Effects of Environmental Variability on Recruitment to South Australian Fisheries: A Preliminary Investigation

Final report for the

Fisheries Research and Development Institute

CE James, CD Dixon, AJ Fowler, A Linnane, JL Luick, S McClatchie,

R McGarvey, JF Middleton, MA Steer and Y Wu

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SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Australian Government

Fisheries Research and Development Corporation

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2006/046	**Effects of environmental variability on recruitment to South Australian fisheries: a preliminary investigation**

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OBJECTIVES:

1. Compile an integrated spatial database of environmental variables including sea surface temperature (SST), wind speed and direction and ENSO events for SA

2. Compile model-based and measured recruitment indices for SA fisheries for southern calamary, King George whiting, western king prawn, southern rock lobster, Western Australian salmon and snapper.

3. Relate recruitment indices for these species to identified environmental variables with the goal of improving current understanding of the effects of environmental variability on recruitment to South Australian fisheries.

southern calamary

Spawning behaviour of southern calamary is highly dependent on vision and can be affected by turbidity resulting from storm events and strong onshore winds. SST may also influence recruitment strength through effects on the growth and mortality rates of developing embryos and paralarvae. Information on SST and wind (as a proxy for turbidity) were compared with calamary catch per unit effort (CPUE) for 1984-2006 in Gulf St. Vincent (GSV) and Spencer Gulf (SG). Wind was poorly correlated with CPUE. The correlation between CPUE and SST was generally positive, with moderate correlations evident for North West GSV and weak to moderate correlations in SG, particularly in the north and south east. This correlation between CPUE and SST reflects previous observations of effects of temperature on catch rates in both GSV and SG.

King George whiting

Nursery areas for King George Whiting are seagrass beds or bare sandy substrate located up to several hundred kilometers from the spawning grounds in the southern parts of GSV and SG. Hydrodynamic modeling for the coastal areas around southern Australia suggests that KGW larvae are advected by ocean currents from the spawning grounds to the nursery areas. To examine the effects of hydrographic processes on recruitment variation, the relationship between average annual wind stress and post-larval KGW recruitment between 1983-2001 was examined using correlation analysis for GSV, SG and the Far West Coast (FWC). Recruitment into the major fishing areas in South Australia shows some correlation with the N-S wind stress, whereas no correlations were observed with the E-W wind stress.

western king prawn

Previous studies have indicated that the size of the spawning biomass of prawns in Spencer Gulf is a key determinant of recruitment strength. Knowledge of prawn biology and the oceanographic processes of Spencer Gulf suggest that recruitment processes are also likely to be affected by water temperature and prevailing winds. Data on SST and wind speed and direction were used to investigate potential environmental factors affecting recruitment for the period 1992-2006. No clear trends with SST or wind strength and direction were determined. Analysis of data on the level of pre-Christmas catch (a surrogate for spawning biomass) showed a highly significant relationship with recruitment, suggesting that this was a better predictor of recruitment strength than environmental variables. During the summer of 2000/01, SST was >1ºC higher than that of any other year between 1994 and 2005 and, in the same year, recruitment into the fishery was twice that of any other year. It is proposed that the warm, summer temperatures resulted in an early spawning and recruitment event that combined with recruits from the previous year to provide an exceptionally high recruitment index.

southern rock lobster

Southern rock lobsters have a long larval duration and limited swimming capacity. In South Australia, it has been suggested that the strength of westerly winds, during late winter and early spring may play a role in the inter-annual variation in recruitment of rock lobster. Hence the effects of wind and SST on recruitment between 1991-2006 in south-eastern Australia were explored. Higher Puerulus Settlement Indices (PSIs) were correlated with (i) westerly winds from May to August (autumn-winter) and November to February (spring-later summer), (ii) southerly winds from March to June (late summer-autumn) and (iii) generally lower SST (<18.5ºC), particularly during November-February (spring-later summer). However, high PSI correlations in the November to February period are influenced by the high settlement index in this period in 2006. Generally, correlations between westerly winds for May to August (autumn-winter) support the previous suggestion that the strength of westerly winds during winter may play a role in the inter-annual variation in recruitment.

Western Australian salmon

Spawning of Western Australian salmon occurs off Australia's south west coast. Some larvae settle in this area but the Leeuwin Current (LC) transports many larvae eastward and these settle about 3-6 months later in the protected coastal waters in SA. The timing of spawning appears to be related to the timing of flow of the LC, which appears to be influenced by ENSO events. To test the hypothesis that salmon abundance in SA waters is influenced by El Niño events, correlation coefficients between the annually averaged NINO 3.4 index and the Pre-Recruitment Index (PRI) (no. of fish/100 m^2 averaged over the period of high abundance) were computed for the perion 1981-1999 in GSV. Results suggest that El Niño events reduced the PRI for salmon in SA, on occasion to near zero. In contrast, La Niña events appear to increase the PRI. This evidence provides further support for the hypothesis that atmospheric climate variation influences recruitment variation of Australian salmon.

snapper

Previous studies for snapper have indicated that recruitment is sensitive to summer SST. In particular, water temperatures in the range of 22-24ºC during the early summer period from mid-November to mid-January are required for successful recruitment. Modelled estimates of snapper recruitment to legal size showed a significant correlation with the number of optimal temperature days each year. Although weak recruitment could occur in years with a large number of optimal days, the inverse was not true. Strong recruitment was never observed when the number of optimal temperature days was <20. While the number of optimal SST days is a necessity for strong recruitment, this alone may not be sufficient to ensure strong recruitment of snapper in SA

ACKNOWLEDGEMENTS

This project was funded by the Fisheries Research and Development Corporation (FRDC). Dr Sam McClatchie, currently at National Oceanic and Atmospheric Administration (NOAA), wrote the original proposal. Weather data were acquired from the Commonwealth Bureau of Meteorology. Sea surface temperature data are from the *Oceans Pathfinder* of the US National Oceanographic Data Center (NODC) Satellite Oceanography Group at NOAA). Historic records of ENSO events were obtained from the KAPLAN EXTENDED v2 from the IRI/LDEO Climate Data Library. We thank Dr. Keith Jones of the Department of Primary Industries and Resources of South Australia (PIRSA) for the salmon data. The authors would also like to thank research scientists Alan Jones, Matthew Hoare, Peter Hawthorne and Kylie Howard for data collection, collation and storage. Richard Drake from the University of Adelaide also provided welcomed advice on linear estimation.

1 GENERAL INTRODUCTION

1.1 Overview

This is the final report to the Fisheries Research and Development Corporation (FRDC) project 2006/046 *"Effects of environmental variability on recruitment to South Australian fisheries: a preliminary study" ($50K)*. The report is divided into nine chapters. This chapter (Chapter 1) outlines the structure of the report, provides background information relevant to the project and presents the main objectives of the study.

Chapter 2 describes the general methods used throughout the report and details the various data sources. Chapters 3 through 8, inclusive, details species-specific investigations of environment – recruitment relationships. These chapters relate to southern calamary (*Sepioteuthis australis*), King George whiting (*Sillaginodes punctatus*), western king prawn (*Peneaus latisulcatus*), southern rock lobster (*Jasus edwardsii*), West Australian salmon (*Arripis truttaceus*) and snapper (*Chrysophyrs auratus*), respectively. Chapter nine is the General Discussion, which summarises and synthesises the overall results of the report.

1.2 Background

The sensitivity of marine species to environmental fluctuations is an important factor to consider in fishery management and stock assessment. There are a few examples in the literature where such knowledge is used to make predictions of key variables of fisheries assessment and management, such as recruitment strength, spawning biomass and commercial landings (Myers 1998). Examples of such studies have generally focused on species with relatively short life spans (~1-2 years), such as squid, prawns, and anchovies, as the associated effects of the environment are manifested considerably faster compared to other longer lived species (Agnew et al. 2002; Oliveira et al. 2005). Developing these predictions for longer lived species has been problematic, as in many cases there is either an insufficient time-series of data, or the analysis incorporates unpredictable "environmental noise" that precludes any meaningful relationships. An important first step in elucidating relationships between the environment and population parameters is to compile the dataset into a form that can be spatially resolved, appropriately averaged and statistically scaled so that the environmental signal can be extracted from the background noise that could otherwise obscure any relationships.

Establishing a convincing link between the environment and population change is challenging, and when correlations are identified it is often difficult to confidently identify the underlying causal mechanism as they are typically inter-connected and multivariate. To gain any insight into the effects of the environment on commercial fisheries a wide range of environmental variables needs to be considered. It has been suggested that those environmental factors that have been proposed to be part of a physical mechanism that could reasonably affect populations should be considered first. Factors such as sea surface temperature (SST), wind speed and wind direction have been amongst the most common environment mechanisms hypothesized to affect recruitment process (Myers 1998). This study investigates whether any of these environmental factors retrospectively correlates with patterns of recruitment for a number of South Australian marine species that are of commercial interest.

1.3 Need

Fisheries recruitment in South Australia (SA) is highly variable and it is unclear what role the environment plays in determining this variability. To separate the impact of environmental factors from the effects of fishing pressure, an understanding of which environmental factors are important, and how they might affect populations of exploited species is required, i.e. only those environmental variables that have been proposed as part of a physical mechanism that could reasonably affect recruitment should be examined. If environmental indices are related to fisheries recruitment of specific species, the indices could be used to: (1) improve current understanding of the physical processes that account for variability in recruitment or, just as importantly, eliminate processes that are not relevant; (2) generate forecasts of recruitment based on predictable environmental factors; and (3) predict long-term consequences of climate change on fisheries.

1.4 Objectives

There are three overall project objectives. These are:

1. To compile an integrated spatial database of environmental variables including SST, wind speed and wind direction and ENSO events for SA;

2. To compile model-based and measured recruitment indices for SA fisheries for southern calamary, King George whiting, western king prawn, southern rock lobster, Western Australian salmon and snapper;

3. To relate recruitment indices for these species to identified environmental variables with the goal of improving current understanding of the effects of environmental variability on recruitment to South Australian fisheries.

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2 GENERAL METHODS

2.1 Data Sources

2.1.1 Fisheries data

Based on the knowledge of key fisheries in South Australia and their biology with long-term (>1 decade) observations of recruitment indices, existing hypotheses regarding the environmental effects on recruitment and a desktop audit of previous studies that have proposed physical mechanises that effect recruitment success, six commercially important species were selected. These were: southern calamary (*Sepioteuthis australis*), King George whiting (*Sillaginodes punctatus*), western king prawn (*Peneaus latisulcatus*), southern rock lobster (*Jasus edwardsii*), West Australian salmon (*Arripis truttaceus*) and snapper (*Chrysophyrs auratus*). Various quantities of fishery-dependent (e.g. Catch and effort data) and -independent (e.g. pre-recruit indices) data were available for these species. These data were collated from a range of published stock assessment reports and unpublished sources (Table 2.1).

2.1.2 Wind data

Historic records of daily wind speed (km h^{-1}) and direction were obtained from the Australian Bureau of meteorology (www.bom.gov.au). These data were collected from nine regional weather stations from coastal locations across the State from 1st January 1983 until 31st May 2006 (N.B. some weather stations were temporally out of service for short periods) (Table 2.2). The stations were selected as they were in close proximity to the main commercial fishing regions (Fig. 2.1). The frequency of these observations varied from 1 to 6 hourly, and wind speeds were 10-minute average wind speeds unless specifically labelled as gusts, in which case they are an almost instantaneous reading. Total wind stress (τ) and wind stress components (τ_x and τ_y) were calculated from the wind velocity ($\vec{v}$) and the east-west and north-south velocity components (u,v) of the wind velocity at 10 m. Note that in contrast to meteorological conventions for wind velocities, which specify the direction from which the wind comes, here wind velocity components has been defined by the direction the wind is heading. This approach is consistent with oceanographic conventions for currents. The magnitudes of wind stresses were determined using the standard empirical relationship as follows:

$$\tau = c_D \rho |\vec{v}|^2$$
$$\tau_x = c_D \rho |\vec{v}| u$$
$$\tau_y = c_D \rho |\vec{v}| v$$

Where ρ is the density of air (~1.22 kg m^3) and c_D is the non-dimensional drag co-efficient calculated following the method of Large and Pond (1981).

Table 2.1. Fisheries abundance data description and sources.

Species	Data Background	Authors
southern calamary	Catch per unit effort (CPUE) was computed from GARFIS database of the Fisheries Statistics Unit as provided by SARDI Aquatic Sciences for 1984-2006. These data were originally provided by fisher log books	Steer et al. (2007)
King George whiting	Recruitment estimates were provided from the South Australian KGW stock assessment model (WhitEst) 1983-2001. This computer fishery model is used to integrate up-to-date data including size and age structures and reproductive characteristic from several data sources, to provide estimates of biological performance indicators on the status of the fishery. The model outputs three principal biological performance indictors: recruitment; legal-size population biomass and exploitation rate	Fowler and McGarvey (2000); McGarvey et al. (2005)
western king prawn	Daily log books provided total pre-Christmas harvest catch and recruitment index was obtained from fishery-independent surveys conducted at 39 stations in northern Spencer Gulf between 1988/89-2006. Although only data post 1994 were of interest as data prior to 1994 was considered patchy and unreliable, except 1998 for which no recruitment data is available	Dixon et al. (2007)
southern rock lobster	Puerulus Settlement Index (PSI) between 1991 and 2006 in the SZRLF from five puerulus monitoring collector sites were combined to estimate an annual index of settlement in terms of numbers of puerulus per collector	Linnane et al. (2007)
Western Australian salmon	Salmon Pre-Recruitment Index (PRI) between 1981 and 2002 were collected using fine mesh beach seine surveys at five sites in Barker Inlet, Gulf St Vincent. Due to logistical and resource issues however there is no data available for 1982-1984 (see Table 1.3). Raw data was supplied by Keith Jones, Recreational Fisheries Project Officer at Primary Industries and Resources South Australia (PIRSA)	K. Jones (unpublished data)
snapper	The 'SnapEst' model integrates four data sources (1) commercial catch and effort data (2) catch length-frequency samples (3) catch at age samples and (4) recreational catch and effort data from the National Recreational and Indigenous Fishing Survey, to carry out maximum likelihood estimation of three critical stock assessment indicators: yearly recruitment (quantified by the recruiting number of 3 year olds), semi-yearly fishable biomass, and semi-yearly exploitation rates. Yearly recruit numbers are designed by the year class when those fish were spawned and thus when they settled as 0+ fish. They reach fishable sizes at ages 3-5 years, depending on how faster they grow and such estimates were available from 1983 to 2003	McGarvey and Feenstra (2004); Fowler et al (2007)

Table 2.2. Temporal environmental data description and sources.

Name	Wind Data	Air Temperature	SST Southern Ocean	ENSO Events	Comments
NINO 3.4 index				Jan 1856 to May 2006	IRI/LDEO Climate Data Library
Oceans Pathfinder			Jan 1985 to Dec 2005		NOAA
Edithburgh	Dec 1983 to Jun 2002				Bureau of Metrology
Adelaide Airport	Dec 1983 to Aug 2006				Bureau of Metrology
Kingscote	Sep 1987 to Aug 2006				Bureau of Metrology
Warooka	Dec 1983 to Aug 2006				Bureau of Metrology
Port Lincoln	Dec 1983 to Mar 2002				Bureau of Metrology
Whyalla (Aero)	Dec 1983 to Aug 2006	Jul 1982 to Aug 2007			Bureau of Metrology
Whyalla (Norrie)	Jan 1960 to Jul 2001	Jan 1960 to Jul 2001			Bureau of Metrology
Ceduna	Dec 1983 to Aug 2006				Bureau of Metrology
Neptune Island	Jan 1962 to May 2006				Bureau of Metrology

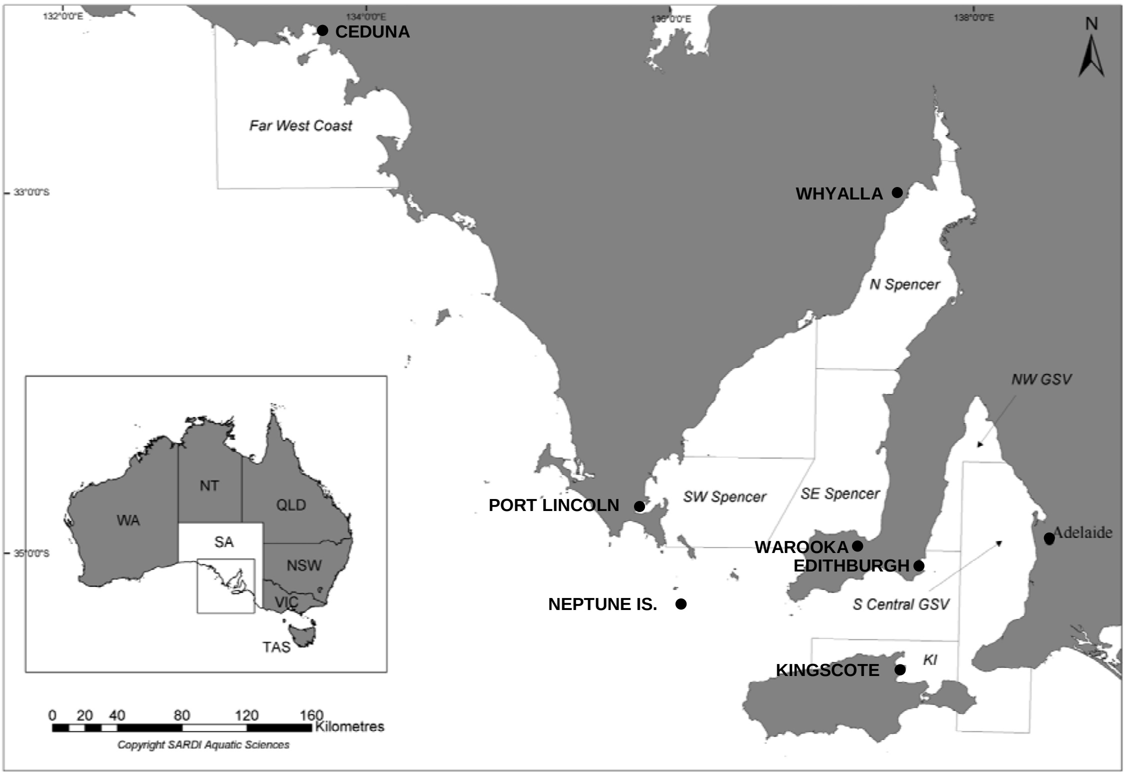

Figure 2.1. Location of main fishing regions and weather stations in South Australia.

2.1.3 Sea surface temperature (SST)

Estimated monthly averaged time series of SST derived from Whyalla (Norrie) air temperature data 1960-2001 and *Oceans Pathfinder* 1985 to 2005 provided SST for 1960-2005 respectively (Table 2.2). This was achieved because direct SST observations throughout GSV and SG are rare or do not exist on sufficiently long time scales i.e. >1 decade. Monthly averaged time series of nighttime SST were therefore obtained from the *Oceans Pathfinder 4* and *5* satellites for the whole South Australian region from 1985 to 2005 that has a listed accuracy of 0.3°–0.5°C at the US National Oceanographic Data Center (NODC) Satellite Oceanography Group at the National Oceanic and Atmospheric Administration (NOAA) (http://www.nodc.noaa.gov). The spatial area are divided into cells, and due to residual cloud data, SST 'spikes' were frequently present in cells adjacent to the coast, however, excluding points that were more than 1 standard deviation different from the mean within a region, reduced these spikes. Kearns et al. (2000) compared the remotely sensed SST estimated from the 4 km-resolution *Oceans Pathfinder* SST algorithm to a SST measured by the Marine Atmospheric Emitted Radiance Interferometer (MAERI) during five oceanographic cruises in the Atlantic and Pacific Oceans and found the average difference between the MAERI and *Oceans Pathfinder* SSTs to be 0.07 ± 0.31ºC from 219 match-ups during the low and mid latitude cruises. In addition, air temperatures from the Commonwealth Bureau of Meteorology (BoM) Whyalla (Norrie) weather station were used to produce an estimate of SST dating back to 1960 (Fig. 2.2). Principally the air temperature data were used to compare with the remotely sensed SST estimated from the *Oceans*

Pathfinder 4 and *5* satellites and to fill in 2 years missing SST data that lapsed between the biological time series data that mostly started in 1983 and SST from NOAA in 1985. To find appropriate lags for the linear estimate, monthly air temperature anomalies were calculated for SST using Whyalla (Norrie) air temperature by subtracting the average seasonal temperature signal. A lagged correlation of temperature anomalies for ± 12 months revealed significant correlations at 9 lags (Figure 2.3). The significant lags of the correlated temperature anomalies were used to form a basis for the linear estimate, the resulting weights are shown in Table 2.3.

To construct a linear estimate, *y*,

$$y = \sum_{i=1}^{n} \lambda_i x_i$$

Where λ_i are the weights and x_i are the dependent variables a covariance matrix is formed, **C**, from the dependent variables (the lagged air temperatures) and then the covariance vector, **v**, from the covariance's of the dependent variables and the known *Oceans Pathfinder* SST data. The optimum weights, λ_i, for forming an estimate of the SST are found from the equation

$$\mathbf{v} = [\mathbf{C}]\lambda$$
$$\lambda = [\mathbf{C}]^{-1}\mathbf{v}$$

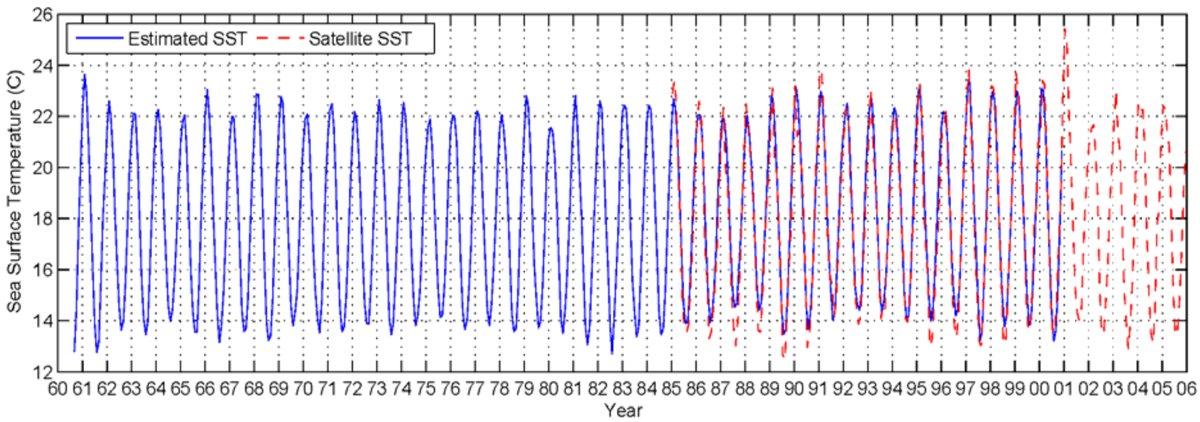

Figure 2.2. Estimated monthly averaged time series of SST derived from Whyalla (Norrie) air temperature data 1960-2001 (blue line) and *Oceans Pathfinder 4* and *5* 1985 to 2005 (red dashed line) providing SST 1960-2005 respectively for the whole South Australian region.

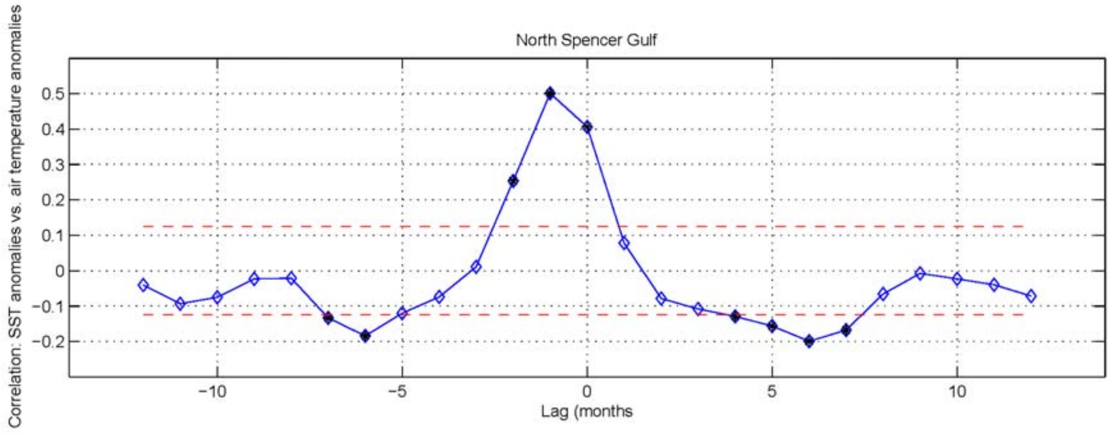

Figure 2.3. Shows correlations between lagged Whyalla (Norrie) air temperature anomalies and NOAA SST anomalies. Correlations that are significantly different from 0 at the 90% confidence interval are highlighted by the black diamonds. Red dashed lines indicate the significance limits for positive and negative correlations.

Table 2.3. Weighting for linear combinations of Whyalla (Norrie) air temperature.

Negative Lag months		-7	-6	-2	-1
Weights		0.13	-0.10	-0.01	0.26
Positive Lags (months)	0	+4	+5	+6	+7
Weights	0.11	-0.17	0.07	-0.16	-0.03

2.1.4 El Niño-Southern Oscillation (ENSO)

Historic records of ENSO events were obtained from the KAPLAN EXTENDED v2 from the IRI/LDEO Climate Data Library (http://ingrid.ldeo.columbia.edu) (see Kaplan et al. 1998) and provided a record of El Niño and La Niña events 1979-2006. El Niño-Southern Oscillation (ENSO) commonly referred to, as El Niño is a global coupled ocean-atmosphere phenomenon that causes global climate variability on inter-annual timescales (Trenberth 1996, 1997). The Pacific Ocean signatures, El Niño and La Niña are important temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. Monitoring of El Niño and La Niña requires observations from both the atmosphere and oceans, and these observations are often summarized in terms of various atmospheric and oceanic indices. In recent decades, indices based on SST have come into common usage because satellites and an observing network of buoys in the equatorial Pacific now allow for the collection of real time, high quality data that measure both surface conditions in the atmosphere and the surface and subsurface temperatures in the ocean.

Indices based on SST are those obtained by simply taking the average value over some specified region of the ocean. There are several regions of the tropical Pacific Ocean that have been highlighted as being important for monitoring and identifying El Niño and La Niña, referred to, as NINO 1-4 index. Of these regions, NINO 3.4 index (5ºS-5ºN; 170ºW-120ºW), which encompasses part of both NINO 3 and 4 (Figure 2.4), is characterised by large variability on El Niño time scales, and that is closer (than NINO 3 index) to the region where changes in local SST are important for shifting the large region of rainfall typically located in the far western Pacific, and one of the most relevant to ENSO events effecting Australia. Generally, the NINO 3.4 index is considered to be better suited for oceanographic purposes as it is based on ocean temperatures rather than atmospheric pressures and hence, selected for the purpose of this study. Using the NINO 3.4 index, an El Niño or La Niña event is identified if the 5-month running-average of the NINO 3.4 index is >0.4ºC or -0.4ºC, respectively for at least 6-consecutive months (Figure 2.5). This is in contrast, to the Southern Oscillation Index (SOI), which is a measure of the difference in surface air pressure between Darwin, Australia and Tahiti, where generally, the SOI is negative during El Niño, and positive during La Niña, but both NINO 3.4 index and SOI agree on indicating strong ENSO events.

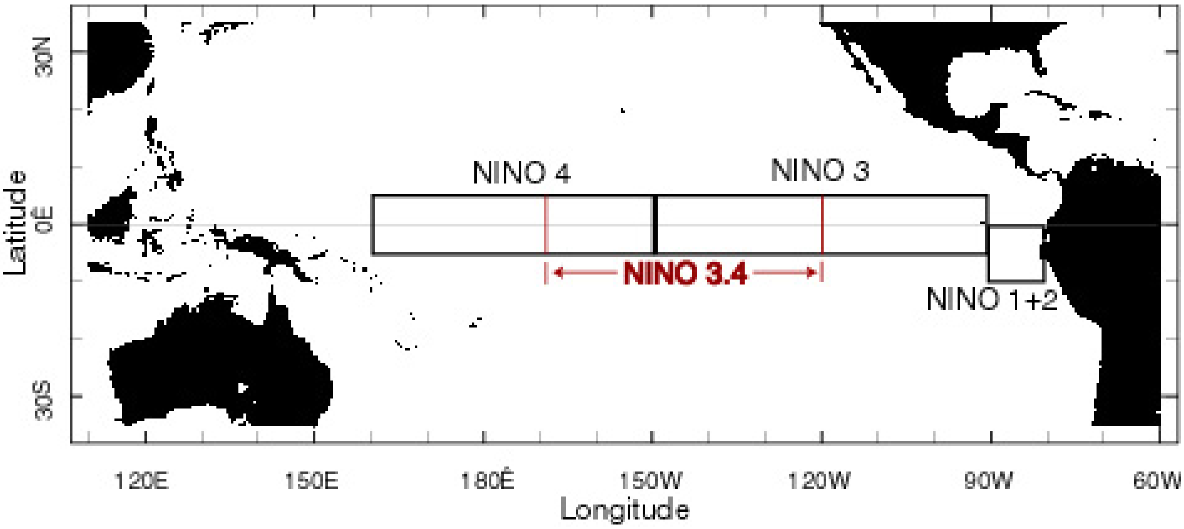

Figure 2.4. Location of the NINO index regions where NINO 3.4 index (5ºS-5ºN; 170ºW-120ºW) encompasses part of both NINO 3 and 4 (IRI for Climate and Society 2008).

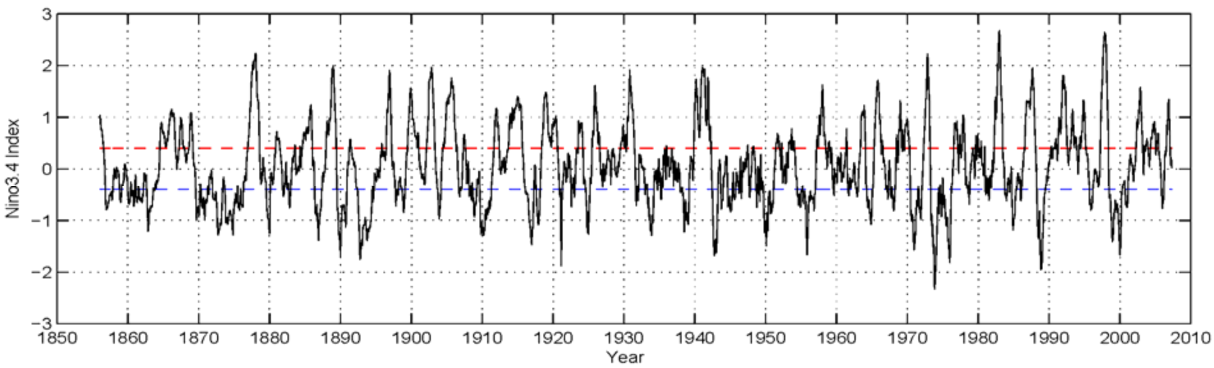

Figure 2.5. El Niño and La Niña events 1856-2007 respectively as indicated by the red and blue dashed line, respectively, derived from the NINO 3.4 index.

2.2 Statistical Analyses

For each species assessed, correlations between the environmental variable and recruitment index were made. To maintain analytical consistency for each of the species, the Pearson product-moment correlation coefficient, typically denoted by *r*, which is a common measure of the correlation between two variables *X* and *Y,* was applied. In addition, a significance level based on a null-hypothesis for 2-tailed Student t-test with *N*-2 degrees of freedom for *N* observations. The significance level, *p*, is related to the confidence interval by

$$100\% \times (1 - p)$$

For the purposes of this study the 90% ($p \leq 0.1$) confidence interval was chosen as the threshold for establishing significant correlations.

A standard technique for identifying physical relationships between two variables is to compute cross-correlations that are lagged in time. If a stronger correlation is determined at a lag other than zero, it may suggest a delay between cause and effect, but only if a casual link can be established through some other means. Significant correlations themselves do not necessarily imply causality. When a recruitment index is determined by a specific date or even in the year (i.e. the last month of larval settlement) the lagged correlations with the environmental variables are confined to the 12 months preceding that date. This is based on the assumption that any significant correlations with environmental events, following the determination of the index, must be spurious. For the purpose of this study, the year assigned to annually average environmental values is determined by the date of the biological index. In a number of cases the environmental variable was not averaged over an entire 12-month period, but only over the period during which it was expected to influence recruitment.

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3 SOUTHERN CALAMARY (*SEPIOTEUTHIS AUSTRALIS*)

C James & M Steer

3.1 Introduction

The southern calamary *Sepioteuthis australis* (Quoy & Gaimard, 1833) is a large loliginid squid, endemic to the inshore waters of southern Australia and northern New Zealand (Winstanley et al. 1983). It is a key component of the ecosystem as a primary consumer of crustaceans and fishes, and as a food source for a variety of predators (Coleman 1984; Gales et al. 1992). Like many other inshore squid species, calamary is of increasing commercial significance, contributing to multi-species, marine fisheries in all southern Australian states. South Australia's commercial calamary fishery is the biggest in Australia, worth an estimated AU$2.5 million per year and within the Marine Scalefish Fishery (MSF) considered a priority species together with King George whiting, snapper and garfish. Currently, trends in spatial and temporal commercial catch, effort and catch per unit of fishing effort (CPUE) data are the only indicators of stock biomass for this fishery. The majority of the commercial catch is landed by the hand jigs and haul net sectors. Estimates of CPUE calculated from the jig sector are considered to provide the most accurate estimate of calamary abundance. This is because jigging specifically targets calamary and provides a relatively robust estimate of targeted effort. Determining targeted effort in the haul net sector is problematic as the majority of fishers are non-specific in their targeted species and are capable of catching a variety of other MSF species. Furthermore, jigging occurs over a much broader spatial and temporal scale than haul netting, providing a more comprehensive insight into distribution and abundance patterns of calamary. For these reasons, estimates of targeted effort, as defined by the number of boat days targeting *S. australis* multiplied by the number of personnel involved, and the associated estimates of CPUE from the jig sector are heavily relied upon.

Over the last two decades, large inter-annual fluctuations in catch have been observed in the South Australian calamary fishery (Steer et al. 2007). Annual commercial landings in 2000/01 peaked at ~500 t but declined in 2002/03 to ~300 t before increasing to ~ 450 t in 2003/04 (Steer et al. 2007). Similar fluctuations have been noted for other squid species worldwide (Boyle and Boletzky 1996; Waluda et al. 2004; Roberts 2005). Studies suggest that environmental variability such as SST and oceanographic processes can influence both the distribution and abundance of various squid populations at a range of scales (Pierce et al. 2008), and have an impact on spawning and recruitment (Boyle and Rodhouse 2005). The life history of southern calamary is typical of most loliginids where they 'live-fast and die-young', exhibiting rapid growth and a sub-annual lifespan (Jackson and Domeier 2003). As a consequence, an environmentally good year, favouring growth and survival can lead to a significant increase in the population, whilst an environmentally poor year can result in reduced stock and the apparent crash in commercial harvest (Boyle and Rodhouse 2005). Time delays associated with compiling and analysing catch and effort data combined with the squid's short lifespan means that there may be no warning of impending low recruitment. Consequently, there is a need for reliable pre-recruit indices that would allow fisheries managers to track the status of the fishery and respond quickly to negative indicators.

The use of environmental proxies, such as sea surface temperature (SST) and wind strength, have demonstrated predictive potential (Pierce and Boyle 2003). Sea surface temperature has been reported to influence recruitment strength in the shortfin squid (*Illex argentinus*) at the time of spawning (Waluda et al. 2001), presumably through providing optimal temperature to developing embryos and paralarvae (Chen et al. 2008). Similarly, Augustyn (1991) identified a relationship between SST and the relative biomass of South Africa's chokka squid *Loligo vulgaris reynaudii* fishery. Increased near shore turbidity, resulting from storm events and strong onshore winds during the spawning season has also resulted in variable abundance. Squid aggregate in shallow water to spawn and depend on clear water for their visually-orientated mating behaviour (Sauer et al 1997; Jantzen and Havenhand 2003a, b). During periods of high, near-shore turbidity, spawning squid tend to move offshore where the effects of swell near the seabed are reduced (Roberts and Sauer 1994; Roberts 1998). It has been suggested that weeks of quiescent sea conditions are required to improve inshore water clarity to re-attract spawning squid (Roberts and Sauer 1994).

Environmental variables have proven difficult to establish reliable assessment and management procedures for cephalopods (Boyle and Rodhouse 2005). This is largely because the effects of stochastic environmental variables on sub-annual species are extreme. To improve our understanding of the observed inter-annual fluctuations in South Australia's calamary fishery we explored retrospective statistical correlations between two environmental parameters, wind stress ($\underset{\cdot}{\tau}$) and sea surface temperature (SST), and relative abundance (CPUE).

3.2 Methods

Retrospective correlations were used to explore whether annual fluctuations in commercial calamary catch rates (CPUE) significantly correlated with local wind conditions and SST. Data were averaged into yearly bins for each time series for the period 1990 to 2006 except for Kangaroo Island (KI) and South West SG wind data, which only covered the period to 2002 (see Table 2.1). Data prior to 1990 was discarded because fishers were only sporadically targeting calamary as a source of bait and that the CPUE for that period can not be compared with later years when calamary were specifically targeted as a commercial species (Steer et al. 2007). As the calamary fishery has undergone extensive development during the early 1990's correlations were calculated for a detrended time series.

3.2.1 Data Sources

3.2.1.1 Wind Data

Historic records of daily wind speed (km h^{-1}) were obtained from the Commonwealth Bureau of Meteorology (http://www.bom.gov.au/). These data were collected from weather stations on the eastern and western sides of GSV and SG (i.e. Adelaide Airport and Edithburgh in GSV, Whyalla (Aero), Warooka and Port Lincoln in SG and Kingscote on KI) from the early 1980s to early-mid 2000s (Table 2.1). These weather stations were chosen on the basis of their proximity to the main calamary fishing regions within GSV and SG i.e. North West Gulf St. Vincent (NWGSV), South Central Gulf St. Vincent (SCGSV), South East Spencer Gulf (SESG), South West Spencer Gulf (SWSG) North Spencer Gulf (NSG) and KI (Figure 2.1). These fishing regions are made up of one or more Marine Fishing Areas (MFA) as recorded by the GARFIS database.

3.2.1.2 Sea Surface Temperature (SST)

Estimates for SST for GSV and SG were obtained from a series of satellite images from the US National Oceanographic Data Center (NODC) Satellite Oceanography Group at the National Oceanic and Atmospheric Administration (NOAA) (Table 3.1).

3.2.1.3 Catch per Unit Effort (CPUE)

Catch per unit effort (CPUE) was calculated from fisheries data sets as provided by SARDI Aquatic Sciences that were originally provided by fisher log books (Table 3.1). CPUE was calculated from estimates of targeted jig effort, as defined by the number of boat days targeting calamary multiplied by the number of personnel involved.

Table 3.1. Identified fishing regions with associated weather station and data sets.

Fishing Region	Weather Station	CPUE Data	Wind Data	SST Data
North West GSV (NWGSV)	Edithburgh	1984-2006	1987-2006	1985-2005
South Central GSV (SCGSV)	Adelaide Airport	1984-2006	1983-2006	1985-2005
South East Spencer Gulf (SESG)	Warooka	1984-2006	1983-2006	1985-2005
South West Spencer Gulf (SWSG)	Port Lincoln	1984-2006	1983-2002	1985-2005
North Spencer Gulf (NSG)	Whyalla (Aero)	1984-2006	1983-2006	1985-2005
Kangaroo Island (KI)	Kingscote	1984-2006	1983-2002	1985-2005

3.3 Results

3.3.1 Wind Strength

Annual estimates of wind stress did not correlate well with annual estimates of CPUE in GSV (Table 3.2). Of the comparisons within GSV, calamary catch rates were moderately improved at KI and SC GSV during years of high wind stress. Catch rate also improved at KI and SC GSV associated with high wind stress. This pattern was reflected in SG, where catch rates appeared to improve during periods of high annual wind stress for SW SG and N SG (Table 3.3). Remaining comparisons were relatively indeterminate.

3.3.2 Sea Surface Temperature (SST)

Years with higher SST, were correlated with higher catch rates in NWGSV and SESG, moderate increases in NSG, and no change in the remaining regions (Tables 3.4 and 3.5).

Table 3.2. Correlation coefficients for detrended yearly averages of calamary CPUE vs. wind strength for the three main fishing regions within Gulf St. Vincent.

Wind Strength at Fishing Region	NWGSV CPUE	SCGSV CPUE	KI CPUE
NWGSV	-0.13 (p = 0.6)	-0.08 (p = 0.8)	0.12 (p = 0.7)
SCGSV	-0.09 (p = 0.8)	**0.43 (p = 0.1)**	**-0.45 (p = 0.08)**
KI	**0.47 (p = 0.1)**	-0.06 (p = 0.9)	**0.48 (p = 0.1)**

Table 3.3. Correlation coefficients for detrended yearly averages of calamary CPUE vs. wind strength for the three main fishing regions within Spencer Gulf.

Wind Strength at Fishing Region	NSG CPUE	SESG CPUE	SWSG CPUE
NSG	**0.56 (p = 0.02)**	0.01 (p = 0.96)	0.15 (p = 0.6)
SESG	-0.37 (p = 0.2)	**-0.11 (p = 0.1)**	0.35 (p = 0.2)
SWSG	**0.09 (p = 0.8)**	-0.26 (p = 0.4)	**0.62 (p = 0.03)**

Table 3.4. Correlation coefficients for detrended yearly averages of calamary CPUE Vs. sea surface temperature (SST) for the Gulf St. Vincent.

	NWGSV CPUE	SCGSV CPUE	KI CPUE
Gulf St Vincent SST	**0.75 (p = 0.001)**	0.16 (p = 0.6)	0.19 (p = 0.5)

Table 3.5. Correlation coefficients for detrended yearly averages of calamary CPUE Vs. sea surface temperature (SST) in the Spencer Gulf.

	NSG CPUE	SESG CPUE	SWSG CPUE
Spencer Gulf SST	**0.39 (p = 0.1)**	**0.75 (p = 0.001)**	-0.08 (p = 0.8)

3.4 Discussion

The timing of peak calamary abundance in SA varies throughout the year, and generally tracks around the Gulf waters in an anti-clockwise direction, starting from the south eastern corner in spring and finishing at the south western corner in winter (Steer et al. 2007). Seasonal patterns in water clarity, associated with summer south easterly and winter south westerly winds, have been suggested to drive the spatial pattern in calamary abundance (Steer et al. 2007). It is known calamary form large spawning aggregations in clear water and it was hypothesised that they would inhabit leeward shores that are relatively protected from prevailing winds. Exploring annual correlates did not support this hypothesis and suggested that calamary catches tended to increase during years of high, average, wind stress, particularly at KI, SCGSV, NSG and SWSG. As weather and oceanographic conditions are highly dynamic and can change over short time scales, it is unlikely that fine scale patterns are going to be detected through the investigation of annual comparisons. Steer et al. (2007) reported that monthly fluctuations in commercial catch rates for *S. australis* appeared to be more highly correlated with local wind conditions, suggesting that comparisons made over shorter time–scales may be more appropriate for this species, particularly as it has a sub-annual life-span.

Variations in average annual SST were weakly to moderately correlated with calamary catch rates in both Gulf waters, particularly in NWGSV, SESG and NSG. Squid populations have been found to respond quickly to changes in sea surface temperature as they have an intrinsic flexibility to rapidly adapt to local conditions and as such their life-history traits and physiology enable them to opportunistically occupy variable environments (Rodhouse and Nigmatullin 1996). It is generally agreed that temperature plays a crucial role in the dynamics of cephalopod lifestyle and that environmental effects on growth in natural populations are pronounced in areas with marked seasonal differences (Pecl 2004), such as southern Australian waters. Such sensitivity to temperature has inherent cascading population effects characterised by accelerated life histories, rapid generational turnover and increased survivorship rates that collectively underpin population expansion, increase biomass and subsequently increase commercial catch rates. Studies have also indicated that oceanographic conditions may alter food type and availability (Jackson and Domeier 2003; Qian et al. 2006; Chen et al. 2008) and thus population growth. The timing of environmental perturbations therefore plays a critical role in the rate of population expansion (Forsythe and Hanlon 1989; Forsythe 1993). Exploring annual correlates cannot resolve these fine-scale perturbations and it is possible that their relative strength was compromised in this study through the inability to detect intra-annual, or seasonal variation.

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4 KING GEORGE WHITING (*SILLAGINODES PUNCTATA*)

C James, R McGarvey, AJ Fowler & L-Y Wu

4.1 Introduction

King George whiting (KGW), *Sillaginodes punctatus* (Cuvier, 1829), is a coastal marine fish of the smelt-whitings family, Sillaginidae. KGW is endemic to Australia, inhabiting the south coast of the country, ranging from southern Western Australia to New South Wales in the east, although the latter appears to be a rare occurrence (McKay 1985). In South Australia, KGW has a broad geographic distribution that includes all waters of Gulf St. Vincent (GSV), Spencer Gulf (SG) and coastal waters to the Far West Coast (FWC) of Eyre Peninsula. Throughout this distribution it is intensively targeted by the commercial and recreational sectors of the Marine Scalefish Fishery (Fowler et al. 2008).

Commercial catch and effort data collected since 1984 indicate that the State-wide, commercial catch of KGW has fallen substantially between 1984 and 2007. Since 1992, catches have decreased, dropping to 550-600 t. yr^{-1} in 1999 and dropping below 450 t. yr^{-1} in 2000, before stabilising at 340-350 t. yr^{-1} between 2004 and 2007 (Fowler et al. 2008). Consequently, in 2007 the commercial catch of KGW was 42% lower than that taken in 1999 and 55% lower than that in 1992 (Fowler et al. 2008). Such a decrease in catch reflects the declining trend in the number of licence holders in the commercial fishery, which accelerated after 1994 when the licence amalgamation scheme was introduced (Fowler et al. 2008). As such, there has been a considerable decrease in the number of commercial fishers who target and/or catch KGW. In 2000/01, the recreational catch of KGW was estimated to be 585 t compared with the 439 t taken by the commercial sector (Fowler et al. 2008). KGW remains the most significant marine scalefish species in South Australia (Kailola et al. 1993).

The life history of KGW is complex (Fowler et al 2000a). The adults and juvenile fish use different habitats (Hyndes et al. 1996) with the juveniles using shallow waters in protected bays, creeks and estuaries (Fowler et al. 2000b). The spawning grounds are in the southern parts of GSV and SG, particularly Tapley's Shoal and Investigator Strait in GSV and Hardwicke Bay in SG (Fowler et al. 2000a). From late March to June, mature adult fish that aggregate during the reproductive season occupy these southern spawning grounds (Fowler et al. 1999), which might relate to seasonal water temperatures (Hyndes et al. 1998). The size and age structures of fishery catches of KGW differ throughout the coastal waters of South Australia. The protected bays in the northern areas support immature fish that have modal sizes of 30 – 32 cm TL and are 3-4 years old. In contrast, at the spawning grounds in the southern areas the populations have broader size and age distributions, with modal sizes of 38 – 40 cm TL and age distributions of 3-17 years (Fowler et al. 2000a). These spawning sub-populations of larger, older fish are replenished annually by the immature adults that migrate from the nursery areas in the north (Fowler et al. 2000a; Fowler et al. 2002). The nursery areas involve seagrass beds (Fowler and Short 1996), with the juveniles apparently using the seagrass as protection and for foraging purposes (Robertson 1977), or bare sandy substrate (Hyndes et al. 1998). The Port River-Barker Inlet is the sea entrance to the Port of Adelaide in GSV, and is reported to have considerable regional importance as a nursery area for the commercial and recreationally important fish stocks of GSV (Jones et al. 1996) as is Franklin Harbor in SG and the FWC bays (Fowler et al. 2008). These important nursery areas are located up to several hundred kilometers from the spawning grounds in the south (Fowler et al. 2000a, b).

It has been suggested that the long, pre-settlement duration for KGW larvae, i.e. 80 to >120 days, would allow the larvae to travel considerable distances from the spawning grounds to the nursery areas (Fowler and Short 1996). It is likely that a major influence on larval supply would be the coastal oceanographic processes that impact on the transport of the larvae (Underwood and Fairweather 1989). For post-larvae to successfully reach the nursery grounds, hydrodynamic modelling for the coastal areas around southern Australia suggests that KGW larvae are advected by ocean currents from the spawning grounds (Jenkins et al. 1997, 2000; Fowler et al. 2000b). In Port Phillip Bay, Victoria, physical processes, such as wind-driven currents and tidal forcing were reported to influence the larval supply to a large single stock of KGW and to influence patterns of settlement as well as the use of the nursery habitat (Jenkins et al. 1997, 2000). In this region, it has been further suggested that the extent of post-larval transport reflects the influence of strong eastward-directed currents that correspond with seasonal shifts in weather patterns (Jenkins et al. 2000).

The difference in relationship between spawning grounds and nursery areas in South Australia and Victoria is likely to be a consequence of regional differences in current regimes and their influence on larval advection (Fowler et al. 2000b). This raises the hypothesis that the success of post-larval KGW recruitment depends on, to a greater or lesser extent, hydrographic processes in GSV, SG and FWC, which are largely influenced by wind strength and direction.

To further examine the effects of hydrographic processes on recruitment variation for South Australia's KGW population, an attempt was made to find simple, direct correlations between the average annual wind strength and direction, and recruitment of post-larval KGW in each of GSV, SG and FWC, using correlation analysis.

4.2 Methods

To test whether wind-driven advection influences the delivery of post-larvae to nursery grounds, the average annual wind strength and direction, and post-larval KGW recruitment for each of GSV, SG and FWC were examined.

Since spawning typically occurs between March and May, followed by settlement between June and November, and with the mean age of the smallest post-larvae at 90-140 days (Fowler et al. 1999), correlations between wind strength and recruitment were investigated for various times during the year. Wind strength components were calculated for the north-south (N-S) and east-west (E-W) direction, and averaged over 3 and 6-month periods, respectively. Three-month periods were computed for each of the 12 months between November (the last month of late settlement) and October of the following year. Wind strength components, averaged over the 6-month settlement period (June to November), were also examined.

4.2.1 Data Sources

4.2.1.1 Recruitment Data

Recruitment estimates were obtained from the South Australian KGW 'WhitEst' stock assessment model (McGarvey et al. 2005). This computer fishery model, developed in an FRDC-funded project (Fowler and McGarvey 2000), is a dynamic, spatial, age-structured model that is used to integrate up-to-date data including size and age structures and reproductive characteristics (Fowler et al. 1999, 2000a, 2002), from several data sources, to provide estimates of biological performance indicators indicative of the status of the fishery (Fowler et al. 2008). The model involves six spatial cells, five of which contribute most of the catch, i.e. FWC, and the upper and southern regions of GSV and SG, while the last cell is located offshore from the FWC (Fowler et al. 2008). The model outputs three principal biological performance indicators: recruitment, legal-size population biomass and exploitation rate. For the purposes of this study, the model estimates of recruitment were applied, which are defined as the number of 1-year old fish. In the recruitment time series presented, the year shown on the X-axis is the year that these fish entered the fishable stock as 3-year olds (Figure 4.1).

4.2.1.2 Wind Data

Historic records of daily wind speed (km h^{-1}) and direction were obtained from the Bureau of Meteorology (http://www.bom.gov.au/). These data were collected from weather stations on the eastern and western sides of GSV, SG and the FWC from the early 1980s to early-mid 2000s (Table 4.1), and were chosen on the basis of their proximity to the main KGW fishing regions within GSV, SG and FWC. There were, however, extended gaps in the Edithburgh and Whyalla wind data from July 1990 to December 1992, and from January 1991 to February 1992, respectively.

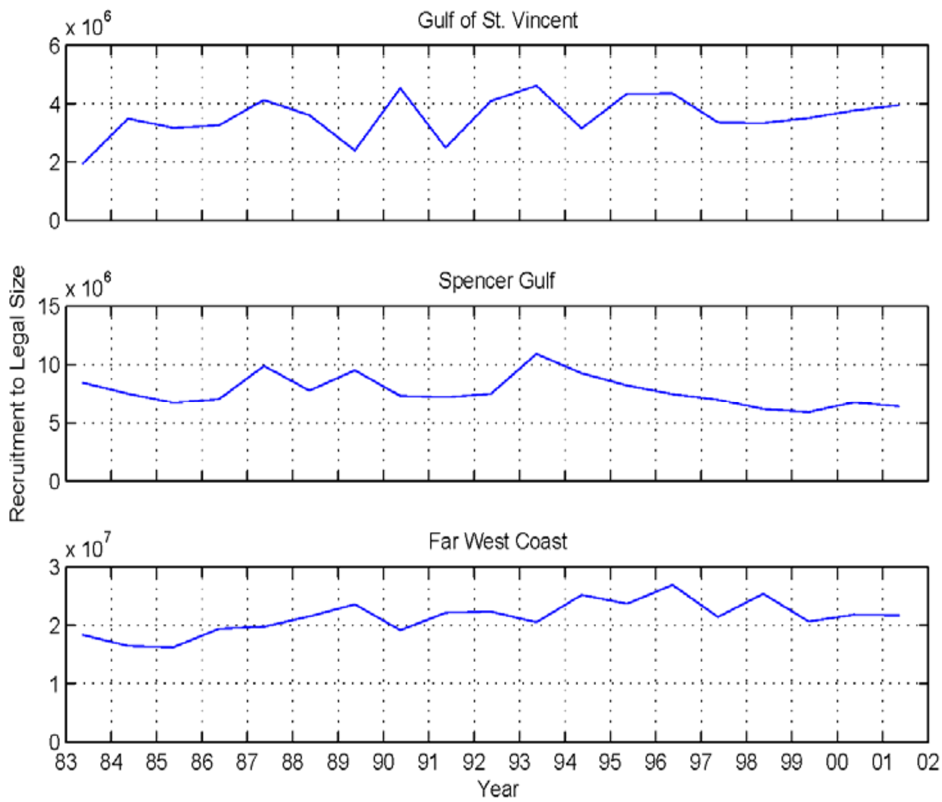

Figure 4.1. KGW yearly recruitment as estimated by the stock assessment model WhitEst (McGarvey et al. 1995).

Table 4.1. Fishing regions from which environmental data were considered in this study.

Fishing Region	Weather Station	Wind Data	KGW Recruitment
South West GSV	Edithburgh	Dec 1983 to Jun 2002	1983-2001
South Central GSV	Adelaide Airport	Dec 1983 to Aug 2006	1983-2001
South East SG	Warooka	Dec 1983 to Aug 2006	1983-2001
South West SG	Port Lincoln	Dec 1983 to Mar 2002	1983-2001
North SG	Whyalla (Aero)	Dec 1983 to Aug 2006	1983-2001
Kangaroo Island	Kingscote	Sep 1987 to Aug 2006	1983-2001
FWC	Ceduna	Dec 1983 to Aug 2006	1983-2001

4.3 Results

4.3.1 Gulf St Vincent

The strongest correlations were obtained for the wind data from Adelaide (Figure 4.2). For the N-S wind stress for the winter and spring months, there were negative correlations with the recruitment estimates (r = -0.62, p = 0.006). Negative values of wind-stress, consistent with southward-directed winds, were associated with high recruitment rates, whilst positive values of wind stress were associated with low values of recruitment (Figure 4.3). For Edithburgh and Kingscote there were no significant correlations between N-S wind stress and recruitment. There were, however, several weak positive correlations between recruitment and the E-W wind stress, as measured at these two places.

4.3.2 Spencer Gulf

The most significant and relevant correlations were recorded for the data from Warooka and Port Lincoln. For each of these there was a positive correlation with the N-S wind stress, as measured in early autumn and late winter (Figure 4.4). Positive values of wind stress, consistent with northward-directed winds were associated with high recruitment rates, whilst negative values of wind stress, i.e. southward directed wind were associated with low values of recruitment (Figure 4.5). There were no significant correlations between E-W wind stress and recruitment.

4.3.3 Far West Coast

There were strong correlations between N-S wind stress as recorded in early winter, and recruitment to the Far West bays (Figure 4.6). High negative values of wind stress, consistent with southward-directed winds were associated with high recruitment rates, whilst lower values were associated with low recruitment (Figure 4.7).

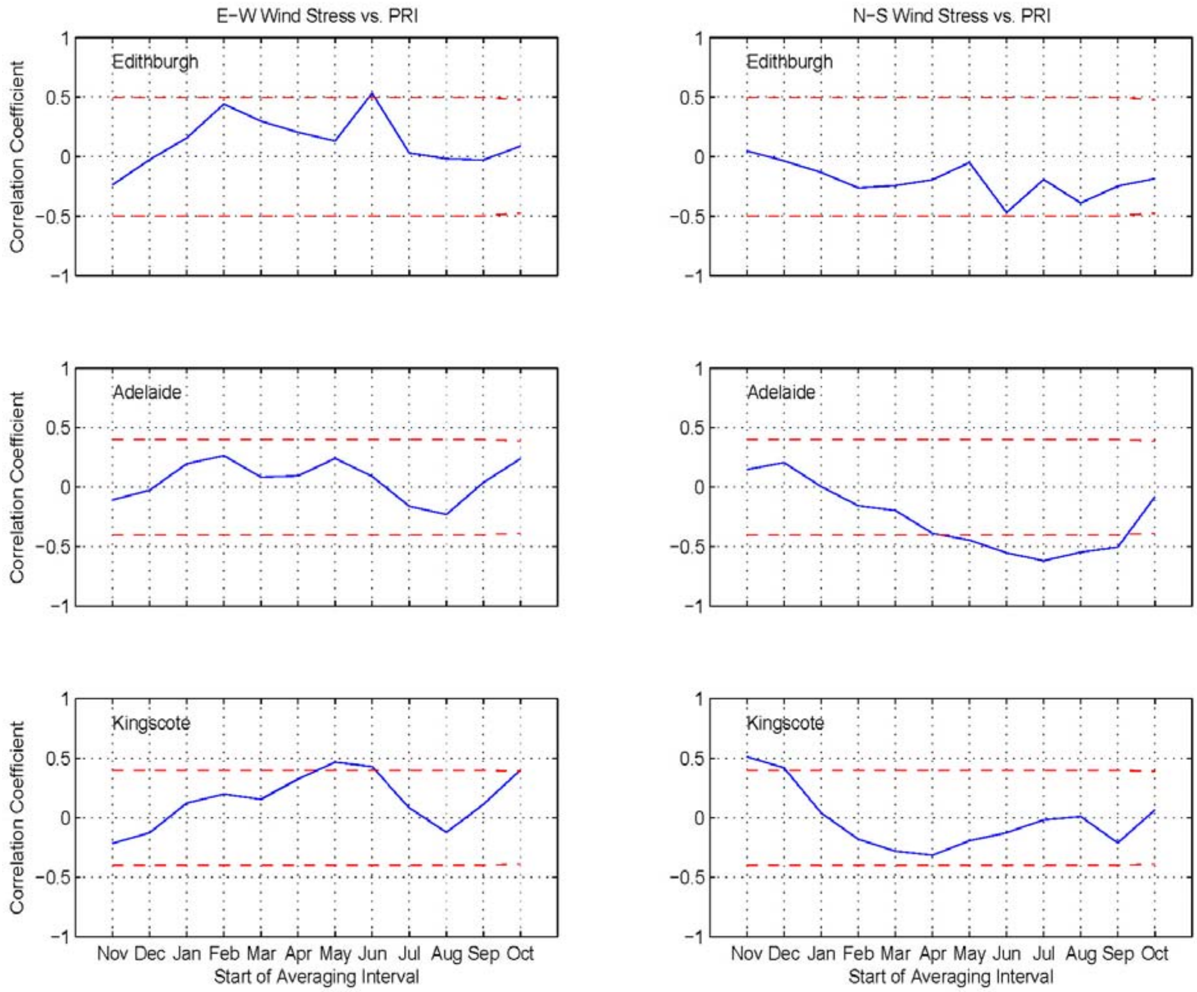

Figure 4.2. Correlations between wind strength Vs. recruitment for KGW in Gulf St. Vincent. Significance limits at the 90% confidence level are indicated with red dashed lines.

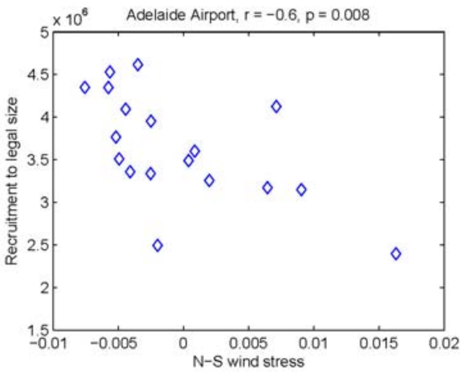

Figure 4.3. Plot of KGW recruitment for GSV Vs. N-S wind stress measured at Adelaide Airport and averaged from June to November.

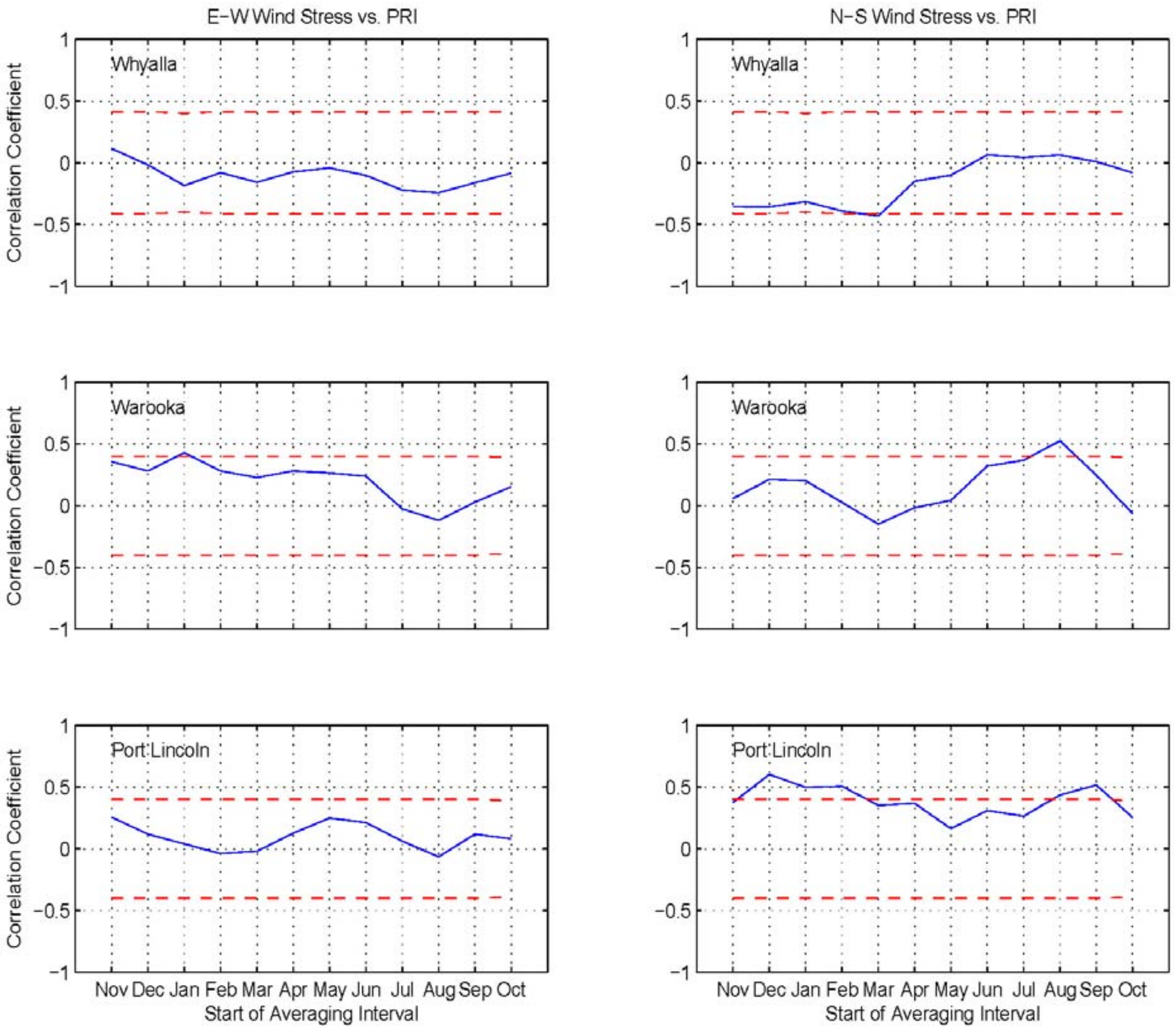

Figure 4.4. Correlations between wind strength Vs. recruitment for KGW in SG. Significance limits at the 90% confidence level are indicated with red dashed lines.

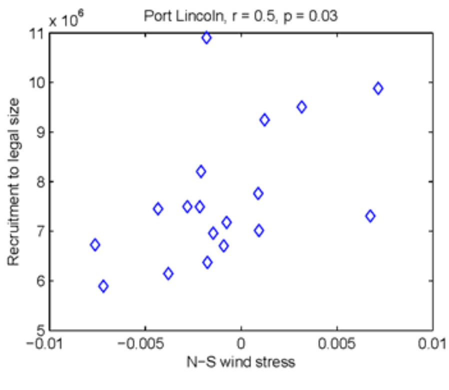

Figure 4.5. Plot of KGW recruitment in SG Vs. N-S wind stress measured at Port Lincoln and averaged from June to November.

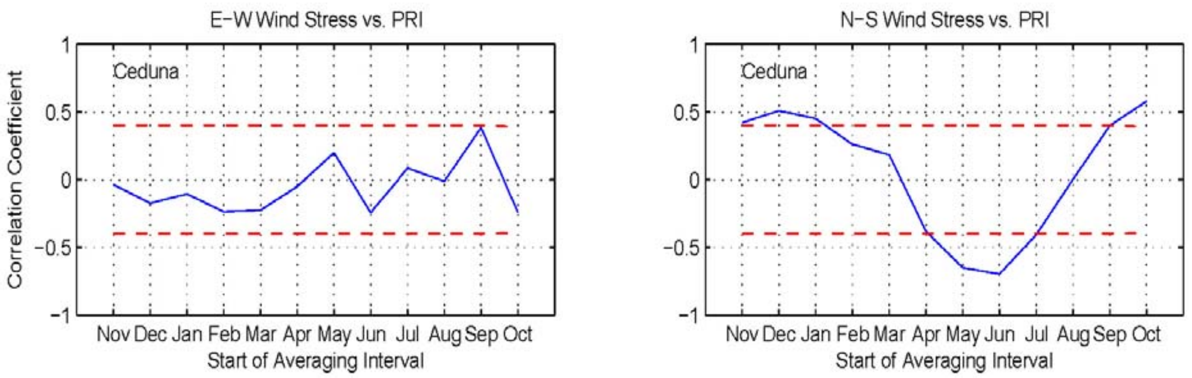

Figure 4.6. Correlations between wind strength Vs. KGW recruitment for the FWC. Significance limits at the 90% confidence level are indicated with red dashed lines.

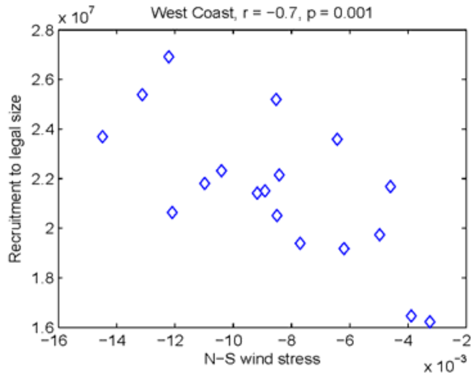

Figure 4.7. Plot of FWC KGW recruitment Vs. N-S wind stress measured at Ceduna, averaged between June and August.

Between June and November (the settlement season for KGW in GSV) the strongest correlations were for wind stress averaged for both GSV and SG (Table 4.2). The results clearly show that in GSV, recruitment was correlated with the southward wind stress near Adelaide Airport over the entire settlement period, as seen in Figure 4.3. A similar negative correlation was also observed for Edithburgh (Figure 4.3). The increasing recruitment also corresponds to the increase in southward wind stress (Figure 4.3).

Table 4.2. The correlation coefficients between KGW recruitment and wind stress components averaged between June and November for GSV and SG, and June to August for the FWC.

Fishing Region	Weather Station	E-W Wind Stress	N-S Wind Stress
GSV	Edithburgh	0.18 (p = 0.6)	-0.56 (p = 0.05)
	Adelaide Airport	0.07 (p = 0.8)	-0.60 (p = 0.008)
	Kingscote	0.28 (p = 0.3)	-0.22 (p = 0.4)
SG	Whyalla (Aero)	-0.16 (p = 0.5)	0.03 (p = 0.9)
	Warooka	0.10 (p = 0.7)	0.40 (p = 0.1)
	Port Lincoln	0.17 (p = 0.5)	0.50 (p = 0.03)
FWC	Ceduna (AMO)	-0.25 (p = 0.3)	0.70 (p = 0.001)

4.4 Discussion

The recruitment of KGW in the major fishing regions of GSV, SG and FWC showed a negative correlation with the N-S wind stress whereas no correlations were observed with the E-W wind stress. For the FWC, the response to surface wind stress is likely the result of Ekman transport, i.e. the natural process by which wind causes movement of water near the ocean surface. This suggests that the north and southward wind stress is likely to drive west and eastward water transport, respectively. For the FWC, there are three important nursery areas: Denial Bay, Streaky Bay and Coffin Bay (Fowler et al. 2008), and these bays generally face west or south-west. Advection into these bays would likely come from the north-west, requiring an eastward Ekman transport, influenced by a southward (negative) wind stress. This is consistent with the strong negative correlation between N-S wind stress and recruitment at Ceduna between spawning and settlement.

In GSV and SG, water movement is less likely influenced by Ekman transport because these are relatively shallow bodies of water with mean depths of 21m (Bye and Kämpf 2008). In GSV, Barker Inlet has a predominantly north-facing entrance, which southward-directed transport would be required to bring larvae to. The correlations of recruitment with wind stress at Adelaide Airport and Edithburgh show that southward-directed wind stress is associated with the strongest recruitment levels (Figure 4.4), and this may reflect the movement of shallow water in response to applied wind stress, where the angle between the applied wind stress and vertically integrated transport might be less than 90º. This is consistent with the correlation for SG, where the nursery areas are a considerable distance to the north of the spawning grounds and northward directed water movement is required to facilitate this movement.

Whilst the recruitment of KGW to the major fishing regions shows some correlations with the N-S wind stress, it should be noted that the extended gaps in the Edithburgh and Whyalla (Aero) wind data might have influenced the overall results.

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5 WESTERN KING PRAWN (*PENAEUS LATISULCATUS*)

J Luick & C Dixon

5.1 Introduction

The Western King Prawn, *Penaeus latisulcatus* (Kishinouye, 1896) has a wide distribution throughout the Indo-West Pacific region (Penn 1980; Grey et al. 1983) and is found around most of coastal Australia (Kailola et al. 1993). Its distribution in South Australia (SA) is unique, being at its lowest temperature limit (~12-13ºC) (Dixon et al. 2007), and as such is primarily restricted to the coastal waters of Gulf St. Vincent (GSV), Spencer Gulf (SG) and Far West Coast (FWC) bays of the Eyre Peninsula (Figure 2.1). The Spencer Gulf Prawn Fishery (SGPF) is the largest in terms of production, value and number of license holders and is the fourth most valuable prawn fishery in Australia (Dixon et al. 2007). SA's other prawn fisheries are based in Gulf St. Vincent Prawn Fishery (Roberts et al. 2007) and the West Coast (Dixon and Roberts 2006). These prawn fisheries are the only single species prawn fisheries in Australia (Dixon et al. 2007). The SGPF is the largest commercial producer of this species in the world and is well known for its stable catch history, collaborative fishery management and strong research history (Dixon and Sloan 2007).

Many aspects of the biology of *P. latisulcatus,* the environment in which they are distributed and the management of the commercial fisheries that harvest them within SA are well documented (see Dixon and Roberts 2006; Roberts et al. 2007; Dixon et al. 2007; Kangas and Dixon 2008). Studies have shown that in SG, *P. latisulcatus* can live for up to 4 years (Dixon *et al.* 2007) and their distribution and abundance is affected by salinity, temperature and the presence of sandy substrate (Potter et al. 1991; Carrick 2003). Adult penaeid prawns usually live in deeper (>10 m) offshore waters where physical conditions are relatively stable but juveniles occupy shallow (<10 m) inshore areas prone to estuarine fluctuations of salinity and water temperature. Physiological studies show that juvenile penaeids are typically euryhaline (Dall et al.1990; Potter et al. 1991; Sang and Fotedar 2004) and can adapt to rapid salinity changes (Carrick 1982; Penn et al. 1988; O'Brien 1994). Higher abundance of *P. latisulcatus* are associated with salinities above 30‰ (Potter et al. 1991), although studies have shown that optimal salinity ranged from 22-34‰, and 100% mortality occurred at salinities <10‰ (Sang and Fotedar 2004). The highly saline waters of northern Spencer Gulf provide an ideal environment for post-larval settlement of *P. latisulcatus.*

Adult *P. latisulcatus* aggregate, mature, mate and spawn offshore between November and March (Carrick 2003). Evidence suggests that individuals spawn on multiple occasions in one spawning season, but no empirical data on spawning frequency is available. In Western Australia, spawning and fecundity were affected by water temperature, with the minimum temperature required being 17ºC (Penn 1980). Courtney and Dredge (1988) demonstrated that the peak reproductive period of *P. latisulcatus* in Queensland was between June and July when water temperatures drop below 25ºC. This leads to the notion that the ideal temperature range for spawning *P. latisulcatus* might be 17-25ºC in SG (Dixon et al 2007).

P. latisulcatus undergo four larval stages (Carrick 2003; Roberts et al. 2007). The duration of the larval phase is dependent on water temperature, with faster development in warmer water (Hudinaga 1942). In SG, water temperatures over the main spawning and larval period range generally from 19-25ºC (Carrick 2003). Recently, experiments conducted for the FRDC project 2008/011 determined that larval development took 34 days at 17 ºC and 15 days at 25 ºC (SARDI, unpublished data). Carrick (1996) demonstrated that larvae were broadly distributed throughout Spencer Gulf, with highest densities found in the north. This observation supports the generalisation that larval advection is substantially influenced by wind strength and direction, as southerly sea breezes generally dominate summer weather patterns.

Larvae settle in juvenile habitats characterised by tidal flats often associated with mangrove forests (Carrick 2003). A high portion of north SG is suitable habitat for juvenile prawns, particularly on the western side near Cowell and Whyalla (Edyvane 1995; Bryars 2003). The timing of juvenile prawns entering the fishery as new recruits is variable and depends largely on the time of settlement (Carrick 1996). In northern SG, recruitment to the fishery is generally observed at peak densities in February, and it is believed that these recruits have resulted from spawning one year previous. Carrick (1996) also suggested that early spawning events (November) may result in recruitment to the fishery the following April and May (5–6 months later).

The early spawning season coincides with high pre-Christmas demand for prawns from local Australian markets. Traditionally, the SGPF harvests in November and December each year to supply this demand. Dixon et al. (2005; 2007) detected a significant correlation between the level of pre-Christmas catch and subsequent catches, suggesting that the level of harvest of spawning females may affect recruitment to the fishery. Whilst these analyses provide some evidence of a stock recruitment relationship (if pre-Christmas harvest is assumed as a surrogate for spawning biomass) no studies to date have examined the relationship between environmental parameters and recruitment to the fishery. In this report, we consider the effects of wind speed and direction and sea surface temperature (SST) on recruitment. Additionally, we further examine the influence of pre-Christmas harvest on recruitment indices for the fishery.

5.2 Methods

Data were obtained from four sources: daily fisher log books, fishery-independent surveys, the Commonwealth Bureau of Meteorology and from the US National Oceanographic Data Center (NODC) Satellite Oceanography Group at the National Oceanic and Atmospheric Administration (NOAA) respectively. For the purpose of this study, the term summer refers to the months of November to March, inclusive (e.g. summer 2001 includes data from November 2001 to March 2002). Trends in recruitment data (from fishery-independent surveys) between 1994 and 2006 in the SGPF were used to explore correlations with wind data, SST and pre-Christmas catch. Wind stress components (τ_x and τ_y) were calculated from the wind velocity ($\vec{V}$) and the east-west and north-south velocity components (u,v) at 10 m.

5.2.1 Data Sources

5.2.1.1 Recruitment Index (RI)

The recruitment index (RI) was obtained from fishery-independent surveys conducted since February 1994 at 39 stations in northern SG. Recruitment index was calculated as the square root transformation of the number of prawns (male <33 mm and females <35 mm carapace length) per nautical mile trawled following Carrick (2003). Length-frequency data were not available for all recruitment sites in February 2004 and subsequently estimates were derived from relative catch rate and mean prawn size data (Dixon et al 2007). Recruitment estimates were not available for 1998.

5.2.1.2 Sea Surface Temperature (SST)

Estimates for sea surface temperature (SST) for Spencer Gulf were obtained from a series of satellite images from the Satellite Oceanography Group at the National Oceanic and

Atmospheric Administration (NOAA) (http://www.nodc.noaa.gov/SatelliteData) for 1994-2005 periods (Table 5.1).

5.2.1.3 Wind Data

Historic records of daily wind speed (km h^{-1}) were obtained from the Commonwealth Bureau of Meteorology (http://www.bom.gov.au). These data were collected from Whyalla (Aero) weather stations on the north-west side of SG from 1994 to 2006 (Table 5.1), and chosen on the basis of its proximity to the nursery areas. A time series of summer (i.e. the months November to March, inclusive) wind data was created for the years 1994-2006. The directional behaviour of the wind was determined from wind roses that summarised the occurrence of wind strength, direction and frequency at Whyalla (Aero). Light winds have little oceanographic effect therefore to avoid over loading, only observations greater than the median speed (4 m/s) were included in analyses. Wind roses in this study were constructed so that the percentage of calm conditions is represented by the size of the centre circle - the bigger the circle, the higher the frequency of calm conditions. The numbers leading out from the centre are the number of occurrences for each radius, and each branch of the rose represents wind coming from that direction.

4.2.1.4. Total pre-Christmas catch

The total pre-Christmas catch (November and December) was obtained from daily logbook data for 1994 to 2006.

5.2.1.4 Analysis

Following linear least-square regression analyses, three predictors: pre-Christmas harvest, wind speed and SST each entered the analysis for three summers i.e. the Recruitment Index for a particular year of interest, the previous summer of that year and the summer before, respectively e.g. 2005/06, 2004/05 and 2003/04.

Table 5.1. Identified fishing region with associated weather station and data sets. * Indicates no recruitment data for 1998, † indicates recruitment indices for February 2004 were determined from relative catch rates at recruitment sites during February 2002 and 2004 surveys, as discussed in the text.

Name	Catch Data	RI Data	Wind Data	SST Data	Comments
SGPF	1994-2006*				Fisher log books
SGPF		1994-2006†			Fish-independent survey
Whyalla (Aero)			1994-2006		Bureau of Metrology
Pathfinder				1991-2005	NOAA

5.3 Results

Statistics for correlations of the predictor variables pre-Christmas harvest, wind speed and SST are summarised in Table 5.2. A highly significant correlation was observed between recruitment indices and the level of pre-Christmas harvest two summers prior. Whilst statistically non-significant, it should be noted that there was a weak correlation (P=0.05) between recruitment and SST in the same year.

Table 5.2. Predictors of Recruitment Index, correlation coefficient (*r*), and probability level of the null hypothesis (*p*). The percent significance level of *r* is 100•(1-*p*).

Predictor	***r***	***p***
Pre-Christmas Harvest:		
a particular year	0.00	0.90
previous summer	0.00	0.90
two summer prior	-0.90	<0.001
Wind speed:		
a particular year	0.43	0.20
previous summer	0.00	0.90
two summer prior	0.00	0.90
Sea surface temperature:		
a particular year	0.63	0.05
previous summer	0.00	0.90
two summer prior	0.00	0.90

5.3.1 Sea Surface Temperature (SST)

Mean SST was plotted against *summer* time for north SG 1994-2005, and hence values on the abscissa correspond to the summer period ending in the indicative year (Figure 5.1). The summer SST of 2000/01 (22.8ºC) was >1ºC higher than all other SSTs observed between 1994 and 2005.

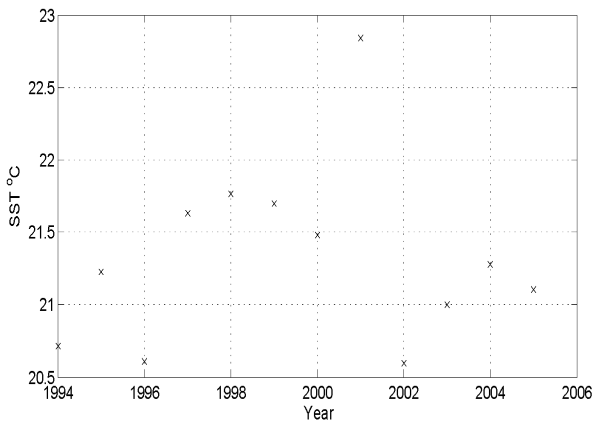

Figure 5.1. February prawn Recruitment Index plotted against SST for 1994-2005.

The weak correlation between recruitment and SST in the same year (Table 5.2) appears to be driven by the outlying data point of 2000/01 (top right of Figure 5.2), where SST was >1 ºC higher than all other years and the recruitment index was substantially higher. Excluding this outlier, there appears to be no correlation between recruitment index and SST.

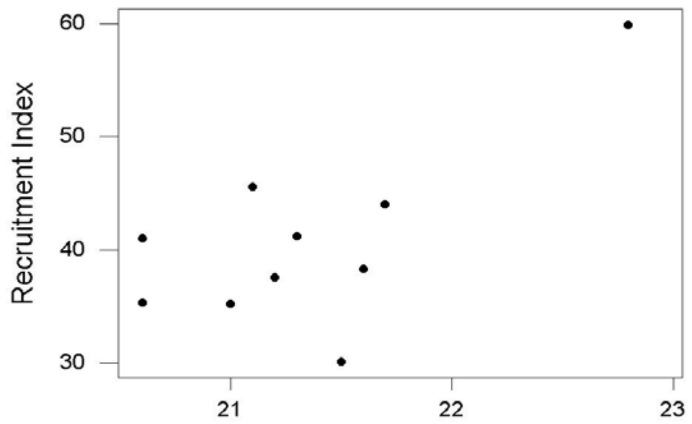

Figure 5.2. Mean sea surface temperature plotted against summer time for 1994-2005.

5.3.2 Wind

During a summer period oceanographically significant wind is typically shown to funnel up into the SG from a predominately southerly direction (Figure 5.3), thus wind speed and not wind direction was applied in the analysis, as wind stress, which is proportional to the square of the wind speed, is the preferred quantity when comparing forcing mechanisms (Figure 5.4).

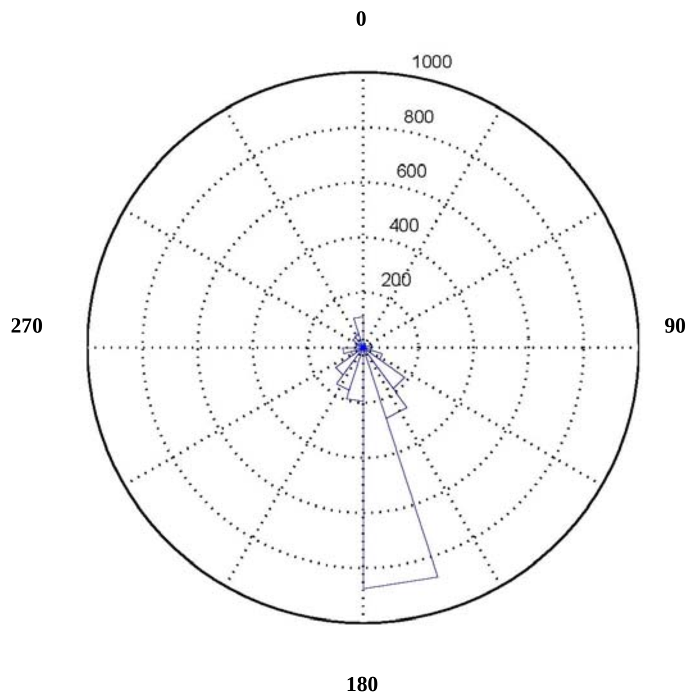

Figure 5.3. Wind rose typical of summer months derived from wind observations at Whyalla (Aero) 1994-2005.

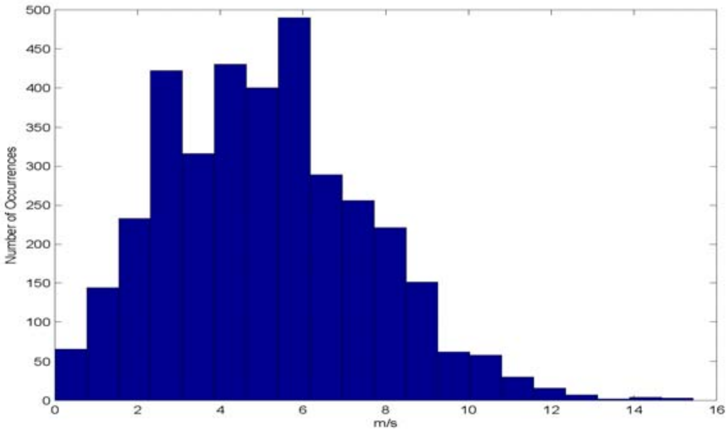

Figure 5.4. Histogram of wind speed for a typical summer derived from wind observations at Whyalla (Aero).

5.3.3 Pre-Christmas Catch

Data on recruitment index were plotted against pre-Christmas harvest two summers prior to investigate the significant correlation between these measures (Table 5.2). With the exception of 2000/01, when SST and the recruitment index were high, recruitment index was strongly and negatively correlated to the level of pre-Christmas harvest two summers prior (Figure 5.5).

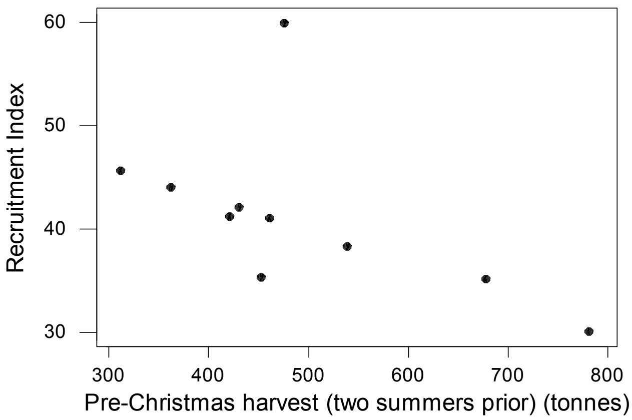

Figure 5.5. Prawn Recruitment Index plotted against pre-Christmas harvest two summers before.

5.4 Discussion

Our analyses found no correlations between wind stress or SST and recruitment to the SGPF. However, this does not suggest that these environmental parameters do not influence recruitment. Rather, the spatial and temporal scales of analyses were most likely inadequate to detect any significant effects. It is important to note that the correlation between February recruitment and the pre-Christmas harvest two summers prior was significantly negative. Indeed, with the exception of 2000/01, the relationship was essentially linear. These results indicate that the extent of spawning biomass is likely a more reliable predictor of recruitment than environmental factors.

The high water temperatures and high recruitment indices observed in the summer of 2000/01 provide stark contrast to both data series that could otherwise be described as of tight range. When considering possible explanations based on the considerable knowledge of the fishery, one hypothesis appears most credible. Generally, it is understood that early spawning events (November) result in recruitment to the fishery the following April and May. Post-larvae from all later spawning events (December-March) are believed to “over-winter” in juvenile habitats and are first observed in the fishery during February surveys (when the recruitment index is determined) the next summer. We propose that the warm summer of 2000/01 resulted in a substantial early spawning event that was observed in the February survey of the same summer, and added to the “normal” recruitment event of over-wintering recruits from the previous year. Considerable evidence supports this finding including: water temperatures; recent evidence to indicate that the larval phase at high water temperatures is short (15 days at 25 ºC); recruitment surveys were held late in February 2001, and; the level of recruitment in February 2001 was approximately twice the mean annual recruitment in all other years (note that the recruitment index is square root transformed).

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6 SOUTHERN ROCK LOBSTER (*JASUS EDWARDSII*)

A Linnane & C James

6.1 Introduction

Southern rock lobster, *Jasus edwardsii* (Hutton 1875) are distributed around southern mainland Australia, Tasmania and New Zealand including the Chatham Islands (Phillips et al. 2006a). In Australia, the main population is found in South Australia where approximately 60% of the total catch is taken annually (Linnane *et al*. 2007). The southern Australian rock lobster fishery is a single species fishery that commenced in 1940-50s The fishery is divided into two geographic zones: a Northern Zone Rock Lobster Fishery (NZRLF) comprising all SA marine waters between the mouth of the Murray River and the Western Australian boarder and a Southern Zone Rock Lobster Fishery (SZRLF) comprising all SA marine waters between the mouth of the Murray River and the Victorian boarder. These zones are further divided into Marine Fishing Areas (MFAs) for statistical and management purposes. The State-wide rock lobster catch is currently ~2,300 tonnes with an economic value exceeeding AUS$100 million per annum (Knight *et al*. 2007).

Jasus edwardsii breeds annually, with hatching in South Australia taking place in spring (September to November) in offshore reefs. The initial naupliosomal phase is short lived with larvae quickly moulting into Stage 1 phyllosomas. Early phyllosoma stages are transported offshore by wind driven surface currents into oceanic habitats (Phillips and Macmillian 1987). Pelagic phyllosomas develop through 11 larval stages before moving shoreward to settle in the coastal zone as benthic puerulus (Booth *et al*. 1991).

Puerulus monitoring has been undertaken in South Australia since the early 1970s (Lewis, 1977) but quantified estimates of settlement did not develop until the 1990s (Prescott *et al.,* 1996). Initially, research was driven by the twin aims of understanding both long-term settlement trends and early life history morphology. The focus of puerulus monitoring was extended in the 1980s with the success in Western Australia of utilising puerulus settlement indices from *Panulirus cygnus* to predict future recruitment to the fishable biomass (Caputi *et al*., 1995; Phillips *et al*., 2000b). An emerging settlement-recruitment relationship also appears evident in *J. edwardsii,* namely in Tasmania (Gardner *et al*., 2001) and New Zealand (Booth and McKenzie, 2009). In both *P. cygnus* and *J. edwardsii*, future commercial catches can be successfully predicted from settlement indices using a 3 – 7 year time lag depending on the fishing region.

Pueruli have poorly developed mouth parts (Nishida *et al*. 1990), and apparently rely almost entirely on stored energy for their migration shoreward, implying a limit to the distance they can migrate (Jeffs et al. 2001). Although, Phillips and Macmillan (1987) have suggested pueruli swim towards sound generated by ocean wave activity in the coastal zone in order to navigate their way shoreward, the overall processes that drive puerulus settlement within inshore grounds on an annual basis, remain poorly understood. Suggested mechanisms include the use of currents, localized eddies and wind (Harris *et al*. 1988; Booth and Stewart 1992; Chiswell and Booth 2008). In SA, it has been suggested that the strength of westerly winds, during late winter and early spring may play a role in the inter-annual variation in recruitment (McGarvey and Matthews 2001). Specifically, both wind and recruitment have been shown shown to exhibit a 10-12 year periodicity, with significant correlations between recruitment and westerly winds lagged by 5-7 years. As a result, puerulus settlement is generally highest during the winter months between June and August (Linnane *et al.* 2007), when westerly winds (eastward wind) are at their strongest.

While some studies have examined the relationship between environmental parameters and puerulus settlement (Bruce *et al.* 2007), little to no published data remains on the effects of wind and sea surface temperature (SST) and settlement. The purpose of this study was to determine the effects of wind speed, wind direction and SST, on settlement patterns of *J. edwardsii* puerulus in the SZRLF of South Australia.

6.2 Methods

Trends in Puerulus Settlement Index (PSI) between 1991 and 2006 in the SZRLF were used to explore correlations with wind data and SST.

Wind stress components (τ_x and τ_y) were calculated from the wind velocity ($\vec{V}$) and the east-west and north-south velocity components (u,v) at 10 m. The settlement period for *J. edwardsii* is ~4 months, therefore 4-month averages of wind stress were correlated with the PSI to investigate possible temporal variations. This process was also used to correlate 4-month averages of SST with the PSI. For each settlement year, the averages are calculated for months immediately preceding September, the last month of the settlement period.

6.2.1 Data Sources

6.2.1.1 Puerulus Settlement Index (PSI)

Data from five puerulus monitoring collector sites, located at Blackfellows Cave, Livigstones Bay, Beachport, Cape Jaffa and Kingston were used to calculate the annual PSI between 1991 and 2006 (Table 6.1). The collectors are similar in design to those described by Booth and Tarring (1986) consisting of angled wooden slats that mimic natural crevice habitat. Monthly inspections involved a diver placing mesh bags around the collectors before they were hauled to the surface for cleaning and collection of pueruli. The PSI is calculated as the mean monthly settlement of puerulus on collectors at these sites.

6.2.1.2 Wind Data

Historic records of daily wind speed (km h^{-1}) were obtained from the Commonwealth Bureau of Meteorology (http://www.bom.gov.au/). These data were collected from the Neptune Island weather station situated 70 km south-south east from Port Lincoln (Figure 2.1) between 1991 and 2006 (Table 6.1). Given that Neptune Island is small and located in relatively exposed waters, this weather station was chosen on the basis that recorded wind data was not as sensitive to land effects, whereas Kingscote weather station, based more closely to the SZRLF, was assumed to have wind data influenced by land effects.

6.2.1.3 Sea Surface Temperature (SST)

Estimates for SST for SA were obtained from a series of satellite images from the US National Oceanographic Data Center (NODC) Satellite Oceanography Group at the National Oceanic and Atmospheric Administration (NOAA) for 1991-2005 period (Table 6.1).

Table 6.1. Identified fishing region with data description and sources.

Name	PSI Data	Wind Data	SST Data	Comments
SZRLF	1991-2006			Linnane et al. 2007
Neptune Island		1991-2006		Bureau of Metrology
Ocean Pathfinder			1991-2005	NOAA

6.3 Results

6.3.1 Puerulus Settlement Index (PSI)

Estimates of the annual index of settlement in terms of numbers of puerulus per collector from five-PSI collector sites in the SZRLF are shown in Figure 6.1. The plot shows that the settlement index is relatively low between 1991 and 2001, except for a peak in 1995. In 2002, the PSI increases to 2.03 puerulus/collector before declining to <1 puerulus/collector in 2003. Indices over three seasons rapidly increase between 2004-2006 with the highest PSI observed at 5.0 puerulus/collector in 2006.

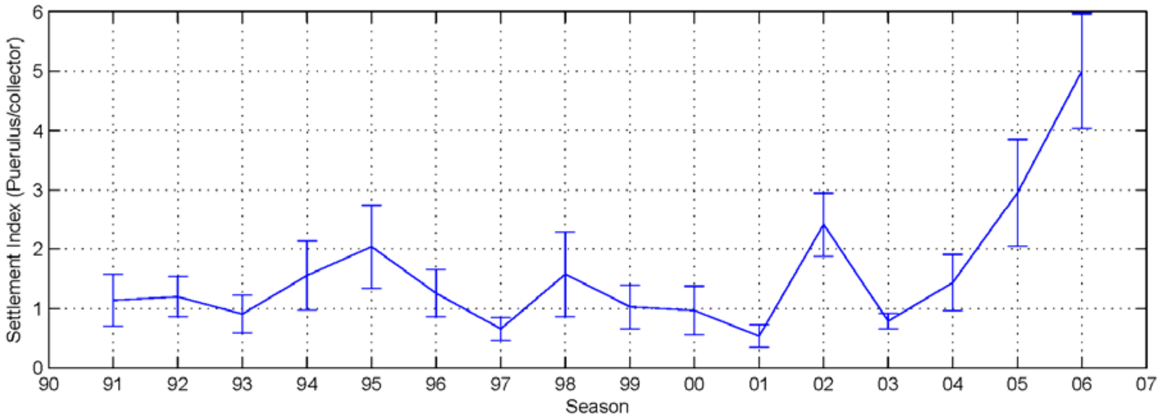

Figure 6.1. PSI between 1991 and 2006 collected from five sites in the SZRLF.

6.3.2 Wind Data

Correlations between N-S and E-W wind stress (i.e. southerly and northerly wind direction and westerly and easterly wind direction) and PSI for different 4 month averaging periods between 1991 and 2006 are shown in Figure 6.2. Significant correlations are observed with the eastward wind stress (τ_x) (i.e. westerly wind) where the Pearson product-moment correlation coefficient, was r = 0.71 (p = 0.002) and r = 0.69 (p = 0.003) for May to August and November to February, respectively (Figure 6.2.A). Northward wind stress (τ_y) (i.e. southerly wind) also shows a significant correlation (r = 0.65, p = 0.005) for the March to June period (Figure 6.2.B). These correlations are further examined and shown in Figure 6.3 and 6.4.

There is an artificially strong correlation between the highest settlement in 2006 and eastward wind stress averaged between May and August (Figure 6.3A). It should be noted that in absence of the 2006 data point, correlations between eastward wind stress and PSI is insignificant r = 0.01 p = 0.002. In the period preceding settlement, Figure 6.3B shows significant correlations (r = 0.69, p = 0.003) that are indicative of strong westward wind stress (easterly wind) averaged between November and February in the period following settlement 1991-2006 are associated with lower settlement while moderate eastward wind stress (westerly wind) is associated with higher settlement. Northerly wind stress (southerly wind) between March and June 1991-2006 was strongly correlated with the settlement index (Figure 6.4).

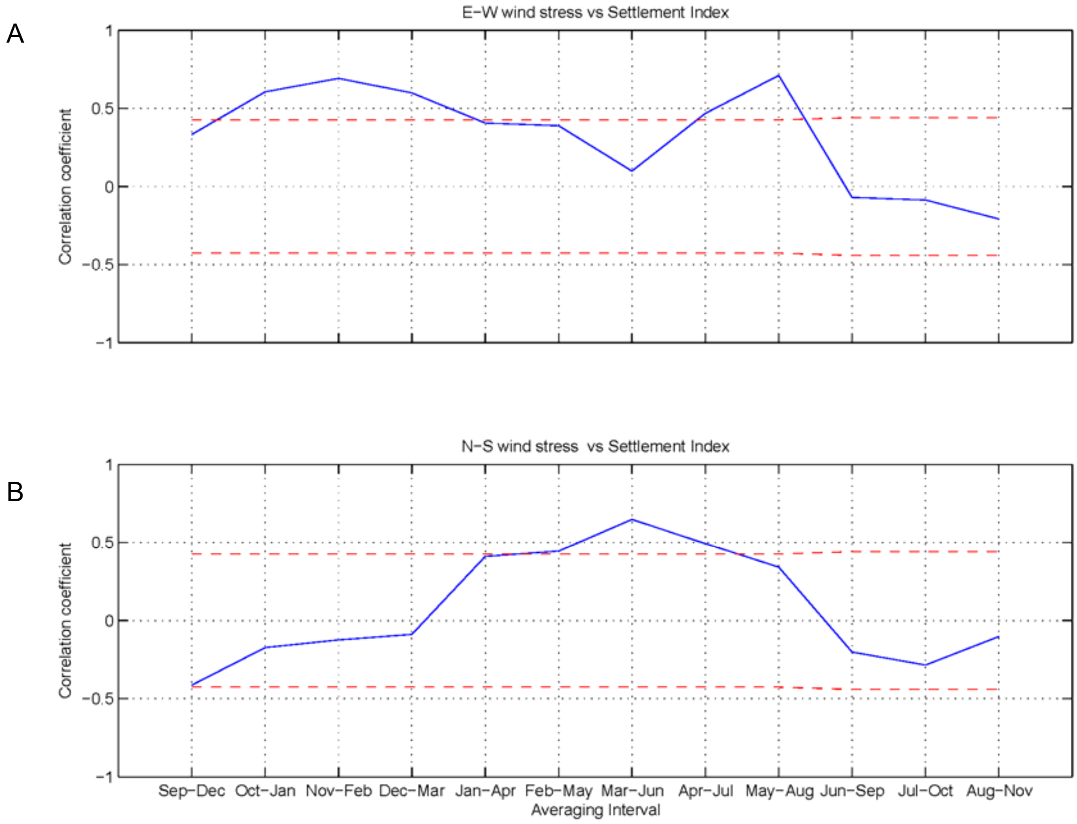

Figure 6.2. Correlation of E-W (A) and N-S (B) wind stress components with puerulus settlement index in the SZRLF 1991-2006. The averaging intervals are shown and the 90% confidence levels for significance are plotted with dashed red lines.

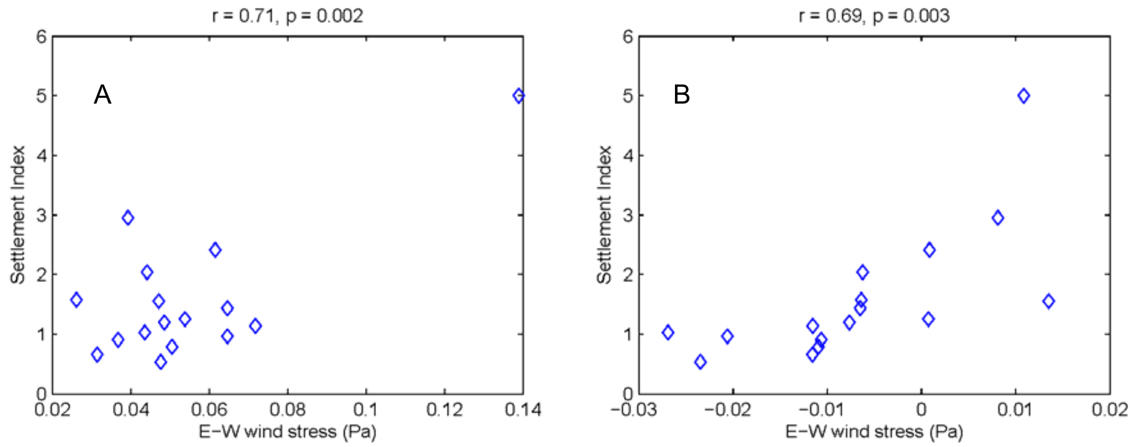

Figure 6.3. E-W wind stress averaged between May and August (A) and November and February (B) Vs PSI

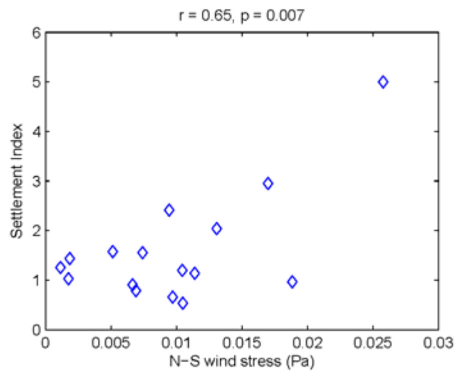

Figure 6.4. N-S wind stress averaged between March and June Vs PSI.

6.3.3 Sea Surface Temperature (SST)

Correlations between SST and PSI for different 4 month averaging periods between 1991 and 2006 are shown in Figure 6.5. A significant negative correlation with SST is observed between the months of November to February (r = -0.65, p = 0.005) suggesting higher temperatures (>18.5ºC) result in lower settlement. However, it should be highlighted that in the absence of the high 2006 settlement, correlations between SST and PSI (Fig. 6.6) are reduced to r = - 0.43, p = 0.1.

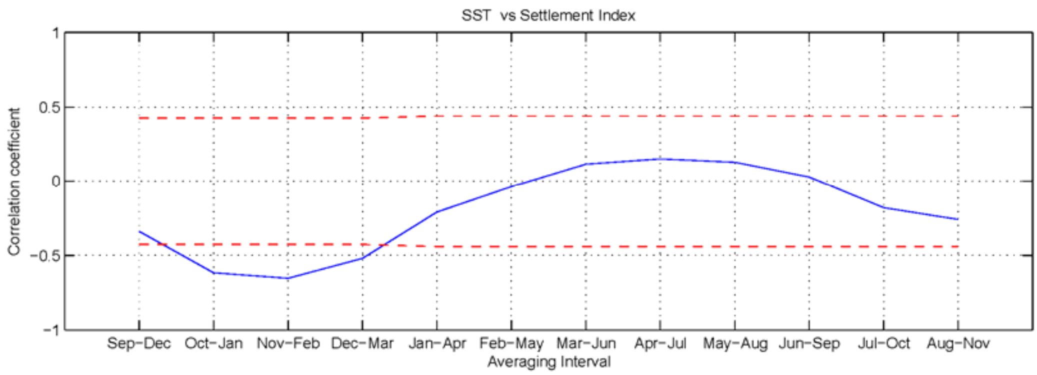

Figure 6.5. Correlation of SST with puerulus settlement index 1991-2006. The averaging intervals are shown and the 90% confidence levels for significance are plotted with dashed red lines.

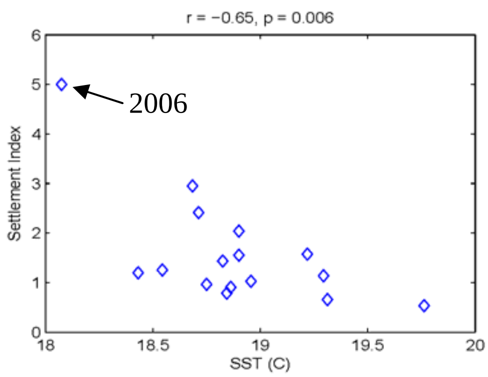

Figure 6.6. Sea surface temperature averaged between November and February Vs PSI between 1991-2006.

6.4 Discussion

Higher PSIs correlated with westerly winds from May to August (autumn-winter) and November to February (spring-later summer) and southerly winds from March to June (late summer-autumn). Higher PSIs also correlated with lower SST (<18.5ºC) during November-February (spring-later summer).

Generally correlations between westerly winds for May to August (autumn-winter) supported previous hypotheses that during winter, the strength of westerly winds (i.e. eastward-directed wind) play a role in the inter-annual variation in puerulus settlement (McGarvey and Matthews 2001). In their study, puerulus settlement was generally highest during the winter months between June and August, when westerly winds are at their strongest. In the current study, the higher PSI observed in 2006 between May and August also correlated with the strongest (0.14 Pa) westerly wind. Interestingly, higher PSI also correlated with westerly wind between November and February and lower (<18.5ºC) SSTs, at a time when South Australia generally experiences easterly winds and higher SST (Bye and Kämpf 2008). In recent years, monthly trends of PSI have tentatively shown a second 'pulse' in January-February (SARDI Aquatic Sciences, unpublished data). Thus, it is possible that the second pulse during this period is associated with periods when SST begins to reduce and wind directions shift from an easterly to westerly direction nearing the end of summer.

Wind driven ocean circulation has been extensively studied in SA (Middleton and Platov 2003; Cirano and Middleton 2004; Bye and Kämpf 2008). Research has shown that during winter, the westerly winds drive an eastward Coastal Current (CC) with average speeds of ~15 cm s^{-1} or ~390 km month. This current is generally confined to the shelf (depths <200 m). Near the coast (depths <10 m), the speed of the CC is reduced to near zero by frictional effects. Superimposed on this average circulation are near-surface Ekman Currents (ECs) that are also wind driven. Notably, the ECs during winter are directed onshore throughout the region and are confined to the surface layer that is typically 50-100 m deep. The average speed of the ECs is 0.5 cm s^{-1} or 13 km month. The highly seasonal winter settlement observed in this study suggests that onshore ECs during this period might have the potential to influence settlement across a large spatial scale. Specifically, inshore puerulus settlement observed in all sites in winter occurs during a period that onshore ECs are strongest (SARDI Aquatic Sciences unpublished data).

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7 WESTERN AUSTRALIAN SALMON (*ARRIPIS TRUTTACEUS*)

J Middleton

7.1 Introduction

The Western Australian salmon *Arripis truttaceus* (Cuvier, 1829) is an important commercial and recreational fishery in Western Australia (WA) and South Australia (SA), and to a lesser extent in Victoria (Figure 7.1). It is a piscivorous, schooling species that inhabits exposed surf beaches and surge zones around rocky reefs as adults, and shallow bays and estuaries as juveniles. It spawns off Australia's south west coast during March and April and while some larvae settle in this area, most advect eastward with the Leeuwin Current (LC) and settle approximately 3-6 months later in the protected coastal waters of SA. The LC is a warm ocean current that flows southward at an average speed of ~0.5 m s^{-1} (2 knot) around Cape Leeuwin on the western coast of Australia to enter the waters south of Australia where its influence extends as far as Tasmania (Caputi et al. 1996) (Figure 7.2). Salmon spawning appears to be related to the timing of flow of the LC (Jones 2008). Juveniles spend ~6-12 months in the inshore nurseries before swimming to more exposed coasts where they aggregate in large schools seaward of the surf zone. After several years (3-6 years) the fish migrate back to the western Australian spawning region in November-January.

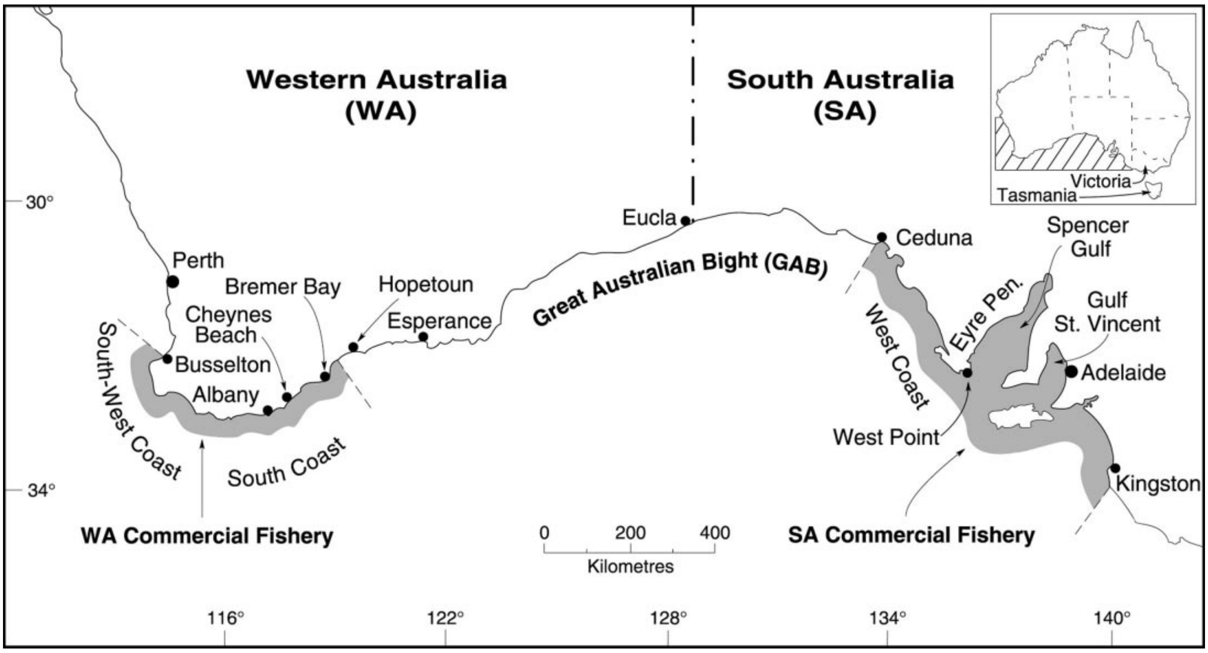

Figure 7.1. Areas of operation of the commercial fishery for western salmon in South Australia (SA) and Western Australia (WA) (Cappo et al. 2000).

The fluctuations in the strength of the LC have a major influence on annual variation in catch of many commercial fisheries occurring off WA and SA (Caputi et al. 1996) including WA salmon (Lenanton et al. 1991; Li and Clarke 2004). Caputi et al. (1996) reported that the strength of the LC has a significant positive influence during the 9 to 11 month larval life of the western rock lobster *(Panulirus cygnus),* as reflected by the level of puerulus settlement. The current strength, however, has a negative influence during the larval life of the scallop *(Amusium balloti)* in Shark Bay, WA. Similarly, current strength has had a negative effect on larval survival of pilchards *(Sardinops saga neopilchardus)* but a positive impact for whitebait *(Hyperlophus vittatus)*. Recently, the relative abundance of 0+ age class of Australian salmon in Barker Inlet, Gulf St Vincent (GSV) were used to successfully correlate recruitment strength with the inter annual variation in sea level heights adjacent to the salmon spawning areas. The average sea level heights over the period that salmon move from WA to SA waters was identified as a 'proxy' for the strength of the LC, the direct transport mechanism responsible for transporting salmon larvae to SA (Lenanton et al. 1991; Li and Clarke 2004). The correlation between sea level height along the southern Australian coast and atmospheric climate variation i.e. El Niño-Southern Oscillation (ENSO) events (Lenanton et al. 1991) supported the hypothesis that recruitment variation of salmon into SA is influenced by such events (Lenanton et al. 1991; Li and Clarke 2004). Lenanton et al. (1991) also identified a possible negative impact of the LC on salmon catchability in the commercial fishery off WA, though its effect on recruitment could not be assessed.

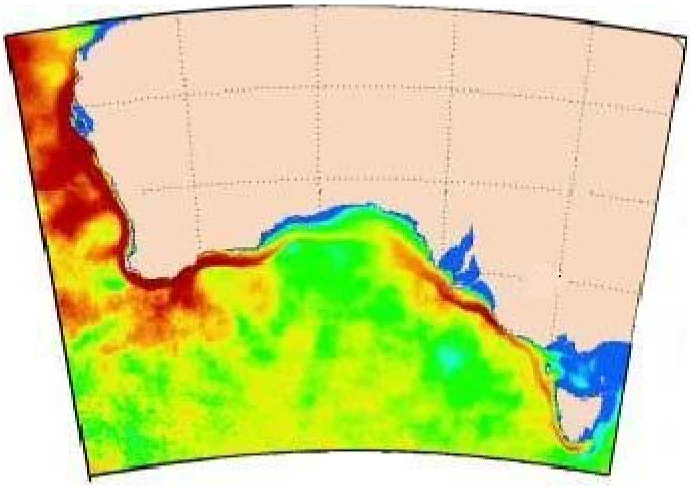

Figure 7.2. The Leeuwin current is a warm ocean current that flows southward around the western coast of Australia to enter the waters south of Australia where its influence extends as far as Tasmania (Ridgway and Condie 2004).

Understanding the influence of annual changes in environmental conditions on catches is important since it might help to interpret whether fluctuations in catches are due to the environment or the impact of fishing on the spawning stock. The purpose of this study was to determine the effects of ENSO events on the strength of the LC, and investigate its influence on Australian salmon recuitment in SA (Lenanton et al. 1991; Li and Clarke 2004).

7.2 Methods

To test the hypothesis that salmon abundance in SA waters is influenced by El Niño events, the correlation coefficient between the annually averaged NINO 3.4 index and the Pre-Recruitment Index (PRI) (no. of fish/100 m^2 averaged over the period of high abundance) were compared against a time series between ENSO events effecting Australia 1979-2002 and PRI 1981 and 1999.

7.2.1 Data Sources

7.2.1.1 Salmon Pre-Recruitment Index (PRI)

At five sites in Barker Inlet, GSV, fine mesh beach seine surveys between 1981 and 1999 were annually monitored each month to identify young-of-year salmon inhabiting these areas in order to produce an annual averaged PRI . Typically, the largest monthly PRIs were found for the month of September, some 3-6 months after spawning off W.A. Due to logistical and resource issues however there were no data available for 1983 (K. Jones, PIRSA Fisheries, pers. comm., Sep 2008).

7.2.1.2 El Niño-Southern Oscillation (ENSO)

Historic records of ENSO events between 1979-2002 were obtained from the KAPLAN EXTENDED v2 from the IRI/LDEO Climate Data Library (see Kaplan et al. 1998). El Niño-Southern Oscillation (ENSO), commonly referred to as El Niño, is a global coupled ocean-atmosphere phenomenon that causes global climate variability on inter-annual timescales (Trenberth 1996, 1997). There are several regions of the tropical Pacific Ocean that have been highlighted as being important for monitoring and identifying El Niño and La Niña, referred to, as NINO 1-4 index. Of these regions, NINO 3.4 index (5ºS-5ºN; 170ºW-120ºW), which encompasses part of both NINO 3 and 4 (Figure 2.4), is characterised by large variability on El Niño time scales, and one of the most relevant to ENSO events effecting Australia. As the NINO 3.4 index is based on ocean temperatures rather than atmospheric pressures, it is generally considered to be better suited for oceanographic purposes and therefore selected for the purpose of this study. Using the NINO 3.4 index, an El Niño or La Niña event is identified if the 5-month running-average of the NINO 3.4 index is >0.4ºC or -0.4ºC, respectively for at least 6-consecutive months.

7.3 Results

7.3.1 Salmon Pre-Recruitment Index (PRI)

Estimates of the annual index of pre-recruitment between 1981 and 1999 are shown in Figure 7.3A and plotted for the September month when the monthly PRI is typically largest. The plot shows that the PRI drops to near zero in 1982, between 1986 and 1987, and in 1993 respectively. In 1984, the highest PRI is observed at ~1.8, and in 1981, 1990 and 1999 the PRI is >1.1. No data are available from 1983.

7.3.2 El Niño-Southern Oscillation (ENSO) – PRI Correlation

El Niño or La Niña events have been identified where the 5-month, running-average of the NINO 3.4 index is >0.4ºC or -0.4ºC, respectively for at least 6-consecutive months between 1979 and 2002 (Figure 7.3B). During this period, four significant El Niño events occurred in 1982-1983, mid 1986-1988, 1991-1995 and 1997-1998 respectively. During this same period, four La Niña events occurred in 1984/85, 1988-1989, 1996 and mid-1998-2001 respectively.

These El Niño and La Niña events are further shown against PRI in Figure 7.3A and generally reveal that PRI drop to near zero during the El Niño events of 1982, mid 1986-1988, 1991-1995. During the 1997-1998 El Niño event, PRI did not drop to near zero but declined from ~0.8 to 0.5. A weak correlation between PRI and NINO 3.4 index (Pearson product-moment correlation coefficient -0.36 (p = 0.1), Figure 7.4). The general trend in Figure 7.4 suggests that La Niña events (shaded blue in Figure 7.3A) correlate with greater PRI values, as seen in 1984/85, 1988-1989, 1996 and mid-1998-2001 (Figure 7.3A).

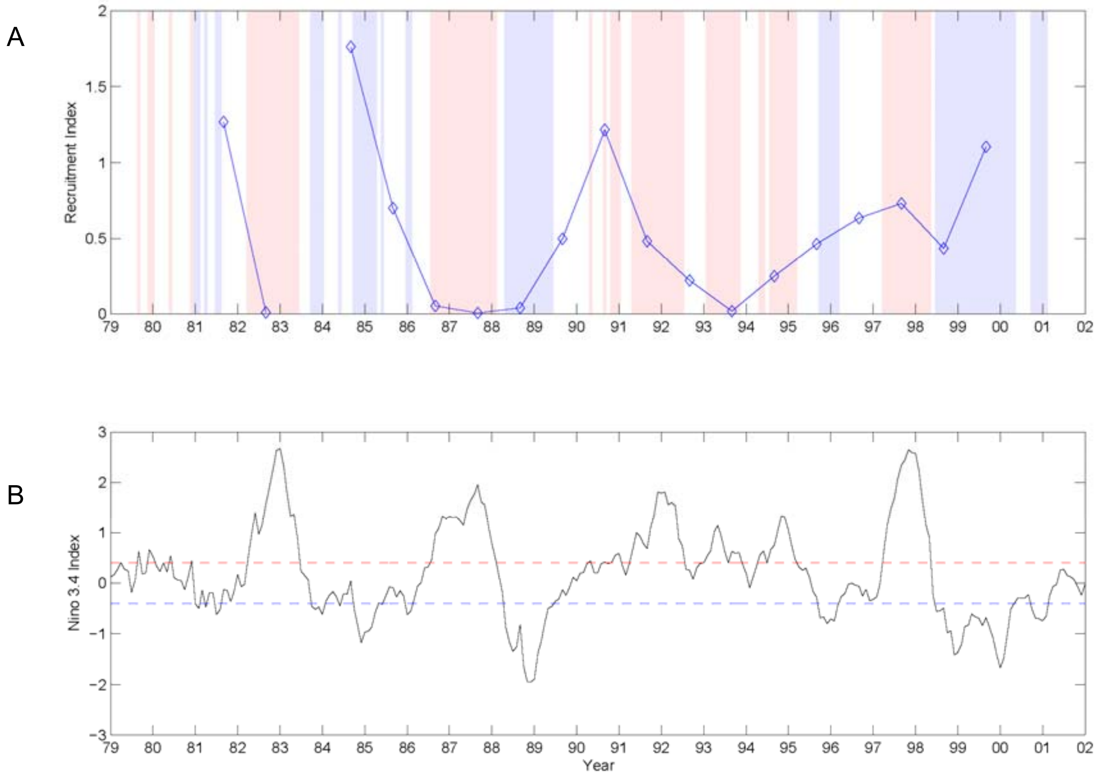

Figure 7.3. Australian salmon (annual) Pre-Recruitment Index with ENSO events shaded red for El Niño and blue for La Niña (A) and El Niño and La Niña events as indicated by the red and blue dashed line, respectively, derived from the NINO 3.4 index (B).

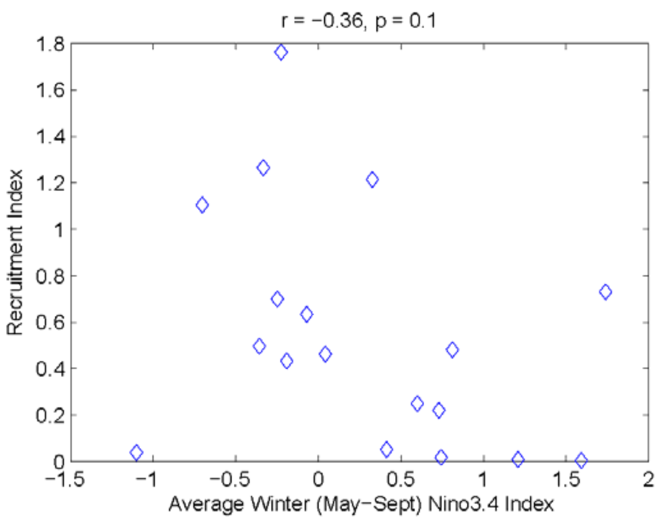

Figure 7.4. Plot of Australian salmon Pre-Recruitment Index in GSV vs. NINO 3.4 index

7.4 Discussion

In this study, the El Niño events appear to reduce PRI for Australian salmon in SA. In contrast, La Niña events have shown to increase PRI for Australian salmon. This evidence provides further support that atmospheric climate variation i.e. ENSO events, influence recruitment variation of Australian salmon (Lenanton et al. 1991; Li and Clarke 2004).

Li and Clarke (2004) found that the anomalous flow of the LC affects the March-September eastward transport of Australian salmon larvae from Western Australia, resulting in higher localised larval retention. This anomaly is emphasised during El Niño events, when westerly equatorial winds push equatorial water eastward, lowering sea level in the western equatorial Pacific Ocean. Due to gaps in the western equatorial Pacific boundary, sea level is lowered around the west coasts of New Guinea and western and southern Australia, thus weakening the flow of the LC and reducing its potential to transport salmon larvae to South Australian waters. During La Niña, when the equatorial winds are anomalously easterly and the sea levels are generally higher in the western equatorial Pacific and the western and southern coasts of Australia, the LC appears more efficient and has greater capacity to transport salmon larvae as indicated by increases in the PRI. The LC is the dominant feature of the oceanography off WA and SA. Thus, it is not surprising that variations in its strength and path influence the recruitment of species within these waters (Caputi et al. 1996). Such physical and biological influence therefore raises questions about the amplitude and frequency of ENSO events and the future of successful Australian salmon recruitment.

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8 SNAPPER (*CHRYSOPHRYS AURATUS*)

C James, AJ Fowler & R McGarvey

8.1 Introduction

Snapper, *Chrysophrys auratus* (Bloch & Schneider, 1801) is a significant fishery species of the family Sparidae. It is distributed broadly throughout the Indo-Pacific region including the warm temperate waters of Australia, New Zealand, Philippines, Indonesia, China, Taiwan and Japan (Paulin 1990, Kailola et al. 1993). Snapper are relatively long-lived, reaching in excess of 40 years of age in Australia (Norriss pers. comm.), and up to 60 years in New Zealand (Francis et al. 1992). They can reach 1.3 m in length and 16 kg in weight (Fowler and Jennings 2003).

In South Australia, snapper are distributed throughout all coastal waters, including Spencer Gulf and Gulf St. Vincent (Fig. 2.1). It is one of the three primary species managed as part of the multi-species Marine Scalefish fishery. In 2007/08, snapper contributed the highest single species biomass to the Marine Scalefish fishery, i.e. 742 t that was worth $5.1 million (Knight et al. 2008). Over the past two decades, however, commercial catches of this species have demonstrated substantial inter-annual variation (Fowler et al. 2007). The catch in 2007/08 was the highest recorded since 1983/84, whilst the lowest was recorded in 1994/95 (223 t). It has also become evident through biological studies on snapper in SA that the population size and age structures show considerable variation (Fowler et al. 2007). This indicates that year class strength is highly variable, whilst only one or a few year classes can dominate catches and sustain the fishery for a number of years. This variability in year class strength appears to be directly related to variation in recruitment of the 0+ age class to the population (Fowler and Jennings 2003). As such, temporal dynamics in recruitment appears to drive the population dynamics and fishery productivity. Consequently, it would be highly beneficial to have some understanding of why 0+ recruitment is so variable and the environmental factors that influence recruitment (Fowler and Jennings 2003).

Since 2000, SARDI has undertaken a study into the dynamics of recruitment of snapper in Northern Spencer Gulf (NSG) (Fowler et al. 2007). This region was chosen for the recruitment study as, until recently, it always produced the highest fishery catches and was also the region in which the only known mass recruitment event had taken place, i.e. in 1991 (Fowler and Jennings 2003). To date, this study in NSG has documented a 250 times variation in recruitment of 0+ fish between years (Fowler unpublished data). It has also identified the high likelihood that water temperature influences the survivorship of eggs and larvae and ultimately the recruitment of the 0+ fish. In particular, the water temperature range of 22 - 24°C appears to be conducive to successful recruitment from spawning activity (Saunders 2009). As such, inter-annual variation in recruitment of 0+ snapper may ultimately depend on windows of opportunity through the spawning season when the environmental conditions are conducive to egg and larval survivorship.

The general aim of this study was to determine the influence of environmental conditions, particularly water temperature, on recruitment success. The hypothesis that the water temperature range of 22 – 24°C through the spawning season influences recruitment was tested by comparing, amongst years, the relationship between the number of days in this prescribed range and the annual recruitment index. Furthermore, it is apparent from population age structures of snapper that in NSG four year classes have been particularly significant, i.e. 1969, 1979, 1991 and 1997. A time series of environmental conditions was developed that included water temperature and El Niño – Southern Oscillation (ENSO) events, to qualitatively consider the environmental conditions that gave rise to good and poor recruitment classes.

8.2 Methods

Quantitative estimates of recruitment were available to this study as output from the computerised stock assessment model SnapEst (McGarvey and Feenstra 2004). This model uses a maximum likelihood approach that integrates several data sources, which include commercial catch and effort data as well as age and length samples from fishery catches that are fitted by length and age-based population dynamics for annual cohorts (McGarvey and Feenstra 2004). Annual recruitment to NSG was quantified by the estimated number of snapper from each spawning season that survived to 2-years of age. Such estimates were available to this study for the time period of 1983 to 2003.

Estimates of sea surface temperature (SST) for NSG for the period of January 1985 to December 2005 were obtained from the Ocean Pathfinder satellite data from the US National Oceanographic Data Centre, at the National Oceanic and Atmospheric Administration (NOAA). A more extensive time series of SST data was developed based on air temperature records that were measured at the Bureau of Meteorology weather station located at Whyalla (Norrie) and the satellite SST data. The relationship between SST and air temperature was determined using simple linear estimation with the estimated SST lagged by an appropriate amount. The air temperature data were available for the period of January 1960 to July 2001. As such, for SST, there were direct estimates available for the period from 1985 to 2005 from Ocean Pathfinder, whilst estimated SST derived from air temperature measurements were available from 1960 to 2007.

To consider the possible influence of ENSO events in this study, the NINO 3.4 index was used. Here, El Niño and La Niña events were recognised if the 5-month running average of the NINO 3.4 index was >0.4°C or <-0.4°respectively, for at least six consecutive months. Historic records of ENSO events were obtained from the KAPLAN EXTENDED SST v2 from the IRI/LDEO Climate Data library (Kaplan et al. 1998).

Spawning by snapper occurs in NSG between November and January (Saunders 2009). Furthermore, the success of recruitment from this spawning seems highest when water temperature is in the range of 22 - 24°C (Fowler and Jennings 2003, Saunders 2009). To assess whether this influenced inter-annual rates of recruitment, the Ocean Pathfinder SST data were used to calculate the number of days whose average temperature was between 22 and 24ºC through the period of November 15 and February 15, i.e. the period of the spawning season that encompasses egg and larval development of successful recruits. Start and end dates were calculated by interpolating between temperatures and dates before and after the onset of the warm period. Furthermore, from the time series of estimated SST that extended back to 1960, the numbers of days in the prescribed temperature range in all years, were also calculated.

8.3 Results

7.3.1 Recruitment estimates from SnapEst

The computer fishery model provided annual estimates of recruitment for three regions, i.e. NSG, Southern Spencer Gulf (SSG) and Gulf St. Vincent (GSV). Whilst in this study we are primarily interested in the recruitment estimates for NSG, the comparison with temporal data from the other regions is also informative. For NSG, recruitment was estimated to be relatively poor through the 1980s, but then attained its highest level in 1991 (Figure 8.1). It then remained relatively low for the period of 1992 to 1996, after which there was a series of years during which recruitment was highly variable, with significant estimates for 1997, 1999 and 2001. These latter year classes contributed 73, 74 and 45% of the recruitment level of 1991, respectively.

The temporal patterns of recruitment to both SSG and GSV were similar to that of NSG, although the relative significance of the year classes subsequent to 1991 were comparatively less than in the former region. Nevertheless, the similarity in the temporal patterns suggests that the influences on recruitment operate at a broad geographic scale.

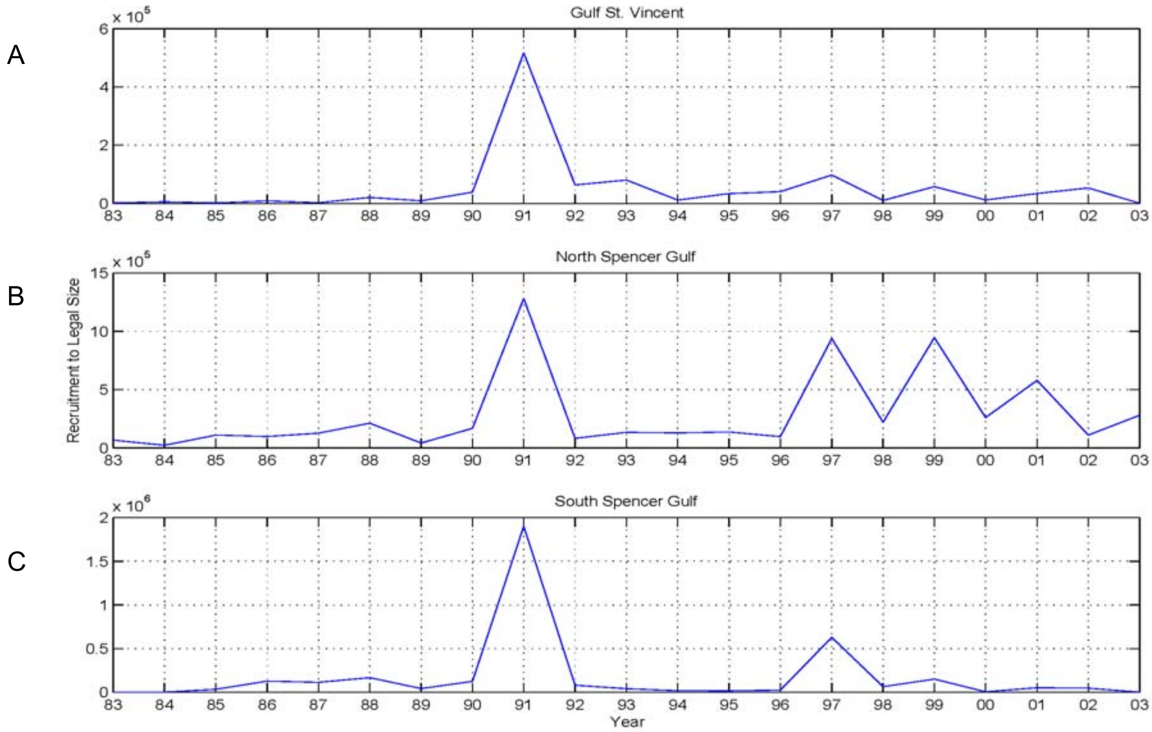

Figure 8.1. Yearly recruitment estimates for the South Australian snapper stocks in GSV (A), NSG (B) and SSG (C). The model defines recruitment of a year class as the number of snapper spawned in any given summer spawning season (e.g. 1991) that reach fishable size at age 3 years.

7.3.2 Comparison between recruitment and SST

The Ocean Pathfinder satellite data from 1985 to 2005 demonstrate significant seasonality where the maximum average temperature in summer was generally in the range of 22 to 24ºC (Figure 8.2). Between 1986 and 2004 the number of days from Nov 15th to Feb 15th whose average temperature was in the range of 22 - 24 °C was highly variable (Figure 8.3). Whilst the average across years was 26 days, in some years such as 1986-89, 1992-94, 1996 and 2000-03, the numbers of days were relatively low. In other years, such as 1991, 1997, 1998, 1999 and 2004 the numbers of days in the prescribed temperature range were relatively high. In fact, for NSG there was a highly significant correlation ($n = 18$, $r = 0.66$, $p = 0.003$) between the recruitment time-series and the number of days in the prescribed temperature range (Figure 8.4). Three of the high recruitment years, i.e. 1991, 1997 and 1999 were in the group with the highest number of favourable days.

The time series of estimates of SST from measured air temperature overlapped with the Ocean Pathfinder data from 1985 to 2001. For this period, they appear to correspond well with respect to those years that provided the highest or lowest temperatures. The estimated SSTs extended from 1960 to 2001. Through this period the number of days for which the average temperature was in the range of 22 to 24ºC averaged 31 days per year, but ranged from zero to 48 days (Figure 8.3). The high recruitment years of 1969, 1979, 1991 and 1997 always related to years when there were at least 30 days in the prescribed temperature range. However, there were other years that also had this number of days in the prescribed range, but were not noted for having received significant recruitment.

The NINO 3.4 index was determined for the period from 1960 to 2005, to identify when El Niño and La Niña events were apparent. Throughout this period there were nine significant El Niño events and seven La Niña events (Figure 8.3). There was no clear relationship between the number of days in the range of 22 - 24°C and either El Niño or La Niña events. However, three out of four high recruitment years, i.e. 1969, 1991 and 1997 were associated with El Niños whilst the fourth, i.e. 1979 did not conform to either an El Niño or La Niña event. Contrary to this however, the higher recruitment years in NSG of 1999 and 2001, each corresponded to La Niña events.

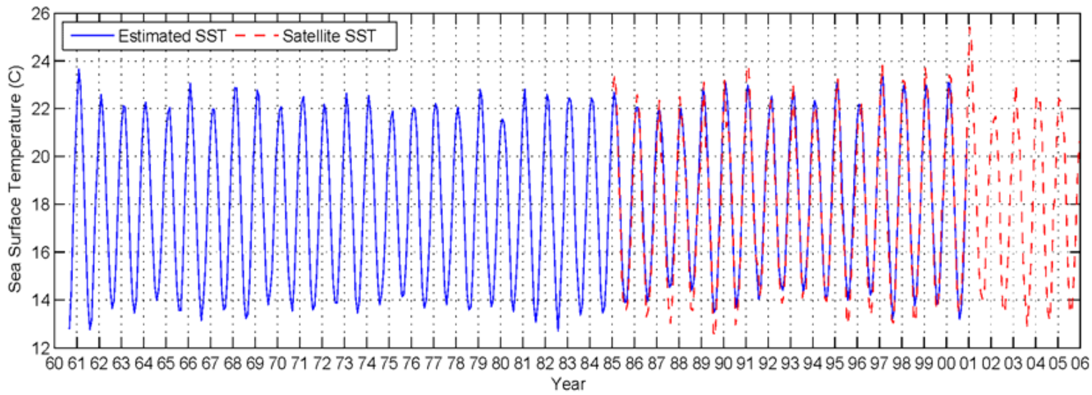

Figure 8.2. Satellite SST data from the Ocean Pathfinder *4* and *5* satellite for 1985 to 2005 (red dashed line). Also, the estimated SST data derived from the air temperatures measured at Whyalla are shown for the period of 1960-2001 (blue line).

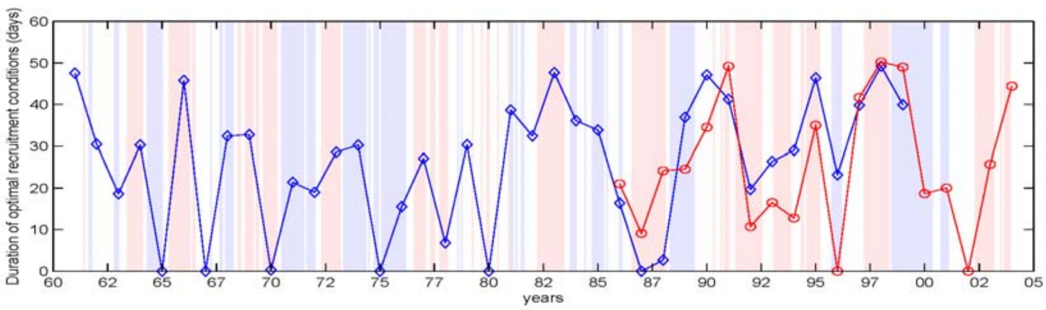

Figure 8.3. The estimated number of days per season for which SST fell in the range of 22-24ºC. Ocean Pathfinder data (red line), and estimated SSTs from air temperature measurements (blue line). ENSO events are also shown derived using the NINO 3.4 index (shaded red for El Niño and blue for La Niña).

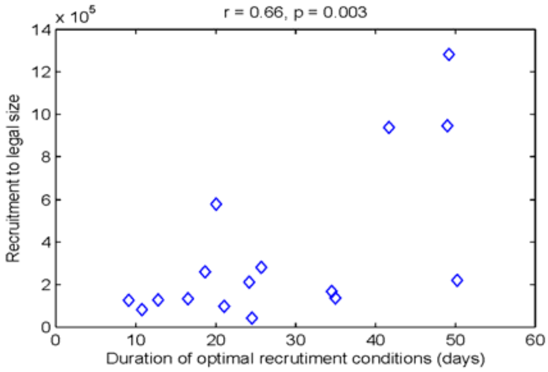

Figure 8.4. Results from correlation analysis between snapper recruitment in NSG and duration of optimal SST days between 15 November and 15 February in each year from 1986 to 2004.

8.4 Discussion

It has been apparent for a number of years that year class strength of snapper in SA is highly variable, which is thought to relate to the recruitment of the 0+ fish (Fowler et al. 2007). Furthermore, it is considered that inter-annual variation in the survivorship of the eggs and larvae is responsible for this variability in recruitment (Fowler and Jennings 2003). The question, therefore, is why do egg and larval survivorship vary so much from year to year? Previous studies, here and elsewhere, have implicated an influence of SST on variable recruitment (Francis 1993, Francis et al. 1997). Furthermore, Fowler and Jennings (2003), suggested that there are 'windows of opportunity' throughout the spawning season when the environmental conditions are conducive for egg and larval survivorship which lead to successful recruitment. However, throughout the same seasons there are also periods when conditions are poor which result in zero or low recruitment. A recent study identified that the 0+ fish that were captured in NSG at the end of several recruitment seasons were spawned and underwent their pre-settlement duration when the SSTs were in the range of 22 to 24ºC, whilst recruitment was lower either below or above this temperature range (Saunders 2009). As such, this study supported the hypothesis that the number of days of the recruitment season whose average temperature fell in the range of 22 to 24ºC varied from year to year, and this ultimately affected the recruitment rate.

The most compelling result from this study was the significant correlation through the period of 1986 to 2004 between the annual recruitment index and the number of days through summer that fell in the prescribed temperature range. This result supports the 'windows of opportunity' hypothesis that the important environmental/spawning conditions are related to SST. Presumably this influence relates to the particular physiological tolerance limits of the snapper eggs and larvae in this region. In a more general sense, this result is consistent with the influence that physical environmental conditions have on local biological processes, which can ultimately drive the population dynamics at a regional scale.

Unfortunately consideration of the longer time series of SST back to 1960 did not provide such a clear-cut result. Whilst for the high recruitment years there were at least a minimum number of days that fell within the prescribed temperature range, nevertheless not all years with high numbers of such days produced significant recruitment. This indicates that recruitment can still be relatively poor even when water temperature conditions appear to be favourable, and also that strong recruitment does not occur when conditions are not favourable. This implies that the number of optimal days is a necessary but not sufficient condition for strong recruitment. It indicates that there are other environmental factors besides SST that influence recruitment or that the resolution of our understanding of how SST operates on the eggs and larvae still needs considerable refinement. There was no clear consistent ENSO effect that was apparent on snapper recruitment.

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9 GENERAL DISCUSSION

J Middleton

9.1 Context of the Study

The planned output of this project was to determine the effect of environmental variability on the recruitment success of southern calamary, King George whiting, western king prawn, southern rock lobster, western Australian salmon and snapper in South Australia (SA), by characterising the relationships between recruitment indices and relevant environmental variables. Environmental parameters that may be useful indicators of recruitment success were identified for five of the six species, as no significant correlations were found for the western king prawn (Table 9.1). The results suggest that hydrodynamic processes may have important effects on the advection of larvae from spawning grounds to nursery grounds for southern rock lobster, KGW and Western Australian salmon, whereas the effects of water temperature on growth and mortality rates of larvae may be more important determinants of the recruitment success of snapper and southern calamary. For western king prawn, the level of pre-Christmas harvest, which is likely to affect the level of effective egg production, appears to be a more important determinant of future recruitment success than the environmental variables that we considered.

Table 9.1. Species with examined environment-recruitment relationship and result (+ implies a significant correlation).

Species	Environmental Variable	Result	Comments
southern calamary	Wind SST	- +	Aggregative behaviour might have been confounded with fishing activity while SST is critical for survival of juveniles
King George whiting	Wind	+	Important for larval advection
western king prawn	Wind SST	- -	Important mechanisms for larval advection and survival.
southern rock lobster	Wind SST	+ +	Significant mechanisms for larval advection and survival
West Australian salmon	ENSO	+	Important for larval advection
snapper	SST ENSO	+ +	Important for juvenile survival relating to critical window of temperature

These findings may provide useful insights into the possible climate-related changes in stock status that may occur over mid- to long-term (decades) forecasts. Predictions based on simple empirical correlations are not satisfactory, as many have failed the test of time (Myers 1998), which is perhaps not surprising given the complex dynamics and the multiple interactions of fish populations. This suggests there is need to identify not only empirical correlations between large-scale environmental indices and fish abundance indices, but also the mechanisms that link environmental variability to the biological changes, including habitat, predation and competition in the oceanic ecosystems and fish populations. For example, since the discovery of the non-native, marine macroalga *Caulerpa taxifolia* in SA, key nursery areas for a number of marine scalefish species including King George whiting in the Barker Inlet, Gulf St Vincent have become heavily infested with *C. taxifolia,* partly due to optimal environmental conditions, which might in turn play a role in the observed inter-annual fluctuations of recruitment. In addition, with factors such as fishing, which were not accounted for in this study, it has become increasingly difficult to separate the relative importance of fishing versus environment as the cause of recruitment variability. While the few examples provided above indicate the influence of environmental variability on fish stocks, taking the step to predict the response of local fisheries to possible future climate change scenarios remains highly speculative. For example, there is no consensus on how ENSO events will change in a warmer climate (Soloman et al. 2007) but these events are likely to continue to be a significant source of periodic variability in SST and ocean currents (e.g. Leeuwin Current), thus potentially causing a shift in the timing of spawning and changes in larval advection. Continuing research, on the other hand, might gradually improve knowledge and understanding to detect environmental variability impacts on fisheries recruitment.

9.2 Uncertainty in Data Sources

One of the main limitations of this study was the quality of the biological datasets. Abundance and recruitment data were mainly obtained from commercial fisheries (e.g. catch, CPUE) and fishery-independent surveys conducted using commercial methods (e.g. prawn trawls and beach seines). Both of these data sources have limitations and biases, including the validity of fisheries data and the coverage and resolution of survey data. The length of the data sets (i.e. number of years covered) also affected our ability to detect environment-recruitment relationships. The average length of recruitment data was 17 years, but the western King prawn data only spanned 11 years. There were also gaps in some datasets, e.g. for western Australian salmon in 1982-1984 and western king prawn in 1998, that may have reduced our capacity to identify significant environment-recruitment correlations. There were also limitations with the meteorological data provided by the Commonwealth Bureau of Meteorology. For example, the quality of data for the period between 1960 and 1998 is thought to have greater uncertainty than data collected more recently, due to limitations in the number and purpose of weather stations. Linking the biological and physical datasets was also problematic because data were often collected at different spatial and temporal scales.

9.3 Future Work

Refinement of existing hypotheses might enable the involvement of other environmental factors, such as rainfall to be identified. In this study the proposed physical mechanisms only explained part of the natural variation in recruitment, therefore other mechanisms are likely to be significant. A more rigorous multivariate analysis would improve current knowledge and understanding of physical interactions and recruitment variability. However, this would undoubtedly require a more timely and complex analysis. For example, it was found that post-larval advection by local currents was important to southern rock lobster, western Australian salmon and King George whiting. Within the waters of Gulf St Vincent and Spencer Gulf these currents are weaker than the dominant tidal currents. Therefore, an accurate numerical simulation of the residual velocity field might be an important next step in identifying the advection pathways from spawning to settlement or nursery areas.

Additionally, while our studies illustrate there are environment-recruitment relationships, consideration should be given as to what extent these environment-recruitment relationships need to be revised as new data and analytical techniques become available. Adding additional data in the time-series will ensure that current environment-recruitment relationships are more robust (Myers 1998).

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10 APPENDIX

10.1 Benefits and beneficiaries

The main beneficiaries of this research will be fishery managers and commercial fishers as they will have a greater understanding of the environmental effect on fishable biomass.

10.2 Planned outcomes

Relationships derived between environmental variables and recruitment variability will mean that fishery productivity can be forecasted in advance, thus warning fishery managers about the likelihood that the fishable biomass will either decrease or increase. This may under-pin a real-time fishery management process.

10.3 Further development

This project was a preliminary study to retrospectively identify the relationship of SST, wind strength and wind direction with patterns of recruitment using univariate analyses. Future research should take a multivariate approach and explore the additional effects of other environmental parameters such as salinity, primary productivity and nutrient loads on the recruitment variability of key commercial species.

10.4 Intellectual Property

There are no Intellectual Property issues associated with this project.

10.5 Staff involved

Dr John Middleton	(SARDI)	Principal Investigator
Dr Sam McClatchie	(NOAA)	Research Scientist
Dr Charles James	(SARDI)	Research Scientist
Mr Cameron Dixon	(SARDI)	Research Scientist
Dr Anthony Fowler	(SARDI)	Research Scientist
Dr Adrian Linnane	(SARDI)	Research Scientist
Dr John Luick	(SARDI)	Research Scientist
Dr Richard McGarvey	(SARDI)	Research Scientist
Dr Mike Steer	(SARDI)	Research Scientist
Ms Lee-Ying Wu	(SARDI)	Research Scientist