west coast.

Belinda Cannell (Murdoch University)
B.Cannell@murdoch.edu.au

The marine 'heatwave' along the west coast in February and March 2011 may impact the Little Penguins (*Eudyptula minor*) that colonise Penguin Island, but this may not be evident until later in the year. The penguins can lay eggs in any month from April – December, and generally peak numbers of eggs are laid in June and a secondary peak in September. Penguins can also lay, and raise, two clutches a year. However, above average annual SSTs have been associated with later laying of eggs and lighter chicks at fledging (Cannell *et al*. in review). This means the penguins are less likely to be able to raise a second clutch in that year, and the lighter chicks have lower chance of survival. Higher SSTs in the months prior to breeding are also associated with later laying of eggs as well as a lower number of chicks produced per pair of penguins (Cannell *et al*. in review). Presumably the above average SSTs impact the availability of fish. Fewer birds also breed in the years when the parameters associated with breeding are lower. So the impact of the marine heat wave may be observed as later breeding, lighter chicks, fewer chicks per pair, fewer penguins attempting to breed and a poorer body condition of the adults.

Effects of the marine heat wave may also be observed in the duration of the foraging trips of the penguins. The incubation and chick raising is shared by both parents. During incubation, one parent forages for an average of 3-4 days before returning to the nest site. However, single day foraging trips are the norm when raising chicks, with the penguins remaining within 25 km of the island (Cannell unpubl. data). In years of poorer breeding success, the foraging trips during both incubation and chick-raising lasted longer than average (Cannell unpubl. data). Longer foraging trips may therefore occur this year, increasing the risk of eggs or chicks being abandoned or chicks starving.

4.4 Influence of marine heat wave on tropical marine pest incursions into temperate waters

Justin McDonald (Department of Fisheries)
justin.mcdonald@fish.wa.gov.au

Towards the end of 2010 there was an increase in the number of marine pest detections in Western Australia. The vast majority of these detections were of the invasive mussel *Perna viri*dis occurring as biofouling. In Australia *Perna viridis* is listed as a high priority pest species. To date, the only reported establishment of this mussel within Australia is in Cairns, Queensland. This Cairns incursion is now believed to have been eradicated.

In April 2011 an emergency response was triggered after the detection of a single *Perna virids* on a naval vessel berthed at Garden Island, Western Australia. This vessel had been in WA coastal waters for the last 6 months. Further examination of this vessel revealed no further *P. viridis*. However examination of an adjacent vessel revealed a small founder population that had recently established inside one of the vessel's sea chests. Growth estimates of the mussels removed from the vessel put an average sized mussel between 37.1 and 71 days old. Back calculating an 'establishment date' from these ages places an average sized animal's origins in the summer months of January 2011 to March 2011. This time period corresponds with an unusual heat pulse occurring along the WA coastline making coastal waters >3 degrees above normal. It is possible that further populations may have established elsewhere during this heat pulse but these may not become evident until later in the year.

Future predictions of climate change put water temperatures increasing anywhere from less than one degree to up to 3 degrees above the current levels. Given this recent event of a tropical species spawning in our temperate waters we should prepare ourselves for further incursions of many more tropical species.

5.0 Overview of Findings – consequences and implications

Environmental anomalies, such as the heat wave described in this report, can potentially affect any of the life history stages of species (*i.e.* larvae, newly settled juveniles, older juveniles and adults) present in the area of influence of the event, and indirectly influence trophic relationships and community structure. Further, in the case of exploited species, the magnitude and distribution of catches can also be affected.

Effects of this warming event reported to date in both workshop presentations and post workshop reports, and as observations by individuals **(Appendix 3),** can be broadly categorised as fish and invertebrate deaths, extensions and contractions in species distributions, variations in recruitment and growth-rates, impacts on trophic relationships and community structure, and variations in catch rates of exploited species **(Table 3).** These effects, which are based primarily on anecdotal observations and the preliminary results from ongoing monitoring projects, can be further grouped under either (i) "mortality" events or (ii) sub-lethal effects, both of which can have either short or long-term implications, noting that for the species/stocks that do experience sub-lethal effects, these effects can also be either be "positive" or "negative".

5.1 Mortality events

Fish kills are extreme events, and require immediate management attention through the enactment of the tried and tested interdepartmental state Fish Kill response program, the aims of which are primarily to document the extent of the mortality, to determine the cause, and mitigate any adverse effects. The stock/fishery-related consequences and resultant management implications are usually short-term, as mortality generally affects only a limited range of the distribution of the stock. However there are exceptions. For example, the recently reported mortality of the sessile Roe's abalone throughout the northern extent of its range may well result in a long-term range reduction, which will have important implications for the future of fishing on the northern area (8) of the WA Roe's Abalone Fishery. Similarly, coral bleaching will also have long-term implications for coral communities in affected areas.

Tropical cyclone Bianca tracked down the coast on January 29, 2011, during the period of elevated marine temperatures, bringing heavy rain to the catchments of river systems located on the mid-west coast. Subsequently the entrance sand bars of rivers such as the Irwin, Greenough, and Chapman were breached by large volumes of silt-laden freshwater runoff that rapidly spread through coastal marine waters, and likely contributed to the conditions that caused the mortality experienced locally by a range of species in the coastal marine community.

Table 3. A summary of the reported events associated with the marine heat wave anomaly in coastal waters of Western Australia, and their likely consequence.

REPORTED EVENTS	EFFECTS			RESEARCH & MANAGEMENT IMPLICATIONS
	Duration		Description	
	Short-term	Long-term		
(i) MORTALITY				
Fish (range of species on west and south coasts)	√		Temporary localised reduction in stock size of affected species	Be aware of any likely consequences of localised reductions in stock size
Roe's abalone		√	The abundance of northern stocks of this species is likely to remain low until the breeding stock recovers. Reductions in stock size in the region north of Kalbarri in Area 8 of the fishery are therefore likely to be long-term	Likely re-assessment of sustainable catch quota for Area 8
Rock lobster	√		Temporary localised reduction in stock size, and, depending on whether newly settled puerulus were affected, possible reduction in magnitude of the strength of the 2010 recruits. Any reduced catches are likely to be localised and inshore, which may have most impact on recreational fishers	Independent check of 2010 recruit strength Monitor 2011/12 catches from both catching sectors
Coral (bleaching)		√	Reduction in size of coral "community"	Assess the extent of mortality, and likely capacity for recovery
Starfish (Cockburn sound)	?	?	Possibly related to elevated SST, and unusually low dissolved oxygen	Assess the extent of mortality
(ii) SUB-LETHAL EFFECTS				
Range extension				

REPORTED EVENTS	EFFECTS		RESEARCH & MANAGEMENT IMPLICATIONS
	Duration	Description	
	Short-term Long-term		
Mackerel species (Spanish, spotted)	√	Temporary southern extension of range	Review any consequences of an elevated 2011 retained catch in West and South Coast Bioregions
Mahi mahi	√	Temporary southern extension of range (caught off Albany)	None
Elongate sunfish	√	Temporary southern/eastern extension of range	None
Tropical reef fish at Rottnest, and around the Busselton Jetty	√	Recruits unlikely to survive through the winter	Inform the (diving/viewing) community of the enhanced recruitment event
Gamefish – Exmouth south.		Change in species composition of the catch, from larger blue marlin to smaller black marlin, the latter recorded as far south as Busselton	Monitor ongoing catch records
Whale sharks	√	Seen off Mandurah, and reported as far south as Cheynes Beach, east of Albany	Continue to record reported sightings
Manta rays		Reported as far south as Albany	Continue to record reported sightings
Invasive tropical mussel *Perna viridis*.		Small population detected in Cockburn Sound	Eradicate the population, and extend monitoring to detect any additional populations
Range contraction			
Roe's abalone	√	Possible longer-term contraction in northern extent of stock distribution	See above
Australian salmon	√	Negligible movement of migrating maturing fish to West Coast spawning areas	Review strength and distribution of 2011 recruitment to west and south coast nursery areas
Enhanced recruitment			

REPORTED EVENTS	EFFECTS			RESEARCH & MANAGEMENT IMPLICATIONS
	Duration		Description	
	Short-term	Long-term		
Shark Bay King prawns		√	Together with higher catchability, has contributed to elevated catches. May also contribute to enhanced breeding stock	Review the abundance of breeding stock in the context of allowable fishing effort
Shark Bay tiger prawns		√	Together with higher catchability, has contributed to elevated catches. May also contribute to enhance breeding stock	Review the abundance of breeding stock in the context of allowable fishing effort
Tropical reef fish at Rottnest, and around Busselton Jetty.	√		Temporary increase in strength, and diversity of recruitment	See above
Reduced growth rates				
Shark Bay and Abrolhos scallops	√		Likely to lead to lower catches	Ensure sufficient breeding stock is retained for the following season
Altered trophic relations				
Australian salmon	√		As a consequence of stocks being confined to the south coast, there are reports of them consuming additional prey species (i.e. Australian herring)	Monitor the strength and distribution of the 2010 and 2011 A. herring recruitment
Little penguins			Later laying of egg clutches, lighter and fewer chicks at fledgling, and greater foraging range	Monitor ongoing breeding success
Altered community structure				
Benthos		√	Changes to the structure and composition of benthic species assemblages	Maintain benthic monitoring programs
Altered catch composition				
South coast commercial fish catches.	√		Lower catch rates, altered species composition, poor condition of landed fish	Once formal monthly catch and effort (CAES) statistics are available, check the extent of the changes
Enhanced catch-rates				
Exmouth blue swimmer crabs	√		Possibly related to improved catchability (and enhanced recruitment that had occurred prior to the warming event)	Ensure sufficient breeding stock is retained for the following season

5.2 Sub-lethal effects

Changes to the range of the distribution of a given species were one of the more commonly reported sub-lethal effects of this event. For example, there were many reports of southerly extensions to the range of tropical species. In virtually all instances reported, the effects will be short-term as it is unlikely that the displaced individuals will be able to tolerate the cooler water temperatures experienced during the following winter. New recruits, particularly those of the more localised sedentary species, such as the damselfish at Rottnest Island, may die and those that survive will almost certainly not be reproductively active. Whilst the consequences for larger more mobile species such as Spanish mackerel are as yet uncertain, observations of catches south of Geographe Bay suggest a highly mobile and dispersed population. Other negative consequences may include difficulty in locating suitable prey, leading to a lowering of body condition, which may also contribute to a reduction in reproductive output for the population. Indeed, while the west and south coast fishing communities have benefited from higher catch-rates, as a consequence those communities in the north may have experienced reduced catch rates. The degree to which these northern fishing communities are affected is likely to be related to the extent, as yet unknown, to which dispersed fish return to northern waters.

The range contraction of Australian salmon has also had some unusual consequences. The absence in the lower west coast spawning grounds of maturing migrating fish from the south coast during 2011 means that most spawning this year is likely to have occurred in nearshore waters off the south coast. As such, survival of larvae and their subsequent eastward distribution via the Leeuwin Current to coastal nursery areas from the Western Great Australian Bight to South Australia may well be compromised. Further, with almost the entire Australian salmon stock located on the south coast, this species is allegedly being forced to source additional prey items to survive. Prominent amongst the additional prey species is Australian herring, itself an extremely popular recreational and commercial species, the stock status of which is currently regarded as uncertain. The absence of migrating fish from the lower west coast has also resulted in the failure of the very significant seasonal recreation fishery for Australian salmon, which has in turn resulted in a major decline in the profitable tourist industry for the Capes-to-Capes region. While reports related to Australian salmon were most prominent, more recent reports of poor recreational catches of the closely related Australian herring along the lower west coast are also likely to be attributed to the elevated temperatures at the time maturing fish recruit from the south coast. Care therefore needs to be taken to ensure that the existing program to monitor recruitment strength of this (and other) prominent nearshore finfish species continues to receive appropriate resourcing.

While it is acknowledged that the heat wave event will alter the community structure of the marine biota in the area of influence (**Appendix 3**), confirmation of the extent of the changes and their likely duration will really become apparent only once the final results of ongoing monitoring become available.

Initial reports from the commercial fishing industry on the south coast suggest that for commercially retained finfish at least, the composition of the catch has changed. Again, confirmation will only be possible once the compulsory catch and effort statistics collected over the duration of the marine heat wave have been processed and analysed.

There were several instances of altered catch rates reported by the commercial fishing industry **(Table 3).** From the perspective of the catches taken by fishers, increases or decreases in catch rate can have respectively positive and negative effects. However, from the perspective of the fishable stock, a positive outcome of improved catch rates for fishers (if not well managed) has the potential to result in depleted breeding stocks, and can thus have a negative effect on the stock. So under such circumstances, it is critically important to monitor ongoing catches from all exploiting sectors to ensure that the total catch remains within the acceptable range to ensure ongoing sustainability.

Most of the fisheries management responses presented in **Table 3** are covered in the ongoing monitoring and assessment protocols currently in place at the Department of Fisheries. Indeed, provision is now made under the Ecosystem Based Fisheries Management (EBFM) arrangements to identify and deal adequately with any broader ecological risks that affect fish and their dependent habitat.

5.3 Relationship with the *El Nino* cycle and climate change

As shown in Section 3.1, this marine-warming anomaly occurred during one of the strongest *La Niña* events experienced since records of such events commenced. Other recent *La Niñas* occurred in 1999-2000 (which was associated with record tropical fish recruitment at Rottnest Island - Pearce and Hutchins, 2009) and 2007-2009 (the consequences of which for fish and fisheries are presented in Lenanton *et al*., 2009). These relationships will be explored in more detail in a subsequent oceanographic analysis (Pearce and Feng, in preparation).

While this heat wave has seen unprecedented warming in waters off the coast of Western Australia, with some major biological consequences, it is in effect superimposed on the underlying long-term ocean warming trend (Pearce & Feng 2007; Caputi *et al.* 2009). Both the longer-term climate trends and shorter-term *El Nino*/Southern Oscillation (ENSO)-related events are likely to play a major role in recruitment variability and commercial and recreational retained catches from waters off Western Australia (*e.g.* Pearce & Phillips, 1988; Lenanton *et al.*, 1991; Caputi *et al*. 2001). A number of environmental factors are currently being monitored in an ongoing program to investigate the impact of climate change on the commercial fisheries of Western Australia (Caputi *et al*. 2010a, 2010b). Fundamental to this initiative is the commencement of the newly-commissioned Western Australian FRDC Project No.2010/535 "Management Implications of Climate Change Effects on Fisheries in Western Australia", together with the initiation of a number of other related projects elsewhere in Australia.

It is almost certain that future warming events (related to the ENSO cycle) will occur, but their frequency and magnitude cannot be forecast at this stage. A well-prepared management response plan will be essential to minimise the potentially disastrous fisheries and ecological issues that may follow such events. Even gradual temperature rises over time have been shown to adversely influence the growth rate and metabolic activity of fish approaching their thermal tolerance limit (Seo et al, 2011; Neuheimer et al., 2011), while sudden short-term events such as the recent heat wave may have more immediate consequences (Sylvester, 1972).

6.0 Likely management responses and priorities for future research

6.1 Environmental Monitoring

The detailed analysis of the warm water anomalies has only been possible because of the extensive network of high-quality temperature monitoring sites along the coast and at the offshore islands. Clearly in order to maintain this capability, both the monitoring at existing sites and the high level of collaboration between the individuals and institutions that manage these sites must continue to be supported and resourced.

6.2 Maintenance of a coastal monitoring database

There was strong workshop support to maintain (and where necessary improve) the capacity for collecting observational data (*e.g.* from commercial and recreational fishers, beach walkers, divers etc) at a broader scale and in a more structured manner. The recent approval of funding to extend the successful Tasmanian "Redmap" project (www.redmap.org.au) nationally provides an excellent opportunity to achieve this in Western Australia. The Department of Fisheries has now committed to involvement in the Redmap Australia project and will be represented at the inaugural meeting of a National Steering committee (Hobart, September 2011).

6.3 WA coral reefs and other coastal marine communities

The extreme ocean warming event observed this year poses difficult challenges for natural resource management. The challenges for local asset managers lie with understanding the complexity of large-scale phenomena and the potential impacts that these events will have on local- to regional- biodiversity. Events such as those forming the basis of this report highlight the importance of robust, long-term, monitoring programs to provide high-quality data on the condition of biological assets. In addition, there is an ongoing need for strategic research to generate an improved understanding of the natural factors, and in some cases anthropogenic stressors, that structure these communities.

Data from ongoing monitoring directly informs the effectiveness of management strategies aimed at minimizing risks to ecosystem structure and function; good data is particularly useful for underpinning assessment of management effectiveness through linked social-ecological measures across research, surveillance, education, community involvement and conservation policy and planning. Whilst nothing can be done locally to directly counter broad-scale anomalous events such as the recent marine heat wave, adaptive management practices that enhance the resilience of marine systems by reducing local-scale anthropogenic impacts associated with acute disturbance events may be necessary.

6.4 Exploited species

While most of the suggested fisheries management responses are likely to be covered in established monitoring and management protocols, the advent of this major warming event does create the need to review the Department of Fisheries (DoF) monitoring priorities, and capabilities. Examples of some stocks that may require additional monitoring attention as a

consequence of these high temperatures include the possible extension of the current Roe's abalone monitoring within Area 8 to include the regions north of Kalbarri, and the determination of the extent to which the rock lobster puerulus that settled in 2010 survive and enter the fishable stock. The extent to which catches of most other exploited species were affected by the heat wave should become clearer once the 2010/11 CAES data and the creel/phone diary survey data have been analysed and reports prepared. This should clarify the degree to which stock of Spanish mackerel, Australian salmon and herring have been affected. Depending on the results, the current level of assessment for these species may need to be reviewed.

6.5 Invasive species

Ongoing monitoring of "invasive" species that may have been able to utilise the "window of opportunity" created by this heat wave to establish themselves in coastal habitats also needs careful consideration. Thus a proposal is being presented to the Royal Australian Navy (RAN) for ongoing monitoring at Garden Island following the detection of *Perna viridis* on naval vessels. The proposal includes a repeat survey of target wharfs, with the collection of pylon scrapes that will be examined for the presence of the mussel, and also the deployment of settlement arrays that will provide ongoing background monitoring. The deployment of settlement arrays at Garden Island will complement an existing program of settlement arrays within Fremantle Port and Cockburn Sound being run by the Department of Fisheries in conjunction with the Fremantle Port Authority.

7.0 Acknowledgements

* To the Department of Fisheries for support and provision of facilities at the Workshop.

* To all the presenters for their presentations.

* Jim Penn for assisting with the outline and structure of this report.

* To all the researchers and members of fishing communities and the public for phoning and emailing in their observations, which have substantially contributed to the overall picture that is emerging. These include Jo Buckee, Randall Freshwater, Jenny Ough, Erica Starling, Pia Boschetti, Barry Hutchins, Noel Chambers and Shannon Armstrong. Kim Smith is especially thanked for collating many of the anecdotal observations into Appendix 3.

* Ocean temperature data have been contributed by Mark Rossbach and Chris Marsh (Department of Fisheries), Alex Hoschke (Curtin University), Kimberly Marrs Ekamper (Murdoch University), Anna Micha (Busselton Jetty), Thomas Wernberg (University of Western Australia), Steven Moyes (Department of Transport), Ken Suber (CSIRO), Damian Thomson (CSIRO), Erica Starling (data from FRDC Project 2007/216: Develop the non-maxima pearl industry at the Abrolhos Islands Pinctada imbricata – with Craig Koltasz and Klaas Hartmann), Jo Buckee (Pelsaert Pearls/Cardno), Rob MacAulay (Curtin University), the Bureau of Meteorology, and the Western Australian Integrated Marine Observing System (IMOS).

* Department of Fisheries staff are thanked for their role in preparing this report for publication: Stephen Emery (overseeing the publication process) and Sandy Clarke and Nicholas Shannon (Figures 1 and 2).

8.0 References

Anon. (1937a). Tons of Dead Fish at Dirk Hartog Island. The Sydney Morning Herald (NSW: 1842-1954) Wednesday 14 July 1937, p 15.

Anon. (1937b). University Lecturer's View. The West Australian (Perth, WA: 1879-1954) Wednesday 14 July 1937, p 18.

Cannell, B.L., L.E.Chambers, R.D.Wooller & J.S.Bradley (in review). Breeding by Little Penguins near Perth, Western Australia is adversely impacted by above average sea surface temperatures and a stronger Leeuwin Current. Submitted to Marine Environmental Protection Series.

Caputi, N., C.Chubb & A.Pearce (2001). Environmental effects on recruitment of the western rock lobster, *Panulirus cygnus*. Marine & Freshwater Research 52, 1167-1174.

Caputi, N., S.de Lestang, M.Feng & A.Pearce (2009). Seasonal variation in the long-term warming trend in water temperature off the Western Australian coast. Marine and Freshwater Research 60, 129-139.

Caputi, N., R.Melville-Smith, S.de Lestang, A.Pearce & M.Feng (2010a). The effect of climate change on the western rock lobster (*Panulirus cygnus*) fishery of Western Australia. Canadian Journal of Fisheries and Aquatic Sciences 67, 85-96.

Caputi, N., A.Pearce & R.Lenanton (2010b). Fisheries-dependent indicators of climate change in Western Australia. WAMSI sub-project 4.2.3. Fisheries Research Report No. 213, Department of Fisheries, Western Australia, 32pp.

Feng, M., G.Meyers, A.Pearce & S.Wijffels (2003). Annual and interannual variations of the Leeuwin Current at 32°S. Journal of Geophysical Research 108(C11), 3355, doi:10.1029/2002JC001763.

Kim, K.H., Y.J.Hwang & S.R.Kwon (2001). Influence of daily water temperature changes on the chemiluminescent response and mortality of cultured rockfish (*Sebastes schlegeli*). Aquaculture 192, 93-99.

Lenanton, R.C., N.Caputi, M.Kangas & M.Craine (2009). The ongoing influence of the Leeuwin Current on economically important fish and invertebrates off temperate Western Australia - has it changed? In: Meney, K. & M. Brocx (editors) 2009. The Leeuwin Current 2007 Symposium. Journal of the Royal Society of Western Australia 92(2), 111-127.

Lenanton, R.C., L.Joll, J.Penn & K.Jones (1991). The influence of the Leeuwin Current on coastal fisheries of Western Australia. Proceedings of the Leeuwin Current Symposium, Perth, March 1991; Journal of the Royal Society of Western Australia 74, 101-114.

Lenanton, R.C., B.Jones & A.F.Pearce (in preparation, a). An historical perspective on fish mortality in Western Australian coastal waters.

Lenanton, R.C., K.A.Smith & E.Lai (in preparation, b). Impacts of the 2010/11 "marine heat wave" on exploited scalefish off Western Australia.

Moore, J. *et al*. (in preparation). Regional-scale coral bleaching on Western Australian reefs.

Neuheimer, A.B., R.E.Thresher, J.M.Lyle & J.M.Semmens (2011). Tolerance limit for fish growth exceeded by warming waters. Nature Climate Change 1, 110-113.

Pearce, A.F. & M.Feng (2007). Observations of warming on the Western Australian continental shelf. Marine and Freshwater Research 58, 914-920.

Pearce, A.F. and M.Feng (in preparation). The rise and fall of the "marine heat wave" off Western Australia, summer 2010/2011.

Pearce, A.F & J.B.Hutchins (2009). Oceanic processes and the recruitment of tropical fish at Rottnest Island (Western Australia). In: Meney, K. & M. Brocx (editors) 2009. The Leeuwin Current 2007 Symposium. Journal of the Royal Society of Western Australia 92(2), 179-195.

Pearce, A.F. & B.F.Phillips (1988). ENSO events, the Leeuwin Current, and larval recruitment of the western rock lobster. Journal du Conseil 45, 13-21.

Seo, H., H.Kudo & M.Kaeriyama (2011). Long-term climate-related changes in somatic growth and population dynamics of Hokkaido chum salmon. Environmental Biology of Fishes 90, 131-142. DOI 10.1007/s10641-010-9725-7.

Smith, KA, M.Hammond and PG. Close (2010). Aggregation and stranding of elongate sunfish (*Ranzania laevis*) (Pisces: Molidae) on the southern coast of Western Australia. Journal of the Royal Society of Western Australia 93: 181-188.

Sylvester, J.R. (1972). Possible effects of thermal effluents on fish: a review. Environmental Pollution 3, 205-215.

9.0 Appendices

Appendix 1. Workshop Agenda

09:00 Welcome (Dan Gaughan)

09:05 Introduction to workshop (Alan Pearce)

First session: The larger-scale perspective

09:10 The Leeuwin Current and ocean temperatures off WA in summer 2011 (Alan Pearce & Ming Feng)

09:30 Dead fish - simmered or chilled? (Brian Jones)

09:45 Unprecedented large-scale bleaching of Western Australian reef corals (James Moore)

10:00 Unusual biological events coinciding with warm ocean conditions along the south-west coast of WA (Kim Smith, Noel Chambers & Gary Jackson)

10:15 Discussion on the "larger-scale" observations

10:30 - 11:00 Morning tea

Second session: More specific/localised observations

11:00 Only a few reports of dead rock lobsters – maybe they don't float! (Simon de Lestang) Kalbarri Abalone mortalities and associated SST anomalies (Anthony Hart)

11:10 Prawn recruitment trends and scallop growth in Shark Bay during 2010/11 - observations after unusually warm sea temperatures and flood events (Mervi Kangas & Errol Sporer)

11:20 Effects of the ocean warming event on biota at the Abrolhos Islands (Scott Evans & Lynda Bellchambers)

11:30 Detecting ecological impacts of the 2011 heat wave through benthic monitoring (Dan Smale, Thomas Wernberg, Tim Langlois & Gary Kendrick)

11:40 Enhanced larval fish recruitment at Rottnest Island (Barry Hutchins)

11:50 Some new visitors to the Busselton Underwater Observatory (Anna Micha)

12:00 General discussion on localised observations

12:10 Summing up -- What now? (Alan Pearce & Gary Jackson)

Appendix 2. List of Registered Attendees

Curtin = Curtin University
CSMC = Cockburn Sound Management Council)
DEC = Department of Environment and Conservation
DoF = Department of Fisheries
Murdoch = Murdoch University
UWA = University of Western Australia

Beckley, Lynnath (Murdoch)
Bellchambers, Lynda (DoF)
Blake, Steve (WAMSI)
Bridgwood, Samantha (DoF)
Brown, Josh (DoF)
Baudains, Graeme (DoF)
Caputi, Nick (DoF)
Connelly, Shirley (Hydrobiology WA)
Cook, Glenn (Bureau of Meteorology)
Coughran, Doug (DEC)
de Lestang, Simon (DoF)
Depczynski, Martial (Curtin)
Edwards, Luke (IVEC)
Evans, Scott (DoF)
Feng, Ming (CSIRO)
Foster, Taryn (UWA)
Friedman, Kim (DEC)
Gaughan, Dan (DoF)
Gilmour, James (Curtin)
Hara, Ana (UWA)
Harris, David (DoF)
Hart, Anthony (DoF)
Hill, Lisa (DoF)
Holmes, Tony (DEC)
Ireland, Steve (DoF)
Jackson, Gary (DoF)
Jones, Brian (DoF)
Keesing, John (CSIRO)
Kippo, Hiski (CSIRO)
Langlois, Tim (UWA)
Leporati, Stephen (DoF)
Lum, Magdeline (Science network)
MacAulay, Rob (Curtin)
McDonald, Justin (DoF)
Marinelli, Marco (Bureau of Meteorology)
Marriott, Ross (DoF)
Marrs Ekamper, Kimberly (Murdoch)
Micha, Anna (Busselton Jetty)
Molony, Brett (DoF)
Moore, Glenn (WA Museum)
Moore, James (DEC)
Moran, Michael (DoF)
Morrison, Sue (WA Museum)
Murphy, Dave (DoF)
Orsini, Jean-Paul (Curtin)
Pearce, Alan (DoF; Curtin)
Penn, Jim (DoF)
Pitcher, Leanna (DoF)
Ridgway, Tyrone (Curtin)
Rose, Tom (CSMC)
Rossbach, Mark (DoF)
Sawyer, Michael (DoF)
Simpson, Chris (DEC)
Slawinski, Dirk (CSIRO)
Smale, Dan (UWA)
Scott, Sarah (Oceanica)
Smith. Kim (DoF)
Sporer, Errol (DoF)
Syers, Clint (DoF)
Stagles, Ian (Recfishwest)
Stephenson, Peter (DoF)
Thomson, Damian (CSIRO)
Vanderklift, Mat (CSIRO)
Weller, Evan (CSIRO)
Wernberg, Thomas (UWA)
Whittle, Phil (Hydrobiology WA)

Appendix 3. Records of individual observations during 2011 (mortality events are highlighted in *underlined italics*).

These reports of some of the consequences of the heat wave were either provided by members of the public or scientific and fishing communities, or were extracted from the Workshop documents

Area/locality	Date	Observations (mortality)	Observer
Shark Bay	13 March	*Dead pink snapper & juvenile dolphins*	M. Kuhn. (DoF)
Kalbarri	Early February	Abalone (Haliotis roei) stocks were stressed but in high abundance (> 50 per m2)	John Craike and Peter Irwin (abalone industry divers)
	Early March	Complete mortality of roe's abalone north of the Murchison river	John Craike and Peter Irwin (abalone industry divers)
	Early April	Dead shells in high numbers around the intertidal reef platforms	Anthony Hart (DoF)
Kalbarri	February	7 different whale sharks	Pia Boschetti (Latitude Fisheries)
Champion Bay (Geraldton)		damselfish, sergeant majors, butterfly fish, shark mackerel, bonito, baitfish, surgeon fish, parrot fish	Rowan Kleindienst (industry)
		Numerous jellyfish	
Abrolhos Islands	early March	*Fish kills (following coral spawning)*	Jo Buckee (industry)
		Coral bleaching (Acroporids)	Jo Buckee
Abrolhos Islands	6-7 March	Baby whale shark	Pia Boschetti
(southern group)	26 February	Dead fish; very dirty water (coral spawn)	Pia Boschetti
Pelsaert Island	26 March	Dead birds	Pia Boschetti
Abrolhos Islands and coastal Green Head to Moore River	27th February	Large fish kills	
Mid-west coast	Early-mid March	Dead wrasse, cobbler, leatherjacket, eel, whiting, A.herring, mullet, blowfish, breaksea cod, seahorses/ sea dragons, dhufish, blue groper.	J. Mutter (DoF); D. Thompson (processor-Cervantes); S. Dobney, S Bryant & R. Alexander-Green Head, L. Eyden-Jurien (commercial fishers)
		Large volumes of dead seagrass and macroalgae on the beaches	"as above"

Area/locality	Date	Observations (mortality)	Observer
Leeman		Water temperature reaching 30-31 degrees	Randall Freshwater (Leeman resident)
		Thousands of dead inshore fish washed up on beaches (species includes cobbler, whiting, flathead, cod, western blue devil, reef fish, mullet, leatherjacket, bream)	
		Many eels, crabs and rock lobster washed up onto beaches.	
		Numbers of dead offshore pelagic fish floating on the surface.	
		Abundant weed floating in deeper water.	
		Inshore sea grass washed to shore in mass.	
		Significant sand movement (due to dead seagrass?)	
		Water visibility is 0% inshore.	
		No evidence of live rock lobster in the inshore reefs. Zero recreational rock lobster catch.	
		Whale shark sighted and photographed 12 nautical miles from Leeman town site.	
		Spanish mackerel sighted in large schools (previously here in low numbers)	
Hillarys Marina	20 March	Damselfish (*Abudefduf bengalensis*)	Douglas Anderson (Murdoch University)
Off Hillarys (20 m water depth)	8th March	orange-spotted toadfish (*Torquigener pallimaculatus*)	Rod Lenanton (DoF)
Cockburn Sound	10 May	Nor-west blowfish (*Lagocephalus sceleratus*)	Perthnow.com.au
Rottnest Island (East Roe Reef; NE coast)	22 April	Bleached corals (in 20m water depth; completely bleached)	Jenny Ough (underwater photographer)
		Three Spot Dascyllus (in 10m water depth)	Jenny Ough
Rottnest Island (Parker Point)	mid-April	Numerous damselfish (*Abudefduf sexfasciatus, A. vaigiensis*)	Barry Hutchins (WA Museum)

Area/locality	Date	Observations (mortality)	Observer
Rottnest Island		New records of red bass, redfin butterflyfish, three-spot dascyllus, johnston damsel, six-banded parrotfish, dusky parrotfish	Barry Hutchins
Off Mandurah		juvenile batfish, whale sharks	R & J Stone (commercial fishers)
Busselton Jetty	end of February	raccoon butterflyfish, reef bannerfish, scissortail sergeant majors	Anna Micha (observatory manager)
Eagle Bay (near Dunsborough)		*Dead leather-back turtle washed up well south of normal range)*	The West Australian 11 May
Margaret River		Spanish mackerel & tuna	Anna Micha
Albany	mid – April 2011	Catch of tropical mackerel-scad (*Decapterus muroadsi*)	Peter Westerberg (commercial fisher)
		Catches of tropical sardine (scaly mackerel)	Peter Westerberg
		Catches of spanish mackerel (to 16kg)	Noel Chambers (DoF)
		Catches of mahi mahi	Noel Chambers
Albany (Two Peoples Bay & Hartmans Beach)	9 - 18 May	*Hundreds of beached elongate sunfish*	Chris Johns (specimen shell diver)
Albany (Cheynes Beach, Goode Beach, Oyster Harbour)	3 May – 26 June	*Many beached elongate sunfish*	Noel Chambers
Albany (Bornholm to Cape Riche)	29 March – 18 April	*Dead A. salmon, A herring & southern sea garfish*	Noel Chambers
Albany (Cheynes Beach)		Whale shark sighted	Shannon Armstrong (DEC)
		Catches of spanish mackerel	
		Manta rays sighted	Shannon Armstrong
			Shannon Armstrong
		Manta ray caught (& released)	T. Westerberg, D Wheatcroft. (commercial fishers)
Albany (Cosy Corner)	27 March	Shark mackerel caught	Noel chambers
Albany (Two Peoples Bay)	18-19 April	Long-tom caught	Noel Chambers