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Fisheries-dependent indicators of climate change in Western Australia

WAMSI Sub-project 4.2.3

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Cover image:
Figure 3.2 – Rate of increasing sea surface temperature in the Indian Ocean during 1951-2004
(from Pearce and Feng 2007).

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Sub-project Objectives

To what degree can the use of fishery-dependent data provide a cost-effective way of assessing whether there have been any changes in the distribution and relative abundance of species?

Executive Summary

The use of fishery-dependent data may be a cost-effective way of assessing whether there have been any changes in the distribution and relative abundance of species. Such indicators are part of an ongoing data gathering system and the costs are relatively low compared to those of a fishery-independent field program. Fishery-dependent data may therefore be obtained at a higher frequency and allow detection of changes faster than would be possible from the results from the direct sampling of specific sites within entire ecosystems.

The overall approach adopted for assessing climate change effects on fisheries in this study was as follows:

1. An understanding the key environmental trends that are occurring in the marine environment off Western Australia (WA) that may affect fisheries e.g. increasing water temperatures, decrease in storms and westerly winds, more frequent ENSO events.
2. Determine the effect environmental variability is having on biological parameters (e.g. recruitment, size at maturity, growth) of fish stocks e.g. examine the relationships between environmental variables and recruitment.
3. Examine the historical variability of the environmental variables that have been identified as affecting fish stocks e.g. determine the nature of their annual variability, particularly the presence of any historic long-term trend.
4. Climate modeling can then be examined to assess the likely future trends in the identified environmental variables in the short-term (10-20 years) and long-term (>30 years).
5. Hypotheses on the effect of these trends on the fisheries can then be developed.

As this project was completed before the climate modeling in WAMSI Node 2, the main focus on this sub-project was on points 1 to 3 above and some preliminary comments on points 4 and 5 were provided on the rock lobster study based on the available climate modeling.

A number of oceanographic and meteorological data sets from both historical and current data sources, within and external to the Department of Fisheries, have been compiled. These include Southern Oscillation Index, sea level, water temperature and salinity, wind strength and direction, ocean current, cyclones, rainfall, winter storms, chlorophyll levels, and Indian Ocean Dipole. These data sets are used to understand the effects of the environment on fisheries.

Some of the key environmental trends that may be affecting fish stocks of Western Australia include: (a) increasing frequency of ENSO events; (b) more years with weaker Leeuwin Currents; (c) increase in water temperature off the lower west coast of WA, particularly in autumn-winter; (d) increase in salinity which includes some large annual fluctuations; (e) change in frequency and location of storms (and rainfall) affecting the lower west coast of WA; and (f) change in frequency of cyclones (and summer rainfall) affecting the north-west of WA.

One of the areas of greatest increase in surface sea temperatures (SST) (0.02ºC per year) in the Indian Ocean over the last 50 years has been occurring off the lower west coast of Australia. Water temperature trends at a number of coastal sites since the early 1970s were examined: two rock lobster puerulus monitoring sites in shallow water (<5 m); four sites from a monitoring program onboard rock lobster vessels that provide bottom water temperature (<36 m); an environmental monitoring site at Rottnest (0-50 m depth). Two global SST datasets were also examined. Caputi *et al.* (2009; Marine and Freshwater Research 60:129-139) examined these data to show that there was a strong seasonal variation in the historic increases in temperature with most of the increases (0.02-0.035ºC per year) only focused on 4-6 months over the austral autumn-winter with little increase (<0.01ºC per year) apparent in the spring-summer period. These increases are also apparent after taking into account the interannual variation in the strength of the Leeuwin Current. The warming trend results in a change to the seasonal temperature cycle over the decades with a delay in the peak temperature during autumn between the 1950s and 2000s of about 10-20 days. A delay in the timing of the minimum temperature is also apparent at Rottnest from August-September to October.

Fisheries data collected from a number of sources are used to assess the effect of environmental conditions on fisheries which then may be useful in assessing effects of climate change on fisheries. The sources of data include: (a) catch and catch rate data from monthly returns or daily logbooks; (b) research staff going onboard commercial vessels to monitor the catch retained and that returned to sea; (c) standardized research survey of stocks (e.g. recruitment and spawning stock) onboard commercial or research vessels; and (d) research survey of stocks independent of commercial vessels.

The western rock lobster fishery has long-term time series (about 35-40 years) on a number of biological variables as well as fishery-independent estimates of recruitment, puerulus settlement, which makes it one of best candidates to study climate change effects on a fishery in Australia (Caputi *et al.* 2010, Can. J. Fish. Aquat. Sci. 67: 85-96). They noted that climate change effects such as increasing water temperatures may have resulted in a decrease in size at maturity, decrease in the size of migrating immature lobsters from shallow to deep water, an increase in the abundance of undersize and legal size lobsters in deep water relative to shallow water and a subsequent shift in catch to deep water. The size of the migrating lobsters is significantly related to the water temperature about the time of puerulus settlement (4 years previously). The impact of climate change on the level and spatial distribution of puerulus settlement, catchability of lobsters in traps, numbers of mature females moulting from the setose (reproductive state) to non-setose state, growth rates, timing of moults and hence the timing of the peak catch rates, were also assessed. Climate change model projections are that the warming trend is likely to continue so that these biological trends may continue. Some of these changes (such as the increasing frequency of El Niño events) may have negative implications on the western rock lobster fishery but others such as increasing water temperature may have some positive influence.

The Leeuwin Current not only affects the western rock lobster fishery, but has been shown to be an important factor associated with changing abundance of a number of key invertebrate and scalefish species harvested by on-shelf commercial fisheries off the Western Australian coast. Lenanton *et al.* (2009, Journal of the Royal Society of WA 92(2): 111-127) reviewed these relationships and` revealed that the addition of more recent data has strengthened the relationship for rock lobster, the only species whose larvae are primarily distributed in the area of the influence of the Leeuwin Current and its offshore eddies. For other invertebrate species, such as scallops and Shark Bay prawns, the addition of new data has weakened the relationships. For prawns, although the underlying trend remains positive, the additional data strongly suggests that the overall production from the fishery has declined since 1989, generally due to different targeting and harvesting strategies. For a number of the scalefish species, the lack of ongoing records of comparable abundance data, primarily as a consequence of changes in the distribution of fishing, relative to the distribution of the stocks, has precluded ongoing exploration of earlier relationships. However preliminary data for some hitherto unreported relationships for other coastal scalefish species suggest that while the Leeuwin Current strength per se is implicated, other physical variables that are likely to be influenced by the Leeuwin Current may also be important. To help unravel these relationships, the underlying mechanism of the influence of the current, particularly the role of salinity and temperature of shelf waters, and factors controlling the availability of nutrients to on-shelf primary production need to be better understood.

The possible climate change trends identified for some fisheries can have significant effects on the stock assessment and management of the fisheries. The changes in some of the biological parameters (e.g. size at maturity and migrating lobsters) of the rock lobster stocks since the 1970s have been included in the population dynamic model of the fishery which generally have a stationarity assumption of parameters. Long-term changes in the abundance of fish stocks, particularly declines, requires an appropriate adjustment of fishing effort or catch quota, for the stocks to be managed sustainably. In addition, changes in the spatial distribution of fish stocks pose some interesting policy dilemmas to evaluate spatial management boundaries. Does fisheries management maintain the current zone structure and recognize that there could be some long-term ‘winners’ and ‘losers’ in that situation or does it adjust the management to maintain some historical equity in the system?

These case studies highlight the value of long-term time series in fisheries and environmental in assessing the effect of climate changes on fisheries. Examples across a number of fisheries indicated that the different types of data obtained for fisheries stock assessments can also be used to understand environmental-fisheries relationships. The variability of these environmental data affecting fish stocks can be examined for historic long-term trends that may have implications for long-term climate change trends in fisheries. Climate change models such as those being developed by WAMSI Node 2 study and the Indian Ocean Climate Initiative can then be examined to assess how these environmental trends may change in the future.

1.0 Introduction (N. Caputi)

1.1 Introduction

The distribution and abundance of many marine fish and invertebrates and their subsequent recruitment to fisheries in WA is strongly influenced by the Leeuwin Current, best known for its effect on the western rock lobster *Panulirus cygnus* (Lenanton *et al.* 2009). Over nearly 40 years the Department of Fisheries (and previously CSIRO) have been using a system of monitoring the settlement of puerulus larvae of the western rock lobster to estimate catches of rock lobsters three and four years after settlement (de Lestang *et al.* 2009). Puerulus settlement varies considerably between years. There is a positive relationship between the strength of the Leeuwin Current and successful puerulus settlement (Pearce and Phillips 1988). Sea level and satellite data are routinely used to measure the strength of the Leeuwin Current and sea surface temperatures off the Western Australian coastline.

While the western rock lobster is the most important commercially fished species in Western Australia, a considerable dataset exists on catch levels, spawning and recruitment survey data and distribution of the other major commercial species. These data can be examined for changes over time as a result of climate change. Existing fisheries data, and data collected in future years, can be used to determine if there is any trend in their abundance and distribution that could be attributable to shifts in climate rather than annual fluctuations in the environment.

WAMSI Projects 4.2.2 and 4.2.3 are closely linked to all policies of the WA government related to understanding and dealing with the effects of global climate change. The primary outcome will be an understanding of the effects of climate change in the marine environment of Western Australia, in an area where such changes are likely to be first experienced. In the estuaries and inshore waters of south-western Australia, major changes in fish communities have been recorded due to anthropogenic effects other than fishing. Many of these systems have significant levels of biological information that have been collected over decades and which provide an excellent basis for developing qualitative and quantitative ecosystem models. They are also areas where data are currently being gathered in a number of projects in, or related to Project 4.2, to provide information on the current status of these systems, in terms of both community structure and function. Ecosystem modelling frameworks have the ability to guide the sort of data which should be collected as a priority in Project 4.2.

The management question that is addressed in this sub-project is:

- To what extent can the data that are available from commercial fishing be used to monitor the influence of environmental variability and climate change?

The use of fishery-dependent data may be a cost-effective way of assessing whether there have been any changes in the distribution and relative abundance of species. Such indicators are part of an ongoing data gathering system and the costs are relatively low compared to those of a fishery-independent field program (see below). Fishery-dependent data may therefore be obtained at a higher frequency and from a wider area and may allow detection of changes faster than would be possible from the results from the direct sampling of specific sites within entire ecosystems outlined in 4.2.2.

The specific activities proposed for this sub-project were:

- Complete assessments of relevant fisheries-dependent and independent data (e.g. the distributional and abundance patterns in puerulus settlement of the western rock lobster related to the Leeuwin Current strength) to determine what change in the patterns and long-term trends would represent a significant shift.

The phases that were proposed in undertaking this work included:

- Obtain long-term time series data for a range of species whose recruitment and other life history stages are likely to show responses to climate change (as reflected in varying responses to the Leeuwin Current).
- Compile long-term time series data for climate, physical oceanography, temperature and other surrogates of climate change that may affect recruitment and other life history stages.
- Assess species – environment relationships.
- Link species / environmental relationships into stock assessment models such that they become incorporated in setting sustainable harvest levels.
- Integrate results from WAMSI Node 2 (e.g. predicted future climate trends) to assess short- and long-term impacts on fisheries.
- Assess whether long-term fisheries monitoring can be aligned with biodiversity monitoring.

The overall approach adopted for assessing climate change effects on fisheries in this study was as follows:

1. Understanding of the key environmental trends occurring in the marine environment off WA.
2. Determine the effect environmental variability is having on fish stocks.
3. Examine the historical variability of the environmental variables affecting fish stocks.
4. Assess the likely future trends in the identified environmental variables in the short-term (10-20 years) and long-term (>30 years).
5. Hypotheses on the effect of these trends on the fisheries can then be developed.

As this project was completed before the climate modeling in WAMSI Node 2, the main focus on this WAMSI sub-project was on points 1 to 3 above and some comment on points 4 and 5 were provided on the rock lobster study based on the available climate modeling at the time. Therefore the key focus of this study is:

- Identification of the available environmental databases that may be relevant to understanding of the environmental effects on fish stocks (Chapter 2);
- Examination of some key environmental trends that may affect fish stocks (Chapter 3, Caputi *et al.* 2009); and
- Examination of some relationships between environmental variables and fish stocks (Chapter 3, Lenanton *et al.* 2009, Caputi *et al.* 2010).

1.2 References

Caputi, N., de Lestang, S., Feng, M., Pearce, A. (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., Mellville-Smith, R., de Lestang, S., Feng, M., Pearce, A. (2010). The effect of climate change on the western rock lobster fishery. Can. J. Fish. Aquat. Sci. 67:85-96

de Lestang, S., Caputi, N., Melville-Smith, R. (2009). Using fine-scale catch predictions to examine spatial variation in growth and catchability of *Panulirus cygnus* along the west coast of Australia. New Zealand Journal of Marine and Freshwater Research, 43: 443–455

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

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.

2.0 Oceanographic and meteorological data (A. Pearce)

2.1 Introduction

Environmental factors play an important role in the life cycles of commercially important finfish and invertebrates, with a number of major fisheries in Western Australia being strongly affected by key environmental variables.

Research over the past two decades has shown clear links between recruitment to a number of Western Australian commercial fisheries (in particular the western rock lobster) and environmental factors including coastal sea level, water temperature and salinity, winds and rainfall. Consequently, relevant oceanographic and meteorological measurements are being compiled into a centralised database at the Department of Fisheries to examine relationships between these environmental variables and recruitment to finfish and invertebrate fisheries. The data include both internal measurements (in-house Departmental environmental datasets) and acquisition from external organisations such as the Bureau of Meteorology and CSIRO. While some of the data are in the public forum and can therefore be freely quoted and used, the data from some external organisations may have restrictions on further distribution and the originating organisation should be approached directly for those datasets.

This chapter describes the oceanographic and meteorological datasets which have been compiled and archived. The processed files are in EXCEL spreadsheet format as well as comma-delimited text files (.csv), and each dataset has accompanying information about the source of the data, location (with latitude/longitude), water and instrument depths, etc. Simple checks on the data quality have been made based on both internal consistency and local oceanographic experience. This is an ongoing project as existing datasets are regularly updated, other historical data become available and new data are acquired.

2.2 Environmental datasets

The oceanographic and meteorological factors which have been shown as relevant to Western Australian coastal fisheries are listed and described in this section.

2.2.1 Southern Oscillation Index (SOI)

The SOI is derived from the atmospheric pressure difference between Tahiti and Darwin and is an index of the phase and strength of El Niño/Southern Oscillation (ENSO) events. During El Niño periods, the SOI is reduced (negative values indicate that the atmospheric pressure at Darwin is greater than that at Tahiti) while positive values occur during La Niña periods.

Although the SOI as such is unlikely to directly affect any of the fisheries, many of the other relevant oceanographic factors such as Leeuwin Current strength, water temperature, frequency of cyclones, are closely linked with oceanic-scale ENSO events (Fig. 2.1), partly by the through-flow of tropical waters from the equatorial Pacific Ocean via the Indonesian Archipelago. Therefore the SOI may be a readily available and generalized measure of the environment.

Monthly values of the SOI since 1876 are available from the Bureau of Meteorology website http://www.bom.gov.au/climate/current/soihtm1.shtml.

2.2.2 Sea level

Pearce & Phillips (1988) found that changes in the strength of the Leeuwin Current are reflected in coastal sea levels (with higher sea levels representing a stronger Current and vice versa), so monitoring sea level at coastal locations can give an index of the net Current strength. The relationship between the flow of the Leeuwin Current and coastal sea level has been verified and quantified by Feng *et al.* (2003). As there is a high correlation between monthly and annual sea levels at all the coastal sites between Carnarvon and Albany (Caputi *et al.* 1996), monthly mean sea levels at Fremantle are a reliable proxy for sea level along the south-western coast of Western Australia.

Monthly values of Fremantle sea level from 1897 to 1983 have been obtained from the National Tidal Centre, while more recent data (from 1984) are available from the University of Hawaii website ftp://ilikai.soest.hawaii.edu/woce/m175.dat. Daily and hourly sea levels for Fremantle are also available from related websites. Monthly sea level data from other Western Australian coastal sites from Broome to Esperance for the period 1966 to 1996 were also obtained from the National Tidal Centre.

Hourly measurements of sea level (as well as other weather-related parameters) are available from the Seaframe facilities at Broome, Hillarys Boat Harbour and Esperance since 1992, operated by the Bureau of Meteorology through the National Tidal Centre. The data are available from the National Tidal Centre.

In general, there is a close relationship between the SOI, Fremantle sea level and water temperature (Fig. 2.1).

2.2.3 Water temperature

Ocean temperature is one of the most important environmental properties for marine life, and is simple and cheap to measure accurately. There are accordingly a host of temperature measurements available off Western Australia on a variety of temporal and spatial scales, although many of these are of a relatively short duration.

a) Large-scale satellite-derived temperatures

Monthly satellite-derived sea surface temperatures (SSTs) are available globally on a 1-degree latitude/longitude grid (about 100 km square) since 1982 (Reynolds & Smith 1994 - the so-called "Reynolds dataset"). The temperatures are derived on a daily basis from satellite thermal infrared sensors, cloud-screened and then "validated" using in situ measurements from surface platforms such as drifting buoys. The monthly temperatures are downloaded by CSIRO Marine & Atmospheric Research (CMAR) in Hobart from the website ftp.emc.ncep.noaa.gov (directory /cmb/sst/oimonth_v2) and reformatted to a text format for the Western Australian region (10° to 50°S, 90° to 130°E). See example of Reynolds SST time series in Fig. 2.1.

b) Monthly in situ temperatures

Water temperatures (as well as salinity and some nutrients) have been sampled on a fortnightly to monthly basis at a CSIRO station in 55 m water depth about 6 km west of Rottnest Island from 1951 to 1956 and from 1968 to the present - the so-called "Rottnest monitoring station"). Temperatures are measured at 10 m intervals between the surface and the seabed, initially using precision-reversing thermometers but more recently using a Conductivity-Temperature-Depth (CTD) profiling instrument. This is the longest time-series of water properties undertaken off Western Australia. The data are available from CSIRO.

During the rock lobster fishing season of November to June each year, monthly near-surface and bottom temperatures have been monitored by Department of Fisheries staff from commercial fishing boats since 1971. Reversing thermometers are used to measure the water temperature in four depth ranges (< 20 m, 20 to 40 m, 40 to 60 m and > 60 m) within a ½-degree latitude band centred on four coastal regions: Dongara, Jurien, Lancelin and Fremantle. More recently, monitoring has also been undertaken off the Abrolhos Islands and Kalbarri. Water temperatures are recorded at the surface and the bottom or maximum depth of 40 m. The data are available from the Department of Fisheries.

Nearer the coast, quasi-monthly temperature measurements are made by the Department of Fisheries at the puerulus collector sites between Quobba Point (24°S) and Augusta (34°S). The measurements are made using a hand-held thermometer at two of the collectors at each site in about 5 m water depth. While some of the sites have changed over the years, the longest temperature time-series are available from Rat Island (since 1971/72 with some gaps), Dongara (since 1968/69), Jurien (since 1969/1970), Alkimos (since 1982/83), and Warnbro and Cape Mentelle since 1984/85 and are continuing. Sampling is generally undertaken near the full moon phase of the month. This dataset has been used in conjunction with the CSIRO Rottnest station data to show a gradual warming of the continental shelf waters off south-western Australia, particularly during the autumn-winter months (Pearce & Feng 2007; Caputi *et al.* 2009). The data are available from the Department of Fisheries.

c) Continuous daily/hourly temperatures

At some of the puerulus collector sites, hourly temperatures have been recorded using self-recording temperature loggers since 1990 (Pearce *et al.* 1999). In addition, near-surface and bottom temperatures were recorded in about 50 m water depth off Green Head between 1990 and 1994 to monitor more open-shelf conditions. Because of logistical problems and instrument failure, the data series is incomplete but will be used to examine the variability of the hourly temperatures during each month and hence assess how representative the long-term single monthly thermometer samples are of the "true" monthly averages. The data are available from the Department of Fisheries.

Hourly water temperatures have been recorded (with occasional gaps) at the Broome, Hillarys and Esperance Seaframe facilities (described in Section 2.2) going back to 1992. These data are available from the National Tidal Centre.

More recently, hourly temperature logger recording by the Department of Fisheries commenced at five sites in Cockburn Sound and four sites in the Peel-Harvey Estuary in 2007 and is planned to continue at least into the near future. The data are available from the Department of Fisheries.

Historical temperature recorder measurements are also available from both Albany (1983 to 1992) and Esperance (1980 to 1991) harbours. The original Grant strip-chart records were digitised and the daily minima and maxima have been extracted and used to derive monthly statistics. Hourly temperatures are available from a temperature logger deployed at Gales Bay in Exmouth Gulf from 1997 to 2000. The data are available from the Department of Fisheries.

Some temperature logger measurements were made at Jurien (1997 to 1998), Ningaloo Reef (1998 to 2001) and the Rowley Shoals (2000 to 2001) by the Department of Environment and Conservation (DEC). The data are available from the Department of Fisheries, by permission of DEC.

2.2.4 Salinity

As salinity variations in the open ocean (away from direct riverine influence and evaporation from shallow nearshore waters) are comparatively small, they are unlikely to directly affect the abundance or distribution of most marine fish species. Accurate measurement of salinity/conductivity is much more difficult and expensive than for temperature, and there are accordingly less good quality salinity data available.

The quasi-monthly monitoring programme undertaken by CSIRO for many decades at the Rottnest station included salinity sampling using long-established sampling methods, the laboratory analyses being carried out on a precision inductive salinometer; in recent years this traditional method has been replaced by a Conductivity-Temperature-Depth (CTD) profiler. The data are available from CSIRO.

Salinity sampling is also undertaken as part of the monthly puerulus monitoring survey program (see Section 2.2.3), although the salinity data are less reliable than the precision of CSIRO values. Similarly, salinity samples are collected during the commercial rock lobster monitoring between November and June each year (Section 2.2.3). The data are available from the Department of Fisheries.

2.2.5 Winds

Wind plays an important role in coastal processes both by driving near-surface current movements and also by enhancing vertical mixing through wave action. Measurements of the coastal current system along the Western Australian coast over the past three decades have shown a strong seasonal variation directly linked to the seasonally-changing wind field, with dominantly northward flow during the summer months (including the Capes Current) and a more southward tendency in winter. These currents (see Section 2.2.6 below) clearly play a role in egg and larval transport along and across the shelf.

a) Large-scale wind fields

On the larger scale of the south-eastern Indian Ocean, monthly mean northward and eastward wind components for 1.875 degree latitude/longitude blocks between 20° and 40°S, 100° and 120°E have been extracted from the National Center for Environmental Prediction (NCEP) by CSIRO Marine & Atmospheric Research. The time-series commenced in 1952 and is ongoing. The data were obtained by CSIRO from: http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.surfaceflux.html

b) Coastal wind stations

On a more regional basis, 1-minute wind and weather observations are obtained from the Bureau of Meteorology Automatic Weather Stations (AWS) for a number of sites along the Western Australian coast between Broome and Eucla, and so are more representative of the nearshore wind field than the NCEP dataset. While most of the sites commenced in 2002, the three sites near Perth (Ocean Reef, Rottnest Island and Swanbourne) go back to 1995. Updates are acquired monthly via ftp. The data are obtained by subscription from the Bureau of Meteorology and may not be further distributed.

Hourly wind measurements are included in the suite of sampling at the Seaframe sites at Broome, Hillarys and Esperance (see Section 2.2.2). Note that the anemometer at Hillarys is relatively low, and winds from certain directions may be partially obstructed by nearby buildings so may not be truly representative of the coastal wind field. These data are available from the National Tidal Centre.

2.2.6 Ocean currents

While transport of pelagic fish eggs and early-stage larvae by ocean currents plays a crucial role in the recruitment process, there are relatively few direct current measurements available for south-western Australian continental shelf and offshore waters. Alongshore currents such as the Leeuwin Current and Capes Current can transport larvae for hundreds of kilometres along the coast, and cross-shelf (onshore-offshore) processes result in an exchange of water (and larvae) between nearshore and offshore waters.

A review is being undertaken of historical current data between Shark Bay and Cape Leeuwin, going back to current mooring programmes in the 1970s (Pearce, in prep.). Many of these were relatively short term (the longest being a year at any one site) and because of the high levels of variability observed, they provide a "snapshot" of conditions over the period and at the place of measurement. Nevertheless, the re-analysis of the original data will assist in quantifying the magnitude and variability of the currents, and can also be used for the validation of ocean current models being developed by CSIRO.

At this stage, data have been acquired from CSIRO, Defence Science and Technology Organisation (DSTO) and the Water Corporation, and the monthly statistics have been derived (Figures 2.2, 2.3). Some of the other datasets are still to be obtained. Future analysis will include a more detailed assessment of the shorter-term alongshore and cross-shelf water movements in relation to larval transport.

The monthly mean alongshore current component (representing the net alongshore current drift) varies with distance offshore (Figure 2.2, upper). In the Leeuwin Current, the monthly mean currents are always southward and up to 60 cm/s, whereas in the shallower wind-driven system near the coast there is a distinct seasonal cycle with northward currents of 10 to 20 cm/s in summer (the Capes Current) and southward at 10 to 15 cm/s in winter. The mid-shelf currents are intermediate between these two. The cross-shelf flow (Figure 2.2, lower) is much weaker with no clear seasonal pattern.

The peak (hourly) currents measured in each month are much higher than the monthly averages in both component directions. Even out beyond the shelf, the alongshore currents can reach 80 cm/s both northward and southward, partly reflecting variability in the mesoscale eddy systems (Figure 2.3, upper), and again there is no discernible seasonal cycle. Nearer the coast, the wind-driven currents can reach 40 cm/s northward or southward in any month. Peak cross-shelf flows along the inner shelf are up to 40 cm/s (as for the alongshore component) (Figure 2.3, lower), and beyond the shelf-break onshore/offshore currents of 60 to 80 cm/s can be found throughout the year. Clearly, appreciable onshore and offshore currents of these magnitudes, even for comparatively brief periods, can have a major influence on larvae crossing the continental shelf either eastwards or westwards.

2.2.7 Waves

Monthly mean wave data (significant wave height and wave period) have been obtained from the Department of Planning and Infrastructure (DPI) for Rottnest Island (1994 to 2002), Cottesloe (1994 to 2002), Jurien (1998 to 2002) and Cape Naturaliste (1999 to 2002). Using a wave period of 8 seconds as a threshold criterion, the waves have been split into sea (period < 8 s) and swell (>= 9 s). The original hourly data have been requested from the DPI.

2.2.8 Rainfall

Rainfall averaged over a nine stations along the lower west coast from Mandurah to Kalbarri has been used as a proxy for westerly winds during storm periods which appear to affect the puerulus settlement (Caputi *et al*. 2001). Rainfall during the summer months associated with tropical cyclones in the north-west are important for the assessment of banana and tiger prawn stocks as well as pearl oyster stocks.

Rainfall data from the Bureau of Meteorology have been obtained from the website: http://www.bom.gov.au/climate/mwr.

2.2.9 Chlorophyll concentrations

With the launch of the SeaWiFS satellite in September 1997, the first operational satellite measurements of the near-surface chlorophyll-a concentrations became available, providing a remote-sensing proxy of phytoplankton abundance. Monthly-averaged chlorophyll concentrations are being provided for the same ocean area and resolution (1 degree latitude/longitude blocks from 10° to 50°S and 90° to 130°E) as the Reynolds SSTs (Section 2.2.3) by CSIRO Marine and Atmospheric Research. The data are available from CSIRO via the website http://www.oceancolor.gsfc.nasa.gov.

2.2.10 Indian Ocean Dipole

The Indian Ocean Dipole (IOD) is a coupled ocean-atmosphere oscillation in the equatorial Indian Ocean, normally characterized by cooling of the waters in the south-eastern equatorial Indian Ocean and corresponding warming in the western equatorial regions, and *vice versa*. The intensity of the IOD is represented by the Dipole Mode Index (DMI) which is the difference in sea-surface temperature (SST) between the western (50° - 70°E and 10°S - 10°N) and south-eastern Indian Ocean (90° - 110°E and 10°S - 0°N). When the DMI is positive, the phenomenon is referred to as the positive IOD and when it is negative, it is referred to as negative IOD.

The website http://www.jamstec.go.jp/frcgc/research/d1/iod/ has a variety of definitions of the DMI; for our purposes we have selected two:

a) monthly values of the SST DMI(1) derived from the HadlSST dataset (1958 to present); and

b) DMI(2) is the difference between the Western and Eastern Pole Indices derived from the NOAA OI SST dataset (1982 to present).

2.3 Conclusions and further work

Some of the historical datasets are complete in that the measurements have ceased, while others are ongoing at least in the short term. Long-term monitoring data (at least 30 years) are clearly of greater value for deriving a reliable "climatology" and for examining trends related to climate change, but even short-term measurements can be used to study the oceanographic processes involved.

Temperatures and salinity off Rottnest Island were part of the original oceanographic work that directly led to the "discovery" and naming of the Leeuwin Current as well as describing its seasonality (Cresswell & Golding 1980). More recently, Pearce & Feng (2007) showed that there has been a gradual warming of about 0.02°C per year off the Western Australian coast since the 1950s, with a higher rate-of-change in autumn-winter (Caputi *et al.* 2009) which has implications for "climate change" effects on coastal fisheries affected by increases in water temperature.

Larger-scale processes, representative of the south-eastern Indian Ocean, affect the larval migration of the western rock lobster and therefore require open-ocean monitoring at least on a monthly basis. Datasets on this scale presently include the satellite-derived Reynolds SST and SeaWiFS chlorophyll products as well as the NCEP winds. Many other global datasets are becoming available, however, and (in collaboration with CSIRO) some of these can be included in our environmental analyses in the future. Satellite products, in particular, will become of increasing value; both chlorophyll and SST data from the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua sensors, for example, are available from 2001 and 2002 respectively.

For the coastal fisheries, on the other hand, more regional and higher-frequency data are required because of the higher variability (both spatially and temporally) of continental shelf waters. There are adequate temperature and wind measurements along the coast, and the synthesis of moored current measurements presently being undertaken by the Integrated Marine Observation System (IMOS) will improve our knowledge of the alongshore and cross-shelf variability of the coastal current system.

This is an ongoing project in that existing datasets will continue to be updated and new data will be acquired to extend the coverage in both space and time.

2.4 References

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., W.J. Fletcher, A.F. Pearce & C.F. Chubb (1996). Effect of the Leeuwin Current on the recruitment of fish and invertebrates along the Western Australian coast. Proceedings of the International Larval Fish Conference, Sydney, August 1995, Marine and Freshwater Research 47, 147-156.

Cresswell, G.R., & T.J. Golding (1980). Observations of a south-flowing current in the southeastern Indian Ocean. Deep-Sea Research 27A, 449-466.

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, 19(1-21).

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

Pearce, A.F., M. Rossbach, M. Tait & R. Brown (1999). Sea temperature variability off Western Australia 1990 to 1994. Fisheries WA Research Report 111, 45pp.

Pearce, A. (in prep.). Review of historical current measurements off south-western Australia.

Reynolds, R.W. & T.M. Smith (1994). Improved global sea surface temperature analyses using optimal interpolation. Journal of Climate 7, 929-948.

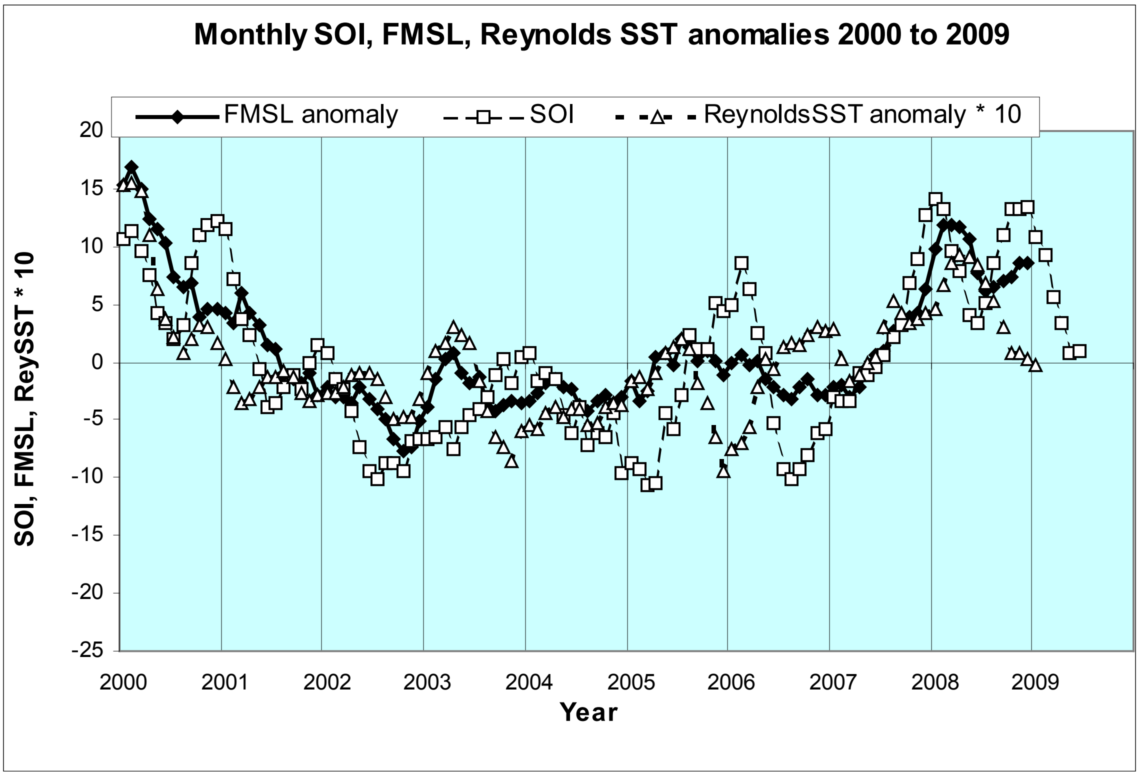
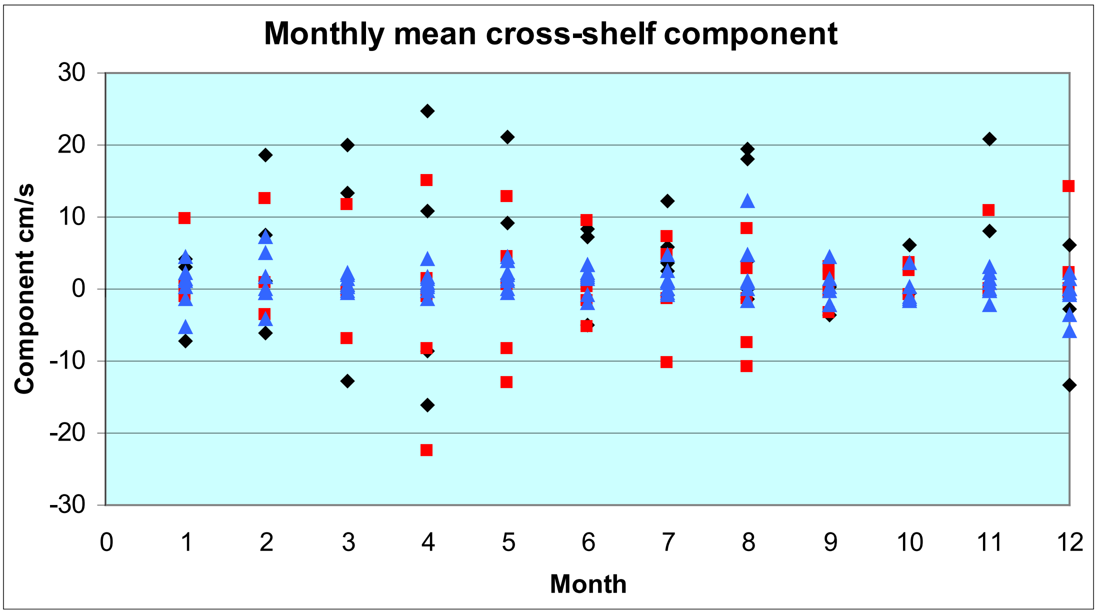


Figure 2.1 Monthly values of the Southern Oscillation Index (SOI), Fremantle mean sea level anomalies (FMSL cm) and Reynolds sea-surface temperature anomalies off Rottnest Island (SST °C * 10) from 2000 to 2009. The monthly anomalies have been derived by subtracting the mean annual cycle from each individual month.



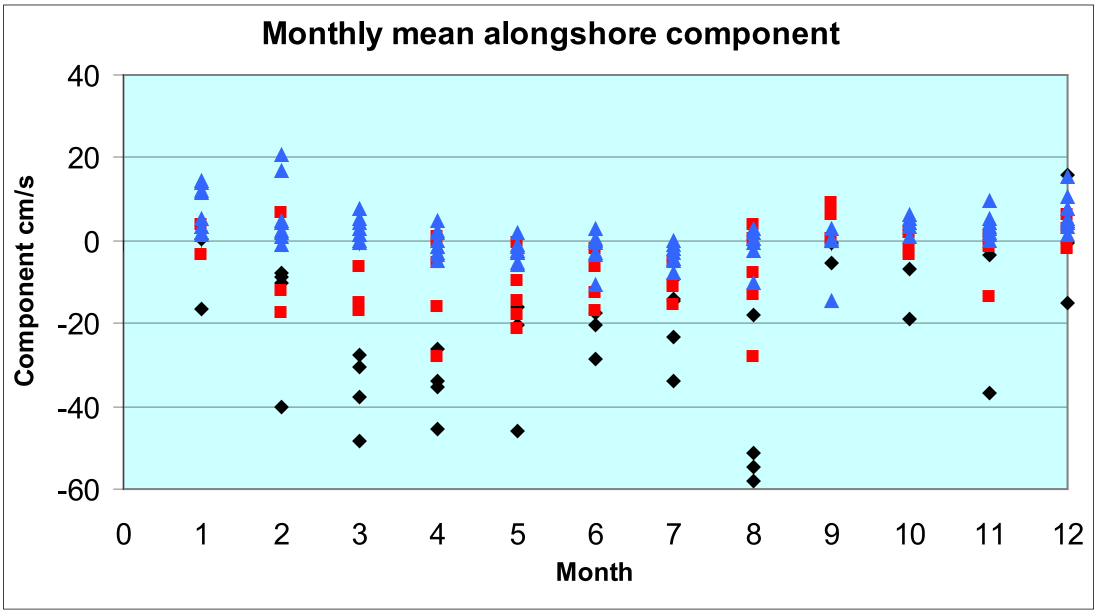
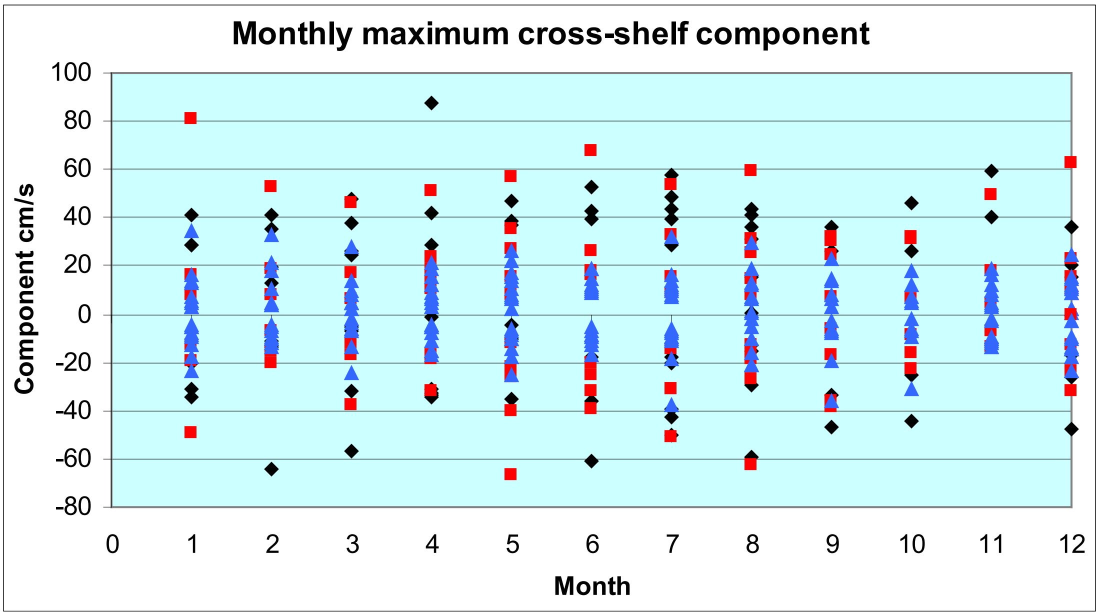


Figure 2.2 `Monthly mean alongshore (upper) and cross-shelf (lower) current components from historical current measurements at a number of sites along the south-western Australian shelf, divided into three depth zones: <50 m (inner shelf, blue triangles); 50-200 m (outer shelf, red squares) and >200 m ("Leeuwin Current", black diamonds). Positive components are northward and eastward which are approximately alongshore and onshore, respectively, to the WA coast. (from Pearce, in prep.).



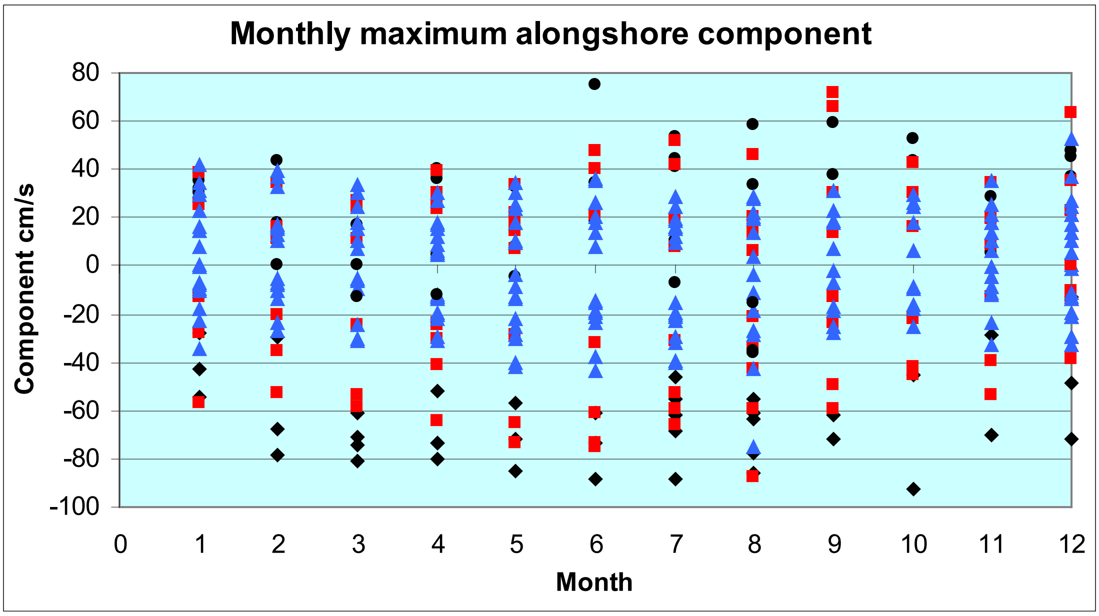


Figure 2.3 Monthly maximum alongshore (upper) and cross-shelf (lower) current components from historical current measurements at a number of sites along the south-western Australian shelf, divided into three depth zones: <50 m (inner shelf, blue triangles); 50-200 m (outer shelf, red squares) and >200 m ("Leeuwin Current", black diamonds). Positive components are northward and eastward which are approximately alongshore and onshore, respectively, to the WA coast. (from Pearce, in prep.).

3.0 Environmental factors affecting fish stocks and their long-term trends (N. Caputi, R. Lenanton and A. Pearce)

3.1 Introduction

The overall approach adopted for assessing climate change effects on fisheries in this study was as follows:

1. An understanding the key environmental trends that are occurring in the marine environment that may affect fisheries e.g. increasing water temperatures, decrease in storms and westerly winds, more frequent ENSO events.
2. Determine the effect environmental variability is having on a biological parameters (e.g. recruitment, size at maturity, growth) of fish stocks e.g. examine the relationship between environmental variables and recruitment.
3. Examine the historic variability of the environmental variables that have been identified as affecting fish stocks e.g. determine the nature of its annual variability, particularly the presence of long-term historic trend.
4. Climate modeling can then be examined to assess the likely future trends in the identified environmental variables in the short-term (10-20 years) and long-term (>30 years).
5. Hypotheses on the effect of these trends on the fisheries can then be developed.

This approach is similar to that adopted in the preliminary assessment of the implications of climate change for Australian fisheries (Hobday *et al.* 2008) which included a chapter on Western Australian fisheries (Matear *et al.* 2008).

As this WAMSI project was completed before the climate modeling in WAMSI Node 2, the main focus on this WAMSI sub-project was on points 1 to 3 above and some comment on points 4 and 5 were provided on the rock lobster study based on the available climate modeling at the time.

This study provides examples of how fisheries data collected from a number of sources may be used to assess the effect of environmental conditions on fisheries which then may be useful in assessing effects of climate change on fisheries. The sources of the fisheries data include: (a) catch and catch rate data from monthly returns or daily logbooks; (b) research staff going on board commercial vessels to monitor the catch retained and that returned to sea during commercial operations; (c) standardized research survey of stocks (e.g. recruitment and spawning stock) onboard commercial or research vessels; and (d) research survey of stocks independent of commercial vessels. Environmental data are often obtained as part of these fisheries monitoring operations (see Chapter 2).

Environmental factors may be affecting biological parameters of fish stocks in a number of ways (e.g. recruitment, size at maturity, growth, catchability). If environmental variables are identified as affecting fish stocks then the historic trends in the environmental variable can then be examined e.g. determine the nature of its annual variability, particularly whether there is a long-term trend.

The influence of the Leeuwin Current (represented by sea level at Fremantle) on a number of commercial fisheries on the west and south coast was examined by Lenanton *et al.* (1991, 2009b) and Caputi *et al.* (1996), showing that for some fisheries a strong current results in higher recruitment while for others the opposite is the case. Nevertheless, it appears that coastal sea level is generally a good indicator of oceanic conditions affecting larval transport and/or survival and hence subsequent catches in a variety of Western Australian fisheries (specific examples provided below).

This chapter highlights some of the key environmental trends that are occurring in the marine environment that may affect fisheries. It then examines some case studies of the effect environmental variability is having on biological parameters of fish stocks and whether there are any long-term historical trends associated with the environmental variable identified.

3.2 Key environmental trends

Some of the key environmental trends that may be affecting fish stocks of Western Australia include:

(a) increasing frequency of ENSO events;

(b) more years with weaker Leeuwin Currents;

(c) increase in water temperature off the lower west coast of WA, particularly in autumn-winter;

(d) increase in salinity which includes some large annual fluctuations;

(e) change in frequency and location of storms (and rainfall) affecting the lower west coast of WA; and

(f) change in frequency of cyclones (and summer rainfall) affecting the north-west of WA.

The increasing frequency of ENSO events since 1990 with 8 in 18 years classified as ENSO years compared to 5 years in the previous 20 years has resulted in more years with a weaker Leeuwin Current in recent years (Fig. 3.1). The trend in annual values of Fremantle sea level for over 100 years indicate a long-term trend with an average increase of 1.54 mm per year (Fig. 3.1) which corresponds to a warming trend in the global surface temperature rather than reflecting an increase in Leeuwin Current strength (Feng *et al.* 2004).

The frequency of cyclones is related to the ENSO cycle and hence the increased frequency of El Niño events may be leading to reduced frequency of cyclone events and associated rainfall.

Pearce & Feng (2007) have shown that there has been a gradual warming of about 0.02°C per year off the Western Australian coast since the 1950s (Fig. 3.2), with a higher rate-of-change in autumn-winter (Fig. 3.3) (Caputi *et al.* 2009). Climate models examining the effect of climate change on the sea–surface temperatures around Australia indicate increases of 1–2°C by the 2030s and 2–3°C by the 2070s (Poloczanska *et al.* 2007). These estimates will be refined for WA waters in climate modeling in WAMSI Node 2 project.

In addition there is a change in the frequency and location of storms approaching the west coast of WA which not only affects the rainfall in the south-west of WA (Bates *et al.* 2008) but also affects the oceanic conditions. This study was part of multi-institution study, Indian Ocean Climate Initiative, that was originally focused on the climate change occurring in the south-west of WA and has now expanded to examine that in the north-west as well (http://www.ioci.org.au/).

The long-term trend in the frequency of ENSO and its effect on the Leeuwin Current and the frequency of cyclones combined with the long-term trend in water temperature and storms off the lower west coast of WA may be having significant implications for "climate change" effects on coastal fisheries which are summarized in the following section.

3.3 Environmental effect on fish stocks

3.3.1 Western rock lobster

The western rock lobster (*Panulirus cygnus*) fishery of the lower west of Western Australia is influenced by a number of environmental factors such as water temperatures, the strength of the Leeuwin Current, and the strength of the westerly winds (Caputi *et al.* 2001). These key environmental factors can affect the western rock lobster throughout its complex life cycle from spawning; the larval stages over the 9–11 months they spend offshore of the continental shelf (Pearce and Phillips 1988, Caputi and Brown 1993, Caputi *et al.* 2001); the level and spatial distribution of the puerulus settlement along the coast; the growth rates of the juveniles; the size of the juveniles migrating from shallow (<40 m) to deeper water (40–100 m) and the subsequent catch distribution; their size at maturity (Melville-Smith and de Lestang 2006); the moulting of mature females from setose to non-setose condition; and the catchability of lobsters in the pots (Morgan 1974).

The relationship between annual western rock lobster puerulus settlement and sea level was first demonstrated by Pearce & Phillips (1988, 1994), indicating that settlement is much higher in La Niña years when the Leeuwin Current is flowing strongly than during ENSO events. Subsequent work by Caputi *et al.* (1996, 2001) using 30 years of settlement and sea level data confirmed and strengthened this relationship (although the 2008/09 settlement was anomalously low suggesting that other factors dominated in that year).

The southerly winds in summer, at the time when the early stage larvae of the rock lobster rise to the water surface, cause an offshore movement in the near-surface waters (the so-called Ekman transport) which carry the larvae out into the open ocean at the start of their 9-11-month migration (Phillips 1981). In the absence of reliable open-ocean wind data, Caputi *et al.* (2001) used rainfall at a number of coastal sites as a proxy for westerly winds to show that puerulus settlement is enhanced when there have been strong storm-generated westerlies between July and November -- the period when the late-stage phyllosomas are returning towards the shelf for the transformation into puerulus and consequent swimming across the continental shelf to settle.

The current strength has also been shown to affect the spatial distribution of the puerulus settlement along the coast (Caputi 2008), with increased settlement southwards when the Leeuwin Current is stronger.

Climate change may be causing an increasing trend in water temperature that may be seasonally variable (Pearce & Feng, 2007; Caputi *et al.* 2009), a weakening of the westerly winds in winter, an increase in the frequency of El Niño events, and an increase in the sea level. Caputi *et al.* (2010) have identified how climate change may be affecting the western rock lobster fishery. They showed that increasing water temperatures over the last 30-35 years may have resulted in a decrease in size at maturity (Fig. 3.4, Melville-Smith and de Lestang 2006), a decrease in the size of migrating lobsters from shallow to deep water, an increase in the abundance of undersize and legal size lobsters in deep water relative to shallow water and a subsequent shift in catch to deep water. The size of the migrating lobsters was significantly related to the water temperature about the time of puerulus settlement (4 years previously).

Climate change model projections indicate that the warming trend is likely to continue even after the greenhouse gas concentrations in the atmospheric are stabilized so that these biological trends may continue. Some of these changes (such as the increasing frequency of El Niño events) may have negative implications on the western rock lobster fishery but some such as increasing water temperature may have some positive influence. These changes would need to be taken into account in stock assessment models which generally have a stationarity assumption of the biological parameters.

3.3.2 Prawns

Rainfall during the summer months associated with tropical cyclones in the north-west WA is important for some banana and tiger prawn stocks. Penn and Caputi (1986) identified that severe cyclones going close to Exmouth Gulf had a significant effect on the tiger prawn recruitment. Depending on the timing and severity of the cyclones, they had a significant positive or negative effect on the recruitment later that year. The category 5 Cyclone Vance in 1999 had a negative effect on the juvenile tiger prawn habitat (seagrass/algal communities) which negatively affected the tiger prawn recruitment the following two years, 2000 and 2001 (Loneregan *et al.* in prep., Sporer *et al.* 2008).

Banana prawn recruitment in some areas of the Gulf of Carpentaria has been shown to be positively related to summer rainfall (Vance *et al.* 1985, Staples *et al.* 1995). This relationship has also been identified in banana prawn stocks in Nickol Bay (Fig. 3.5, Kangas *et al.* 2008), Onslow and the Kimberley. Examination of the trend in summer (December-March) rainfall and banana prawn catch in Nickol Bay since 1966 shows no significant long-term trend.

Western king prawn catches in Shark Bay have been shown to be positively related to the strength of the Leeuwin Current during the period the prawns are recruiting into the fishery (Caputi *et al.* 1996, Lenanton *et al.* 2009b). The higher catches may be related to improved catchability, growth and survival associated with warmer temperatures. However the overall production from the fishery has declined since 1989, generally due to different targeting and harvesting strategies.

3.3.3 Scallops

The saucer scallop fishery in Shark Bay shows large annual variations in recruitment which appears to be affected by the strength of the Leeuwin Current during the peak spawning period, April to July (Joll and Caputi 1995, Lenanton *et al.* 2009b). The relationship is also apparent in the scallop fishery in the Abrolhos Is. (Lenanton *et al.* 2009b). All years with good recruitment occur in El Niño years but not every El Niño year is associated with good recruitment (Fig. 3.6), indicating that other factors must also be affecting recruitment. Hence, in general, the scallop fishery may benefit by the increased frequency in ENSO events that may be occurring.

3.3.4 Blue swimmer crabs

The blue swimmer crab recruitment in Cockburn Sound, close to the Perth Metropolitan area, is significantly correlated with the coastal water temperature during the late winter/spring period prior to spawning in summer (de Lestang *et al.* in prep.). A series of four years of low water temperatures (obtained from puerulus settlement monitoring in the adjacent Warnbro Sound), combined with heavy fishing pressure, resulted in a significant reduction in recruitment which resulted in the fishery being closed for three years, 2007 to 2009 (Johnston *et al.* in prep.). Hence despite the general increase in water temperature on the lower west coast of WA, the trend in the Warnbro Sound water temperature in August-September since it has been measured in 1985 shows no significant trend. This is a similar result to the water temperature trends obtained from longer time series at similar depth at Dongara/Jurien since 1972 during August-September (Fig. 3.3, Caputi *et al.* 2009). This highlights the importance of examining the environmental conditions at the appropriate spatial and temporal scale that affects the fish stocks.

3.3.5 Pearl oysters

Hart *et al.* (1999) highlighted the possible effect of ENSO events on recruitment of pearl oyster stocks using legal-size catch rates that are based on 2-3 year-classes. The development of a recruitment index for pearl oyster stocks, using piggyback spat that are 0+ and 1+ year old (Hart and Joll 2006), has enabled an improved assessment of the environmental factors affecting recruitment at 80 Mile Beach, near Broome (Hart et al., in press). Sea-surface temperature during the summer spawning period is positively related to the 0+ recruitment measured later that year while a negative relationship with summer rainfall at Bidyadanga (associated with tropical cyclones in the north-west of WA) has also been identified. This has been highlighted by the record spat settlement in 2005 being associated with the lowest December rainfall in about 40 years. Using the long-term time series based on the standardised fisher's catch rates of culture shell since 1984, northward winds, lagged three years, i.e. near the time of spawning, were also identified as negative significant factor on recruitment (Hart et al., in press). The trend in December rainfall since the 1960s is positive while the trend in water temperature in December since 1982 is positive with a 2^{o}C increase occurring since the 1980s. The northward wind component has also been decreasing since the early 1980s. The net affect of these trends is an increase in recruitment of pearl oysters since the 1980s.

3.3.6 Whitebait

The whitebait catches in the lower-west coast are significantly positively correlated to the strength of the Leeuwin Current in the previous year during the spawning/larval period (Fig. 3.7, Caputi *et al.* 1996, Lenanton *et al.* 2009b). Thus the abundance of this species is likely to be affected by the trends in the ENSO cycle and its subsequent effect on the Leeuwin Current. If the increasing frequency of El Niño events continues and there are more years of weaker Leeuwin Currents then this will have a negative influence on the whitebait catches.

3.3.7 Tailor and Dhufish

Temperature distributions were used by Lenanton *et al.* (1996) to suggest that tailor spawn along the inner continental shelf between spring and autumn. The only link to date with salinity and commercial fisheries is that of Lenanton *et al.* (2009a), who found that recruitment indices for both dhufish and tailor are highly correlated with salinity in the period November to June each year (Fig. 3.8 and 3.9), although the actual mechanism for this link is presently unclear. The increased salinity is associated with strong northerly component of winds from the Naturaliste site in the summer (Fig. 3.9) which indicates that these environmental conditions may reflect years when the Capes Current is strong (Lenanton *et al.* 2009a).

Although an increasing trend in salinity since the 1950s, with some large annual fluctuations, has been identified at Rottnest (Pearce & Feng 2007), the salinity data used in this assessment shows no trend since the early 1980s. However the wind data does show a significant ($p<0.01$) positive trend which could have a positive effect on dhufish recruitment.

A model of likely changes in demersal fish communities in response to temperature changes, using the alongshore temperature gradient, is being developed by Langlois *et al.* (in prep.).

3.3.8 Marron

Marron catches in the rivers and dams of the south-west of WA have been shown to be generally positively related to the rainfall and river flow in this region (de Graaf and Baharthah 2008). The decrease in rainfall since the mid 1970s (Bates *et al.* 2008), particularly in the early winter (May-July) has meant that these stocks are under pressure from changing climate.

3.4 Discussion and Conclusions

The case studies indicate that the different types of data obtained for fisheries stock assessments can provide the basis for an assessment of environmental-fisheries relationships which may then also be used to gain an understanding of the possible climate change effects on the stocks.

Catch data from monthly returns was used as a measure of the annual recruitment of banana prawn and whitebait fish stocks and the environmental effects on these recruitments were identified. The banana prawn catch is assumed to reflect the general abundance of that year and the whitebait catches have been adjusted to take into account the developing phase of the fishery. Research staff going on board commercial rock lobster vessels for about 40 years to monitor the catch retained and that returned to sea during commercial operations have provided valuable biological data on the trends in the size of migrating lobsters and changes in the size of maturity that may be affected by the increase in water temperature. Standardised research survey of prawn and scallop stocks (recruitment and spawning stock) onboard commercial or research vessels in Shark Bay and Exmouth Gulf have provided long-term data sets to evaluate the stock trends. Long-standing research surveys of stocks independent of commercial vessels such as the monthly puerulus monitoring program (40 years) also provide a valuable data source to evaluate long-term trends in abundance, spatial and seasonal distribution. More recently the tailor and blue swimmer crab research recruitment surveys have also been established which can be used to assess environmental effects on their recruitment variability.

Environmental data collected as part of these fisheries monitoring programs such as the rock lobster onboard commercial monitoring and the puerulus surveys have also proven valuable in assessing long-term trends in water temperature and salinity (Pearce & Feng 2007, Caputi *et al.* 2009).

The variability of these environmental data, that have been shown to affect fish stocks, can be examined for historic long-term trends that may have implications for long-term trends in fisheries. This has identified a number of fisheries that may be affected by the effects of climate change and require monitoring. The western rock lobster fishery has long-term time series (about 35-40 years) in a number of biological variables as well as fishery-independent estimates of recruitment, puerulus settlement, which makes it one of the best candidates in Australia to study climate change effects on a fishery (Caputi *et al.* 2010). It also covers a large area of the lower west coast with an extended larval life of 9-11 months that extends 100s km offshore and hence is affected by a large array of environmental conditions.

Having identified what environmental variables have affected fish stocks and how these may have changed historically, climate change models such as those being developed by WAMSI Node 2 study and the Indian Ocean Climate Initiative can then be examined to assess how these environmental trends may change in the future. These may indicate the expected trends in the ENSO cycle, Leeuwin Current strength, water temperature, storms and wind strength and direction in the south-west WA, and cyclones and rainfall in the north-west WA. The seasonal variation in these trends may also be particularly important as it is often the environmental conditions in particular months (e.g. spawning and larval periods) and specific locations that are critical in their effect on fisheries rather than the average environmental condition for the whole year over a large geographic area. This was the case in the effect of water temperature on blue swimmer crab recruitment in that there was a general increase in water temperature in the lower west coast of WA, however in the nearshore areas in August-September period, prior to spawning of the crabs, no increase was apparent.

3.4.1 Implications for fisheries stock assessment and management

The possible climate change trends identified for some fisheries can have significant effects on the stock assessment and management of the fisheries. The changes in some of the biological parameters (e.g. size at maturity and migrating lobsters) of the rock lobster stocks since the 1970s have been included in the population dynamic model of the fishery. The series of low puerulus settlement over the last three years that will affect the catches and breeding stock within the next 4-5 years have also been factored into the assessment and management of the fishery.

Long-term changes in the abundance of fish stocks, particularly declines, requires an appropriate adjustment of fishing effort or catch quota, for the stocks to be managed sustainably. This has been particularly noticeable in the recreational marron fishery which regularly achieved catches of 300,000 to 700,000 marron per year over 130 days of fishing in the 1970s and 1980s with catches since 2000 generally being less that 100,000 and fishing season restricted to 13-16 days (de Graaf and Baharthah 2008).

Changes in the spatial distribution of fish stocks also poses some interesting policy dilemmas to evaluate. If there are movements in the spatial distribution of stocks due to for example, long-term changes in water temperature or strength of the Leeuwin Current or Capes Currents that affects larval distribution then these can cause long-term changes in spatial distribution of stocks and fish communities. If there are fixed management boundaries used in the management of these stocks then there could be some significant increases in some zones and decreases in other zones. Does fisheries management maintain the current zone structure and recognize that there could be some long-term ‘winners’ and ‘losers’ in that situation or does it adjust the management to maintain some historical equity in the system?

3.4.2 Future Research

These case studies highlight the value of long-term time series in fisheries and environmental in assessing the effect of climate changes on fisheries. The establishment of a good measure of recruitment, which provide a predictive ability of future catches, is particularly valuable. These may identify a series of low recruitment that may be due to environmental effects which may then require a significant adjustment to the management of the fishery. Fisheries can be severely overfished when heavy fishing continues after a period of low recruitment. Cockburn Sound blue swimmer crab fishery is a recent example of this scenario (de Lestang *et al.* in prep., Johnston *et al.* in prep.).

Once environmental factors affecting fisheries are identified then their historic trends and assessment of future trends helps identify the fisheries that may be vulnerable to climate change, positively or negatively. Though global climate models that provide a general direction of environmental trends are valuable, the effect on fisheries may require a more specific assessment of the trends at more regional level, e.g. Leeuwin Current and Capes Current. The environmental trends during particularly times of the year, e.g. spawning and larval periods, may also be particularly important. This highlights the importance of local climate change initiatives in Western Australia e.g. WAMSI Node 2 examining marine climate change effects off WA and the Indian Ocean Climate Initiative (IOCI) examining storms and rainfall in the lower south-western coast and cyclones in the north-western coast of WA. The development of the Integrated Marine Observation System (IMOS) in Australia in also a valuable initiative in providing an understanding of environmental trends.

3.5 References

Ayvazian, S.G., Craine, M., Lenanton, R., Brown, J., Nowara, G. (in prep.). An approach to assess the juvenile-recruitment relationship to the tailor (*Pomatomus saltatrix*) fishery in the Swan River estuary, Western Australia.

Bates, B.C., Hope, P., Ryan, B., Smith, I. and Charles, S. 2008. Key findings from the Indian Ocean Climate Initiative and their impact on policy development in Australia. Clim. Change 89(3–4): 339–354

Caputi, N. (2008). Impact of the Leeuwin Current on the spatial distribution of the puerulus settlement of the western rock lobster (*Panulirus cygnus*) and implications for the fishery of Western Australia. Fisheries Oceanography 17(2), 147-152.

Caputi, N. and Brown, R.S. 1993. The effect of environment on puerulus settlement of the western rock lobster (*Panulirus cygnus*) in Western Australia. Fish. Oceanogr. 2: 1–10.

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., W.J. Fletcher, A.F. Pearce & C.F. Chubb (1996). Effect of the Leeuwin Current on the recruitment of fish and invertebrates along the Western Australian coast. Proceedings of the International Larval Fish Conference, Sydney, August 1995, Marine and Freshwater Research 47, 147-156.

Caputi, N., R. Melville-Smith, S. de Lestang, A. Pearce & M. Feng (2010). The effect of climate change on the western rock lobster (*Panulirus cygnus*) fishery of Western Australia. Can. J. Fish. Aquat. Sci. 67:85-96.

de Graaf, M. and T. Baharthah (2008). Marron fishery status report. In: State of the Fisheries Report 2007/08, eds WJ Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp 257-260.

de Lestang, S., L.M. Bellchambers, N. Caputi, A.W. Thomson, M.B. Pember, D.J. Johnston and D.C. Harris (in prep.) Stock-recruitment-environment relationship for a *Portunus pelagicus* fishery in Western Australia. Lowell Wakefield Symposium Proceedings.

Feng, M., Li, Y. and Meyers, G. 2004. Multidecadal variations of Fremantle sea level: footprint of climate variability in the tropical Pacific. Geophys. Res. Lett. 31: L16302, doi:10.1029/2004GL019947.

Hart A.M., Joll L., Skepper C. (1999). Growth of pearl oysters in the southern and northern areas of the pearl oyster fishery, and examination of environmental influences on recruitment to the pearl oyster stocks. Final Report to Fisheries Research and Development Corporation. Project No: 95/41 39 pp.

Hart A.M., Murphy D., Thompson A. (in press). Environmental and technology influences on stock abundance and fishing power in the silver-lipped pearl oyster fishery. ICES Journal of Marine Science.

Hart A.M., Joll L. (2006). Growth, mortality, recruitment, and sex ratio in wild stocks of the silver-lipped pearl oyster *Pinctada maxima* (Jameson)(Mollusca: Pteriidae) in Western Australia. Journal of Shellfish Research. 25 (1): 201-210.

Hobday, A, E. Polocaznska, R. Matear (eds) (2008). Implications of climate change for Australian fisheries and aquaculture: a preliminary assessment. Report to the Department of Climate Change, Canberra, Australia, August 2008.

Johnston, D, D. Harris, N. Caputi and A. Thomson (in prep.). Decline in blue swimmer crab (*Portunus pelagicus*) stocks in Cockburn Sound, Western Australia – history, contributing factors and potential future management strategy. Lowell Wakefield Symposium Proceedings.

Joll, L.M. and N. Caputi (1995). Environmental influences on recruitment in the saucer scallop (*Amusium balloti*) fishery of Shark Bay, Western Australia. ICES Marine Science Symposia (Actes du symposium) 199: 47-53.

Kangas, M., E. Sporer, S. Brown (2008). Nickol Bay prawn managed fishery status report. In: State of the Fisheries Report 2007/08, eds WJ Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp 136-139.

Langlois, T., Anderson, E. Harvey, J. Meeuwig, Radford, A. Pearce *et al.* (in prep.). Fish community composition and temperature: regional models for monitoring long term changes.

Lenanton, R.C., S.G. Ayzavian, A.F. Pearce, R.A. Steckis & G. Young (1996). Tailor (Pomatomus saltatrix) off Western Australia -- where does it spawn and how are the larvae distributed? Marine and Freshwater Research 47, 337-346.

Lenanton, R., St John, J., Keay, I., Wakefield, C., Jackson, G., Wise, B. and Gaughan, D. (2009a). Spatial scales of exploitation among populations of demersal scalefish: implications for management. Part 2: Stock structure and biology of two indicator species, West Australian dhufish (Glaucosoma hebraicum) and pink snapper (Pargus auratus), in the West Coast Bioregion. Final report to Fisheries Research and Development Corporation on Project No. 2003/052. Fisheries Research Report No. 174. Department of Fisheries, Western Australia. 187p.

Lenanton, R.C., N. Caputi, M. Kangas & M. Craine (2009b). The ongoing influence of the Leeuwin Current on economically important fish and invertebrates off temperate Western Australia – has it changed? 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.

Loneragan, N. R., Kangas, M., Haywood, M.D.E., Kenyon, R.A., Caputi, N. and Sporer, E. (in prep.). The influence of seagrass dynamics and cyclones on the recruitment of tiger prawns (shrimp) Penaeus esculentus in Exmouth Gulf, Western Australia.

Matear, R., A. Hobday, N. Caputi (2008). In: Hobday, A, E. Polocaznska, R. Matear (eds). Implications of climate change for Australian fisheries and aquaculture: a preliminary assessment. Report to the Department of Climate Change, Canberra, Australia, August 2008.

Melville-Smith, R. and de Lestang, S. (2006). Spatial and temporal variation in the size at maturity of the western rock lobster, Panulirus cygnus George. Mar. Biol. 150: 183–195.

Morgan, G.R. (1974). Aspects of the population dynamics of the western rock lobster, Panulirus cygnus George. II. Seasonal changes in the catchability coefficient. Mar. Freshw. Res. 25: 249–259.

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

Pearce, A.F. & B.F. Phillips (1994). Oceanic processes, puerulus settlement and recruitment of the western rock lobster *Panulirus cygnus*. In: Sammarco, P.W. and M.L. Heron, The bio-physics of marine larval dispersal. American Geophysical Union, Coastal and Estuarine Studies 45,279-303.

Penn, J.W. and N. Caputi (1986). Spawning stock-recruitment relationships and environmental influences on the tiger prawn (*Penaeus esculentus*) fishery in Exmouth Gulf, Western Australia. Aust. J. Mar. Freshwater Res. 37, 491-505.

Phillips, B.F. (1981). The circulation of the southeastern Indian Ocean and the planktonic life of the western rock lobster. Oceanography and Marine Biology Annual Review 19, 11-29.

Poloczanska, E.S., Babcock, R.C., Butler, A., Hobday, A.J., Hoegh-Guldberg, O., Kunz, T.J., Matear, R., Milton, D., Okey, T.A. and Richardson, A.J. (2007). Climate change and Australian marine life. Oceanogr. Mar. Biol. Annu. Rev. 45: 409–480.

Sporer, E., Kangas, M., Brown, S. (2008). Exmouth Gulf prawn managed fishery status report. In: State of the Fisheries Report 2007/08, eds WJ Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp 95-99.

Staples D.J., Vance D.J. and Loneragan N.R. (1995). Penaeid prawn recruitment variability: effect of the environment. In: Courtney A.J., Cosgrove M.G. (eds) Proceedings of the workshop of spawning stock-recruitment relationships (SRRs) in Australian Crustacean Fisheries, Department of Primary Industries, Brisbane, Queensland, pp.41-50.

Vance D.J., Staples, D.J. and Kerr J.D. (1985). Factors affecting year-to-year variation in the catch of banana prawns (*Penaeus merguiensis*) in the Gulf of Caprentaria, Australia. J. Cons. Int. Explor. Mer. 42: 83-97.

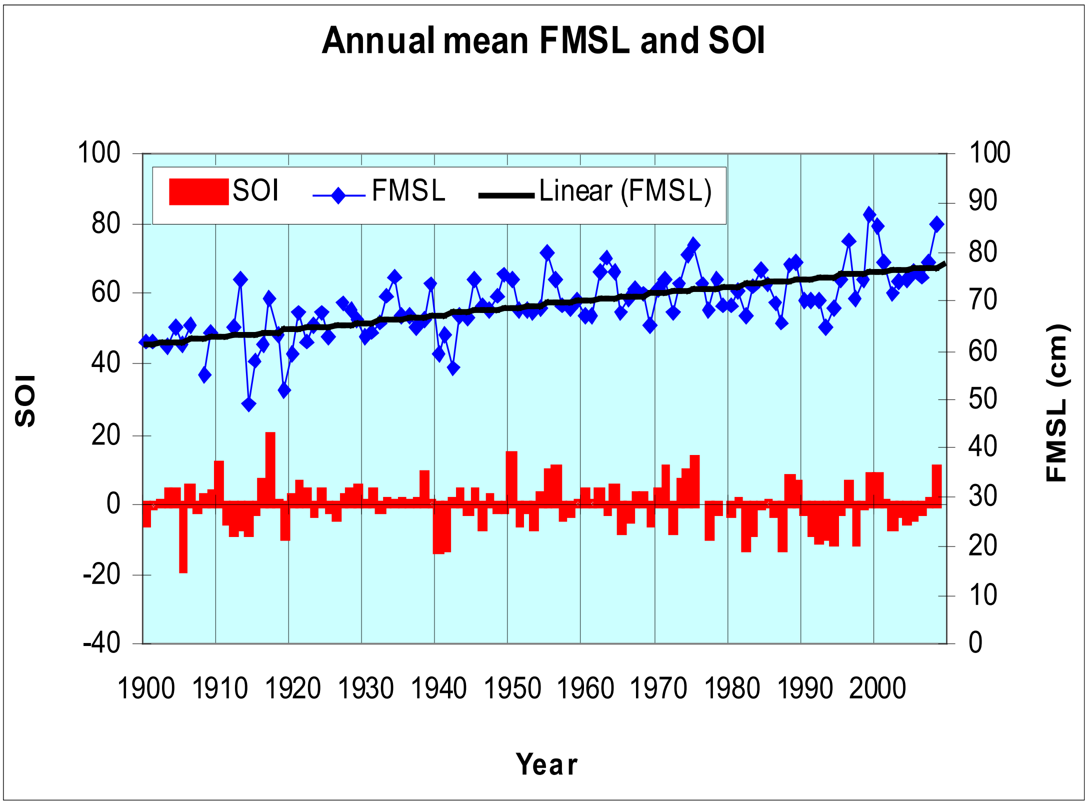


Figure 3.1 Annual values of SOI and Fremantle mean sea level (FMSL) with trend line. Updated from Feng *et al.* (2004).

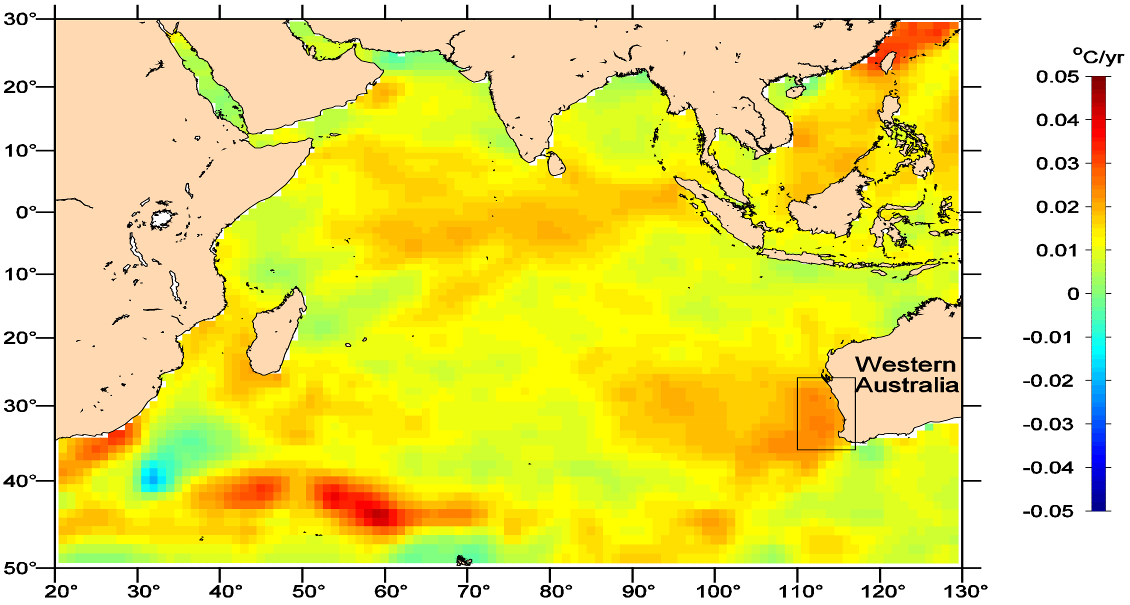


Figure 3.2 Rate of increasing sea surface temperature in the Indian Ocean during 1951-2004 (from Pearce and Feng 2007).

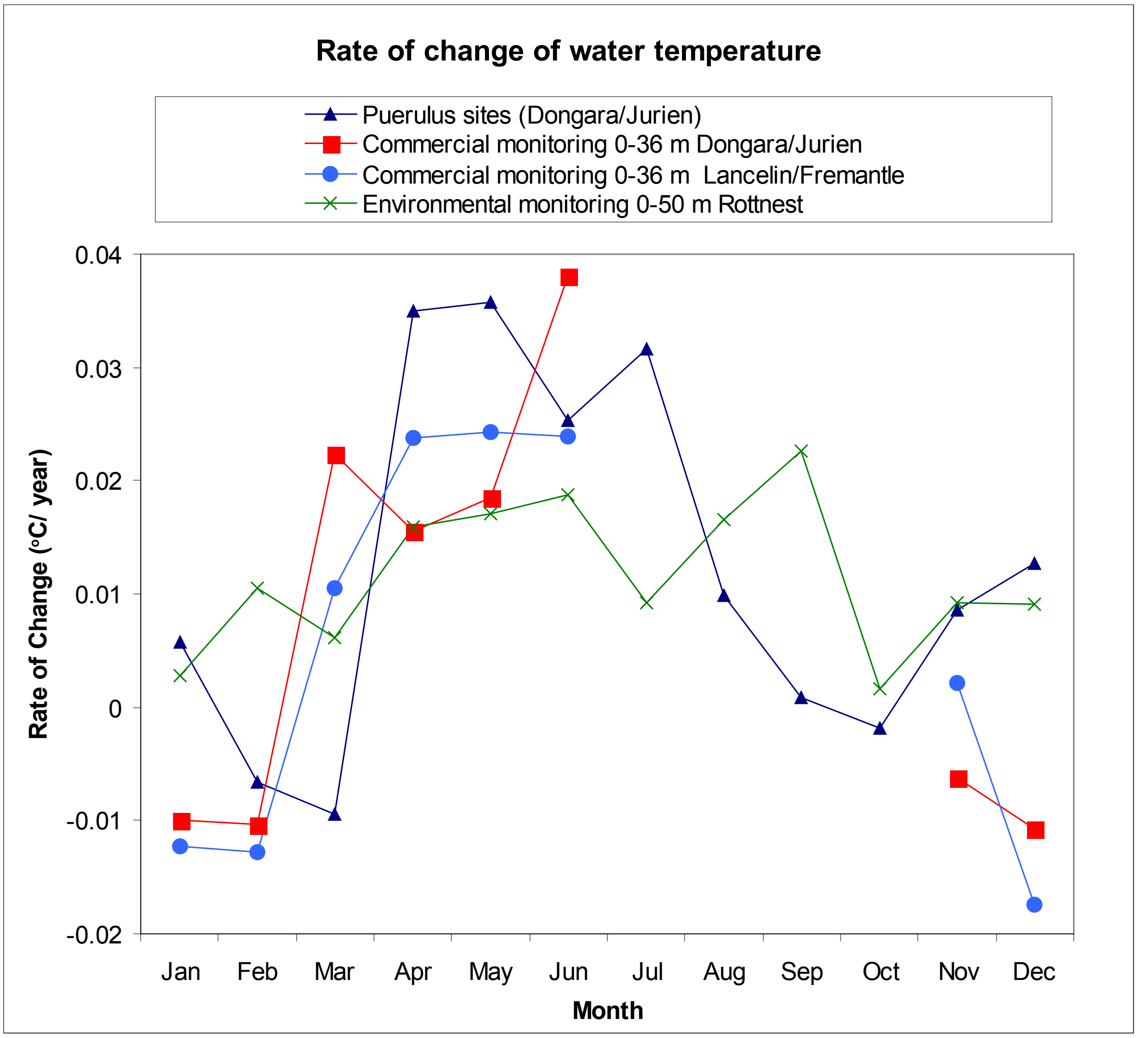


Figure 3.3 The rate of increase of water temperature (oC per year) for each month at the puerulus collector sites (Dongara and Jurien) since 1970,the Rottnest station (0-50 m) since 1951,the commercial monitoring program sites (Dongara/Jurien and Lancelin/Fremantle) for bottom water temperature less than 36 m during the fishing season (November-June) since 1971/72 (from Caputi *et al.* 2009).

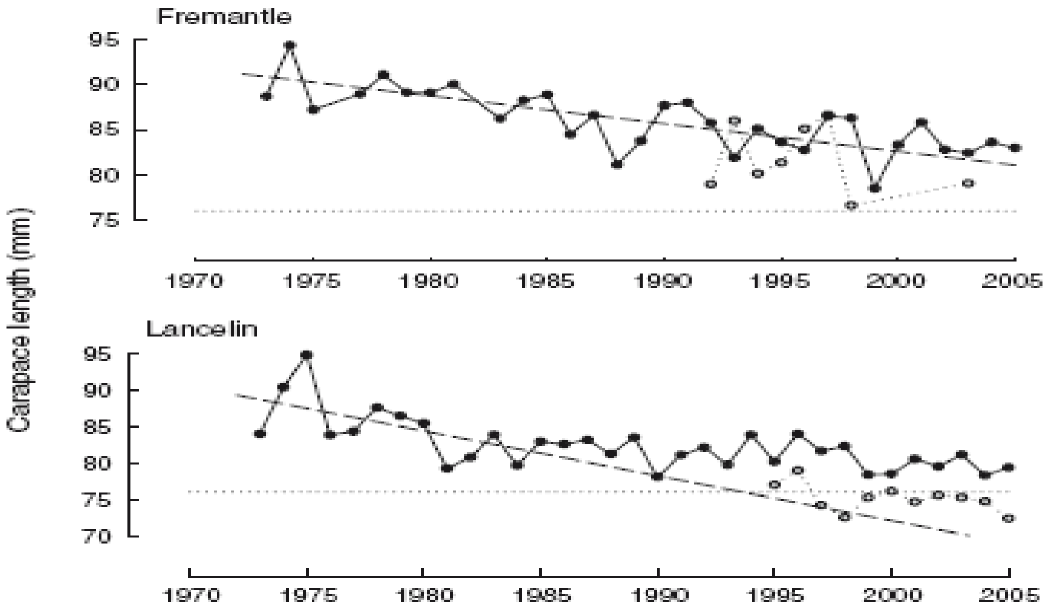


Figure 3.4 Mean carapace length of the smallest 10% of mature female rock lobsters from the commercial monitoring program (solid circle) and data collected from a research breeding stock survey with no escape gaps (open circle). The 76 mm minimum length is indicated and the dashed line represents the regression line for data before 1986 (when 1 escape gap was used) after which 3 or 4 escape gaps were used which would have affected the catch rate of small lobsters close to the minimum length (from Melville-Smith and de Lestang 2006).

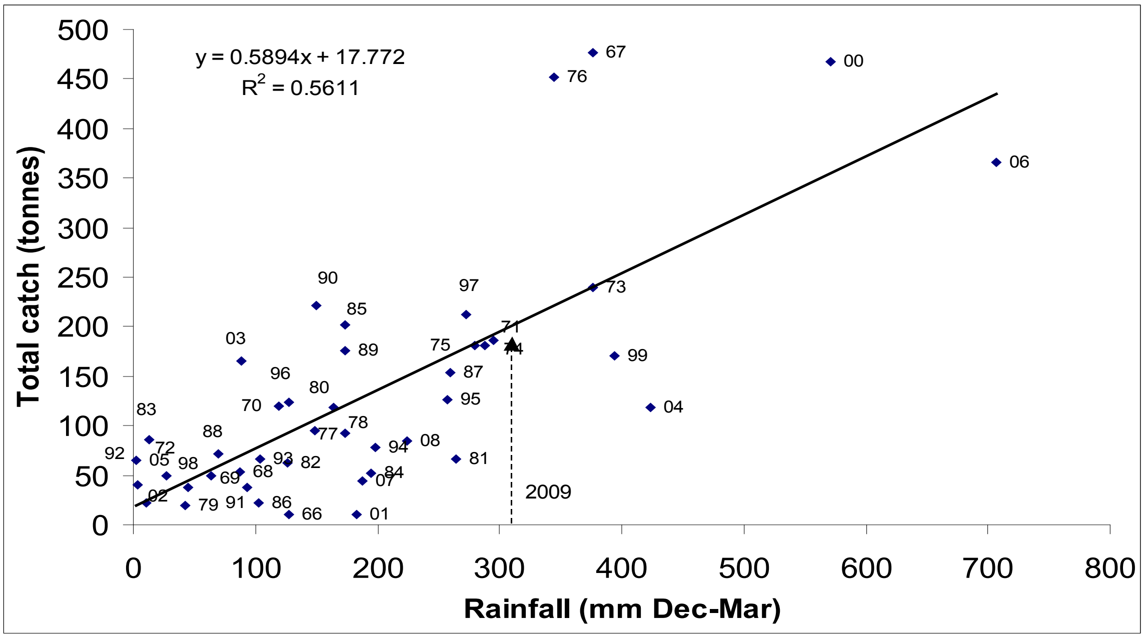


Figure 3.5 Relationship between banana prawn landings in Nickol Bay and rainfall between December And March for the 1966 – 2008, with rainfall level for 2009 indicated (updated from Kangas *et al.* 2008).

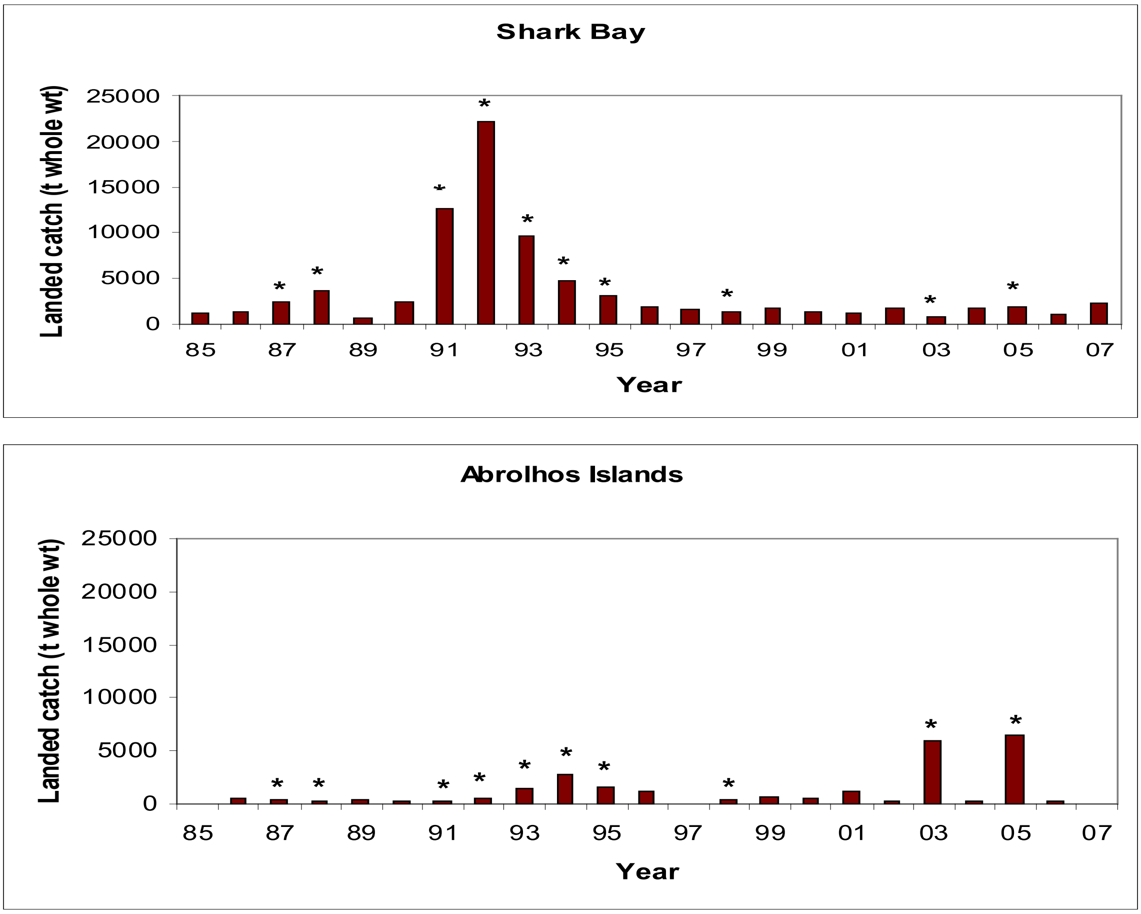


Figure 3.6 Landed catch of scallops in Shark Bay and the Abrolhos Is. with ENSO years indicated by * (from Lenanton *et al.* 2009b).

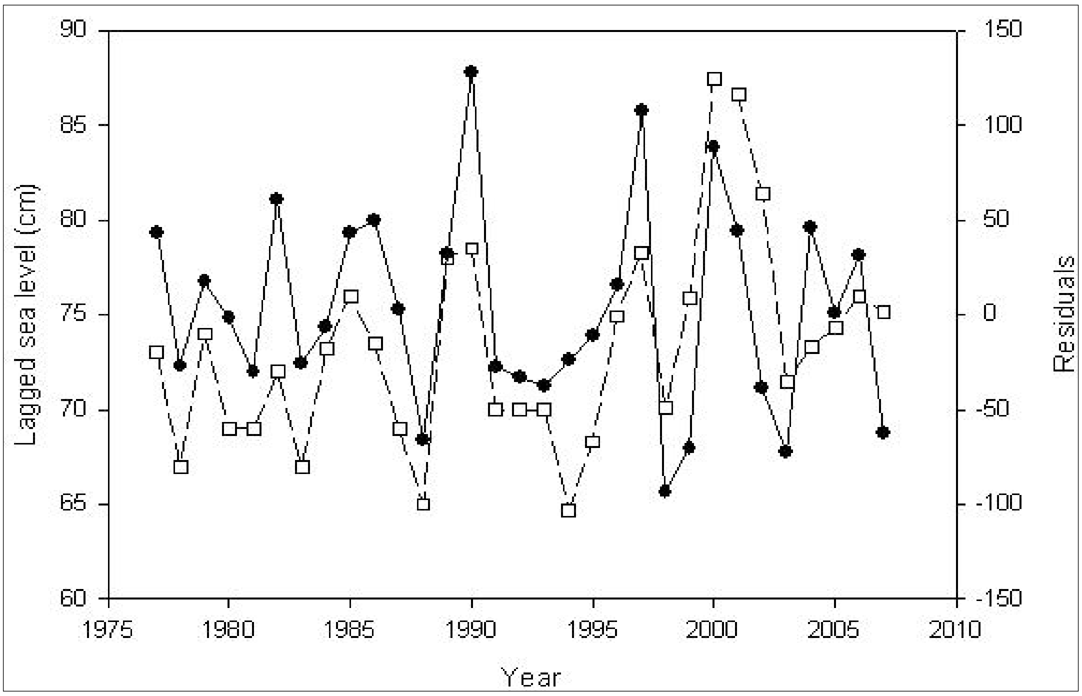


Figure 3.7 Time series of the residuals of whitebait catches (●), which takes into account the trend in the time series, and sea-level time series lagged 1 year (☐)(updated from Caputi *et al.* 1996, Lenanton *et al.* 2009b).

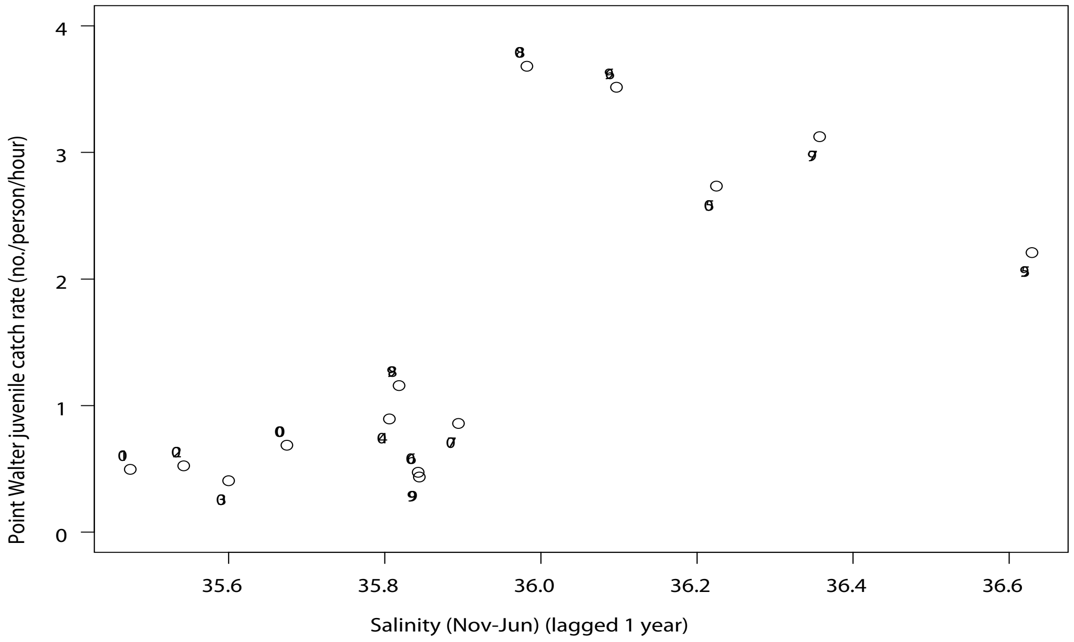


Figure 3.8 The relationship between the annual index of recruitment of tailor (measured between February and April each year), and the mean salinity of continental shelf waters between Fremantle and Dongara measured between November and June lagged by one year (from Lenanton *et al.* 2009b and Ayvazian *et al.* in prep.).

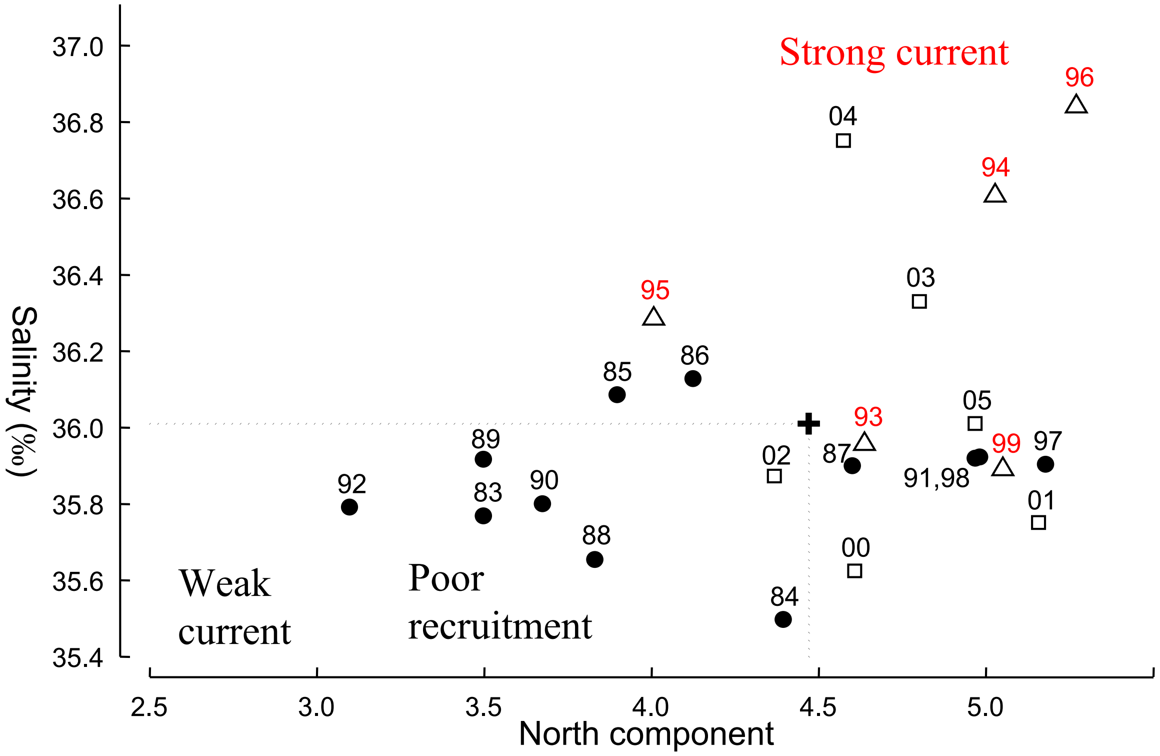


Figure 3.9 The relationship between the annual back calculated indices of dhufish recruitment (0+ year class) abundance in three classes, good (triangle), average (square) and poor (circle) and the Capes Current in December-February as measured by the average sea surface salinity of continental shelf waters between Fremantle and Dongara and the north component of wind each year. The + represents the mean salinity and north wind component) (from Lenanton *et al.* 2009a).

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- National Tidal Centre in Adelaide for sea level data and the Seaframe data;
- WA Department of Planning and Infrastructure (DPI) for wave data;
- Bureau of Meteorology for coastal wind and rainfall data;
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