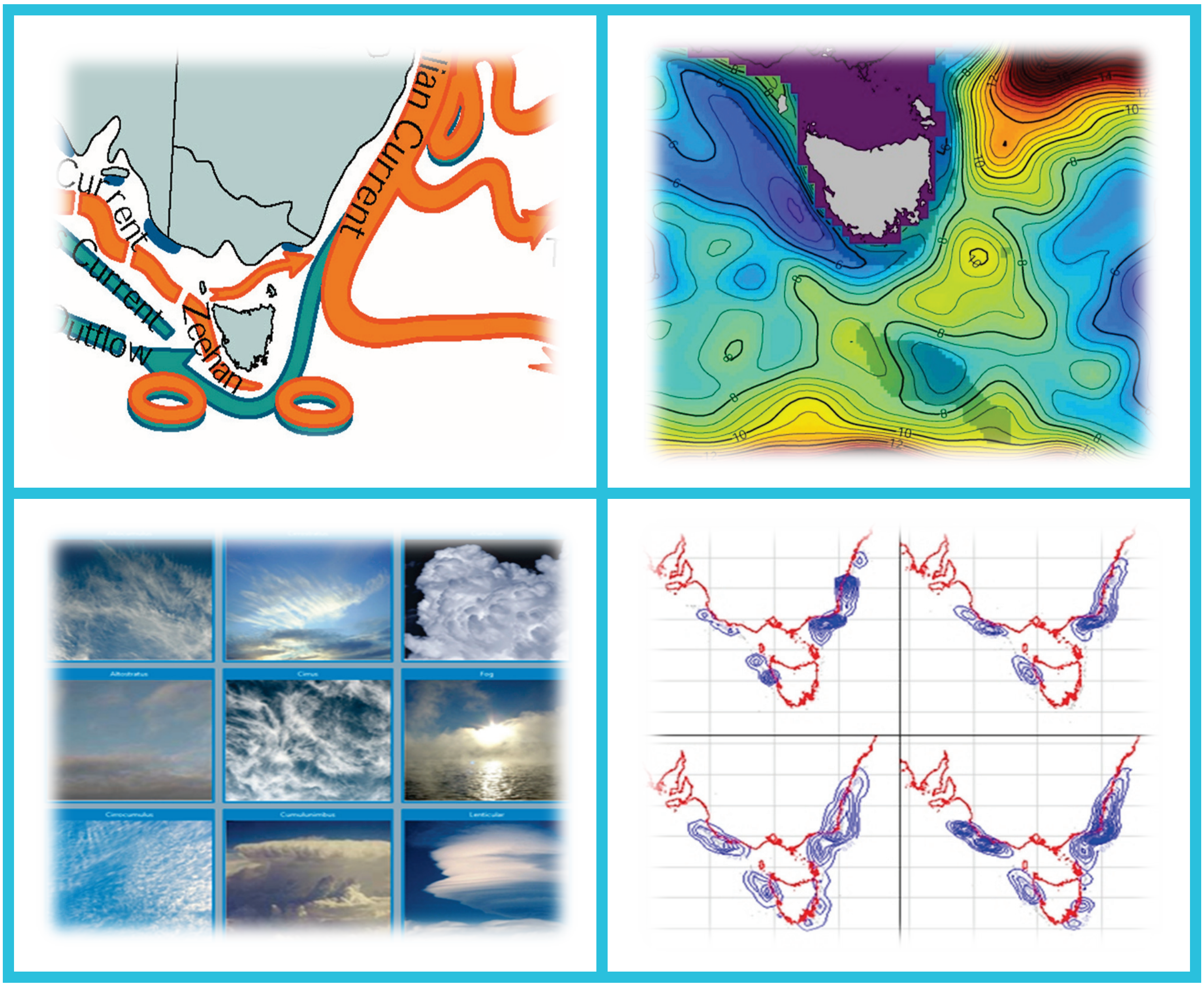
The influence of environmental factors on recruitment and availability of fish stocks in south-east Australia



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OBJECTIVES:

1. Hold a workshop with major stakeholder groups to develop hypotheses about the major environmental drivers and their potential influence of gross fishery characteristics (catch composition, seasonal variations, recruitment pulses etc).
2. Model the influence of environmental and oceanographic conditions on fishery recruitment success and availability.
3. Examine the efficacy of industry-based environmental data collection capabilities.
4. Trial environmental data collection instrumentation on strategic fishing vessels across the SESSF and methods of incorporating this information into assessments.

1 NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED:
The key objectives of this project were to develop: (1) a set of models to enable the incorporation/investigation of the influence of environmental and oceanographic influences on fisheries in south-east Australia; and (2) a method of incorporating these models into species stock assessments. Models were developed that investigated the influence of environmental and oceanographic factors on fisheries in south-east Australia. SST and temperature-at-depth showed some potential for inclusion in CPUE standardisations; however, regular, in situ measurements of these parameters were not available. The effect of incorporating observed relationships between environmental variables and CPUE into the existing CPUE frameworks (and hence, into species stock assessments) was examined using GLMs. Minor improvements in the fit of the model for pink ling were observed, however, it was concluded that including environmental variables was unlikely to make any practical difference to an assessment. The current practice of using month and depth as proxies for these environmental factors appears to be appropriate in most cases. For some species, such as Bight redfish, where improved model fits can be obtained by the use of additional environmental variables, the data and models are available for the Resources Assessment Groups to consider and apply these changes as appropriate.

Furthermore, the project planned to assist industry members in setting up and maintaining a database that combines catch and effort information with extensive fine-scale data on environmental and oceanographic variables. At the end of the project, the fishing industry have developed the capabilities for the ongoing collection of extensive fishery-related data by their own means. Industry collection of environmental data was successfully trialled on otter trawl and Danish seine vessels in the SESSF. Methods were developed in line with the Olfish DDL database, into which environmental data are recorded and combined with catch and effort data. This system enables easy interrogation of data collected, including the effect of environmental data on catch and catch rate.

The main goal of this project was for all stakeholders to obtain a better understanding of the influence of environmental and oceanographic factors on major fish species in the Southern and Eastern Scalefish and Shark Fishery (SESSF). To achieve this, CSIRO first compiled a large range of databases containing environmental and oceanographic information on south-east Australia. We then conducted a workshop with industry members from a range of fisheries, scientists, managers and oceanographers to discuss the environmental and oceanographic factors considered important to fisheries in south-east Australia on a species by species basis.

Key oceanographic processes off the south-east of Australia were summarised, showing the influence of the two major subtropical gyre systems — the South Pacific in the east and the Indian Ocean in the west. These systems are connected south of Tasmania making that region dependent on transport from the East Australian Current from the north and the Antarctic Circumpolar Current from the south-west. Seasonal flow patterns are influenced by the East Australian Current and the Zeehan Current. On the east coast in summer there is a polewards flow of warm, saline water, and there is a reversal of this flow in winter with cool, fresh, modified subantarctic surface waters drawn up from the south. Off the west coast, the Zeehan Current operates 180° out of phase with the East Australian Current. Its strongest poleward flow is in winter when it projects warm, relatively saline waters down the west Tasmanian coast and around the southern tip of Tasmania.

Industry members revealed a wealth of information on their understanding of the influence of environmental factors on their fisheries and targeting of particular species. Water temperature and currents were the most common factors discussed, and in turn, these were related to season, which was also identified as being important in influencing catches of SESSF species. Other related, but difficult to quantify factors included the depth of feed layers, and the depth of the thermocline together with information on what target fish were eating and what other (often invertebrate) species were present. Results of the workshop suggested that factors affecting catch rates or availability of target species are complex, often inter-related, and may act on different spatial and temporal scales.

The next phase of the project was to take the outcomes of the workshop and endeavour to develop models which described or explained the environmental and oceanographic influences on the SESSF. Various modelling approaches were used throughout this project. Linear mixed-effects models were used to examine the influence of a range of environmental variables on catch rates. General Linear Modelling (GLM) was used to investigate the incorporation of environmental factors into the existing CPUE framework, and correlation analysis was done to investigate whether individual environmental parameters may be influencing catch rates, availability and recruitment indices.

At the outset of the project, it was expected that such modelling would result in further environmental parameters being included in the CPUE standardisations used in stock assessments. A surprising outcome was that, apart from a few exceptions, the addition of extra environmental variables made very little difference to the standardised CPUE time series currently being used. This was largely because two of the most influential parameters in the current SESSF CPUE standardisations – month and depth – effectively acted as proxies for the two most influential “environmental variables” – SST and temperature-at-depth. In situ measurements of SST and temperature-at-depth have not been made routinely in the past 20 years, in contrast with the measurements of month and trawl depth which are routinely collected in the logbook data. To incorporate these environmental parameters would either require use of remotely sensed data or modelled data, or a combination of the two, and the associated error in these values. Ultimately, the ease of using month and trawl depth from the logbook data in standardised CPUE analysis, and the fact that they appear to capture a large part of the variability associated with SST and temperature-at-depth leads to the conclusion that there is little value in adding further environmental variables into the CPUE standardisations used in most SESSF stock assessment at this stage.

The recruitment patterns of several species inhabiting geographically similar distributions were significantly correlated, suggesting common external influences affecting recruitment. The nature, extent and potential causes of such correlations are likely to be complicated and, given the various life history stages between spawning and recruitment to the fishery upon which they may act, very difficult to establish. A more detailed exploration of the ecosystem influences on the recruitment dynamics of blue grenadier showed that the cycling in biomass and recruitment observed for this population could be derived from natural cycles in prey and predator dynamics. This work illustrated that ecosystem models of this kind can be used to develop, and explore, hypotheses about stock dynamics and the role that commercial and non-target populations have in the broader environment.

Despite the extensive array of environmental data available to this project, it was difficult to match or represent the broad spatial and/or temporal scale of the environmental/biological parameters with the fine spatial/temporal scales that fishers considered to influence their catches. Many of the environmental and oceanographic data are either modelled or measured at the scale of tens of kilometres, many days or a number of degrees, whereas good fishers target their best catches with tolerances of hundreds of metres, a few hours or half a degree in temperature.

The collection of basic environmental data by industry members was successful and offers a way of overcoming the problems associated with differences in scale between the environment and fisheries datasets. A simple method of collecting environmental data was developed that was only a small time burden on skippers, yet has the potential to provide very useful information on the same scale as the catch and effort data recorded in the logbooks. The success of this trial was aided by the natural interest of fishers to learn more about the environment in which they fish. The archival temperature-depth tags chosen proved robust, reliable and easy to use.

While the use of large scale environmental data may not yield significant improvements in stock assessments for most SESSF species, fine-scale data collected from selected vessels using methods developed during this project may, in the longer term, be useful for incorporation into CPUE standardisations in the future. To facilitate this, we would recommend that a select group of vessels continue to collect basic environmental data together with temperature and depth information from data-loggers placed on the fishing gear.

KEYWORDS:

Recruitment, availability, environment, oceanography

2 ACKNOWLEDGEMENTS

We would like to thank the following people for their contributions to this project: Scott Foster, Jason Hartog, Alistair Hobday, Jim Dell, Ron Thresher, Robin Thomson, John McKinlay, Sally Wayte and Gavin Fay. We would also like to thank participants of the workshop held on the 4–5th December, 2006 (Appendix 7). The trial of data collection on industry vessels could not have been done without the cooperation and dedication of the SESSF skippers/owners listed in Table 47.

3 BACKGROUND

For many years, the fishing industry has stressed the importance of environmental conditions in determining catch rates and the composition of catches from all fisheries operating in south-east Australia. Although this need has also been recognised by scientists, unfortunately there has been little support for compiling these data and incorporating them in a quantitative manner into stock assessments of fisheries in south-east Australia. As such, the influence of environment factors on fishery trends in this region tends to remain as "anecdotal information" that has little influence on formal stock assessments.

In a process that uses catch and unstandardised catch rates as critical inputs into stock assessments or major performance indicators — both of which influence decisions on setting annual TAC's — lack of recognition as to the importance of environmental influences has lead to considerable frustration for industry, scientists and managers alike. Put simply, the use of catches and catch rates as proxies for abundance are confounded by the effects of two major external factors. One major set of factors is associated with species targeting and market demands to which commercial fishers react. To account for this, fishery independent data are required. Following a feasibility study (Knuckey and Gason, 2006), fishery independent surveys have been operating in the Great Australian Bight Trawl sector of the SESSF for five years (eg. Knuckey *et al.* 2008) and are underway in the SESSF (Peel *et al.* Submitted). The other major factor is the influence of the biological and oceanographic environment — this is what will be addressed in the current project.

There are a multitude of fisheries in Australia and around the world that formally incorporate environmental and oceanographic variables into stock assessments (e.g. Brill, 1994; Fiksen and Slotte, 2002; Sinclair and Crawford, 2005). In many cases, these variables are critical in determining targeting and catch rates. A good example is the use of sea surface temperatures and phytoplankton concentration for targeting and catching tuna which is used in stock assessments (Schick *et al.*, 2004). It is difficult to understand why there has been no formal analysis of the influence of environmental variables on catches from fisheries in south-east Australia.

During 2000–2001, preliminarily attempts to correlate "broad-scale" catch rates of SESSF species with "broad-scale" environmental variables showed promise. A range of environmental variables were obtained from Government organisations and the literature including water temperature, rainfall, nutrients, salinity, river outflow and Southern Oscillation Index (Koopman, unpublished data). Most of these data were "point-measures", taken from a single location such as a physico-chemical monitoring site off Port Hacking, NSW. As such, these "point-measures" were used as a proxy for environmental conditions over very large areas. Cyclical catches of tiger flathead by both historical (Figure 1a) and recent (Figure 1b, c and d) otter board and Danish seine vessels were significantly correlated with Southern Oscillation Index (SOI) and sea surface temperature. These environmental variables appeared to explain 30–70% of the variation in catch and catch rate. Correlations between environmental factors and catch rates of redfish were also investigated. Low SOI values appeared to coincide with a stronger influence of cold water on the east coast, which leads to improved overall catch rates for redfish. However, when the data were disaggregated to monthly strata, little correlation was apparent (Wise 2002). While these results were presented to industry and management, the rudimentary methods analysis used for meant that these results were never carried through to inclusion in stock assessments. In addition, the large number of variables tested, at different spatial and temporal scales, meant that the chances of obtaining significantly correlations were high.

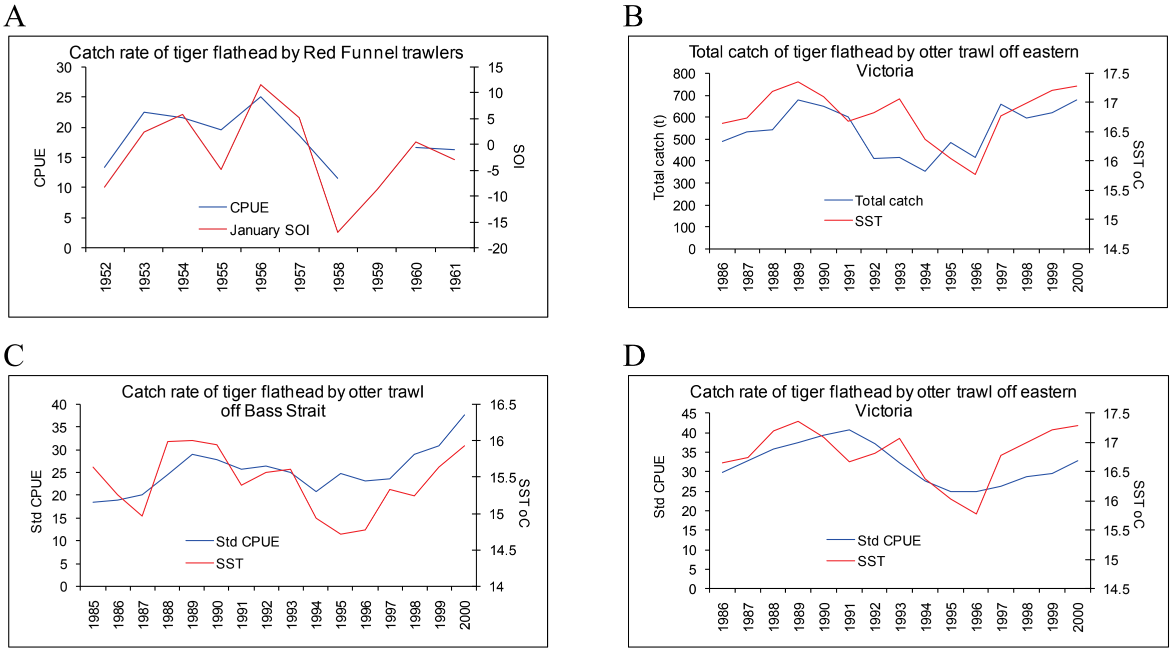

Figure 1. Examples preliminary attempts to correlate environmental variables with catch and catch rate. A) Catch rate of tiger flathead by the Red Funnel Trawlers against SOI ($R^2 = 0.78$); B) Total catch (t) of tiger flathead by Danish seine fishery off eastern Victoria against sea surface temperature ($R^2 = 0.39$); C) Catch rate of tiger flathead by otter trawl off Bass Strait against sea surface temperature ($R^2 = 0.25$); D) Catch rate of tiger flathead by otter trawl off Eastern Victoria against sea surface temperature ($R^2 = 0.31$).

There is no doubt that numerous SESSF fishers use bottom temperature as a means of targeting large catches of certain fish species and to explain long-term cycles in catches with reference to environmental conditions. Long-term cycles in catches are evident for many species in the SESSF and it is considered that these reflect environmental and oceanographic cycles. For example, the collapse of eastern gemfish stocks has been linked to high fishing pressure combined with a long series of poor westerly winds off Australia's east coast (Harris *et al.*, 1988; Bax, 1995; Thresher, 1994); the pattern of recruitment of orange roughy off Tasmania reflects the 50 year fluctuations in bottom water temperature; intermittent spawning of blue grenadier in New Zealand has been directly linked to oceanographic conditions (Francis *et al.*, 2005); cyclic recruitment of blue grenadier also occurs in south-east Australia although the environmental drivers have yet to be determined (Tuck *et al.*, 2004; Punt *et al.*, 2006). With such evidence of the potential influence of environmental factors on catches and catch rates of fish in south-east Australia, there is no excuse for not formally investigating the inclusion of them in standardised CPUE analyses and quantitative stock assessment models.

There is a significant amount of data available for a wide range of environmental variables. Although this information is often difficult or expensive to obtain, CSIRO have collated extensive databases over the years and worked them into a format that can be accessed and used for scientific studies. This project will benefit from links established with CSIRO’s Wealth from Oceans flagship; a research initiative to improve Australia’s knowledge of ocean systems and processes. Oceanographic projects proceeding under the research themes of Wealth from Oceans provided valuable data inputs to the models proposed here, and facilitate the generation of hypotheses that link environmental factors to fishery statistics. The aim of the current project is to utilise the information in these datasets to explore potential meso-scale relationships between environmental conditions and gross characteristics (catch rate, recruitment, catchability, seasonal catch composition etc) of fisheries in south-east Australia.

4 NEED

The dynamics of fish stocks are significantly influenced by environmental and oceanographic factors. Although this is now recognised by industry and scientists alike, there is concern that the application of single species stock assessments or CPUE analyses does not incorporate information about the broader environmental and oceanographic factors. There are clear examples in the SESSF of cyclic patterns in recruitment and availability and indications of regime shifts, but there has been little support for compiling these data and incorporating them in a quantitative manner into stock assessments of fisheries in south-east Australia. Much of this information about the influence of environmental factors is in the heads of experienced fishers but needs to be formally (and quantitatively) incorporated into the assessments/analyses that underpin the TAC setting process for the fishery.

From information passed down through generations and decades of their own experiences, good fishers have an informed understanding of the influence of environmental and oceanographic factors on fish stocks and are looking for ways to bring this information into the stock assessment process. Scientists have yet to extensively examine these relationships. Industry and scientists would both appreciate the means to incorporate environmental and oceanographic data into the stock assessment process in a formal manner. This project provides the datasets and models that would enable this to occur.

Most importantly, this project is the first step in the process of getting fishers to collect the information that is needed to manage the fish stocks. With the burden of increasing costs of fishery monitoring, data collection and analysis, the fishing industry is looking towards cost-effective alternatives to this work always being undertaken by government agencies. Industry members are already purchasing software that will enable them to collect and analyse much of this information themselves. There is a need for this to be a coordinated process, which will ultimately empower the industry to bring valuable interpretations and analysis into the stock assessment process in a quantitative manner. Using the resources from this project to begin with, we aim to assess whether industry can be self-sufficient in collecting these data by the end of this three-year project.

5 OBJECTIVES

1. Hold a workshop with major stakeholder groups to develop hypotheses about the major environmental drivers and their potential influence of gross fishery characteristics (catch composition, seasonal variations, recruitment pulses, etc).
2. Model the influence of environmental and oceanographic conditions on fishery recruitment success and availability.
3. Examine the efficacy of industry-based environmental data collection capabilities.
4. Trial environmental data collection instrumentation on strategic fishing vessels across the SESSF and methods of incorporating this information into assessments.

6 GENERAL METHODS

6.1 STAGE 1 – ESTABLISHING THE BIG PICTURE

6.1.1 Collation of environmental and oceanographic datasets

CSIRO has compiled a large range of databases containing environmental and oceanographic information on south-east Australia. Although it is in various formats, most of it is available to use in a project of this nature. Environmental time series data from 1986, when logbook information was first collected in the SESSF are used, however, where available, longer time series information will be accessed to correlate with fisheries for which we have data over corresponding time periods e.g. the Southern Shark Fishery. The datasets were summarised to some extent on spatial (broad region) and temporal (month) scales to assist in broad-scale applications. The likely environmental datasets used are described in relevant chapters. This project benefits greatly by linking to CSIRO's Wealth from Oceans projects and *CSIRO Atlas of Regional Seas (CARS).*

6.1.2 Collation of fishery data

Information on the catch composition and catch rate of important SESSF species is summarised on a scale suitable for incorporation with the environmental and oceanographic datasets. The summaries utilise logbook data from the Gillnet Hook and Trap (GHAT), South East Trawl (SET), Great Australian Bight Trawl (GABT), and Southern Shark (SSF) sectors of the SESSF, as well as observer data.

6.1.3 Scoping workshop

Industry was consulted for ideas on the species that are most influenced by environmental and oceanographic fluctuations. This was achieved both via input from the various fisheries assessment groups and an Industry workshop. Industry members from a range of different fisheries, scientists and oceanographers were invited to participate in the workshop. Using the combined knowledge of workshop participants, a range of hypotheses were developed to correlate major environmental factors with key characteristics of the fisheries.

6.1.4 Modelling

A range of modelling approaches were used throughout this project and are described in detail in each chapter. Effects of the environment on cycles in blue grenadier biomass, abundance and recruitment modelled using Atlantis SE (Chapter 7.5). Linear mixed-effects models were used to examine the influence of a range of environmental variables on catch rates (Chapter 7.6). General Linear Modelling (GLM) was used to investigate the incorporation of environmental factors in the existing CPUE framework (Chapter 7.7), and correlation analysis was done to investigate whether individual environmental parameters may be influencing catch rates (Chapter 7.8), availability (Chapter 7.9) and recruitment indices (Chapter 7.10).

6.2 STAGE 2 – INDUSTRY BASED MONITORING

Having established which environmental and oceanographic factors were most important, the efficacy of industry-based data collection capabilities was examined. A network of fishing industry members was to be set up with the capability to collect such environmental data across the fishery in conjunction with fishery catch and catch rate data. Apart from environmental observations made by the skipper, archival temperature/depth tags were deployed on fishing gear to record and measure these factors during each shot.

7 RESULTS AND DISCUSSION

7.1 INDUSTRY WORKSHOP

Ian Knuckey and Matt Koopman

7.1.1 Introduction

It has long been suggested that there is patterns in recruitment and availability related to oceanographic factors, but there has been little support for compiling these data and incorporating them in a quantitative manner into stock assessments of fisheries in south-east Australia. Much of this information is in the heads of experienced fishers but needs to be formally (and quantitatively) incorporated into the assessments/analyses that underpin the TAC setting process for the fishery.

Any examination of the influence of environmental variables on fisheries requires well formed hypotheses to test. From information passed down through generations and decades of their own experiences, good fishers have an informed understanding of the influence of environmental and oceanographic factors on fish stocks. It is clear that capturing this anecdotal information is important in the development of hypotheses of the influence of the environment on catches and catch rates, which may lead to the development of frameworks to incorporate these variables in the stock assessment process.

To bring this knowledge out, a workshop was held with industry members from a range of fisheries, scientists and oceanographers to discuss the environmental factors that were important to fisheries in south-east Australia on a species by species basis.

The main objectives of the workshop were to:

1. develop hypotheses to model;
2. review and identify available data to support hypotheses;
3. demonstrate some of the environmental influences quantitatively at RAGs/MACs; and,
4. integrate systems within fisheries to collect robust environmental information for future additional work.

7.1.2 Methods

The workshop titled “Environmental effects on fish stocks: What are the influences in south-east Australia?” was held in Melbourne on December 4th and 5th, 2006 (Appendix 6). Invitations were sent to people considered to have in-depth knowledge of fisheries in south-east Australia and the potential influence of environmental factors on the broad meso-scale characteristics of the fisheries. These people included a range of industry members from different sectors of the SESSF and State fisheries, scientists and oceanographers (Appendix 7).

Participants were exposed to a range of information to stimulate thought and discussion of how the environment could act on fisheries (Appendix 6). Topics covered included oceanography and climatology, available fisheries data, fish recruitment and ecosystem modelling. Region by region, fishing industry members discussed the factors that they thought most influenced catches, catch rates, availability and recruitment of different fish stocks. A summary of these factors for each species is presented in Table 1, and detailed outcomes are in Appendix 7. Using the combined knowledge of workshop participants present, ideas on the influence of major environmental factors on key characteristics of the fisheries were developed for examination in the later chapters of this report.

Table 1. Summary of potential environmental drivers identified by industry members the workshop for considered species.

Species	Currents/eddies	Season	Moon phase	Water temperature	Wind/storms	Water color/rainfall	Feed/Upwelling	Diurnal/tides
Royal red prawns	EAC. Fishing is best in 2–3 knot north–south current. Fishing is bad in cold south–north current.	Fishing is best during summer.	Fishing is best on the full moon.	See currents/eddies.				
Ocean jacket		More abundant during warmer months.		Prefer warm water, and disappear after a cold water change.				
Mirror dory	Move in as eddies hit the shelf.	More small fish are available during summer months.		In the west, catches are best when the thermocline is higher in water column and water temp is 15°C at depth (16.5–17°C at the surface).				
Squid	Like to sit in front of eddies at the change from warm to cold water.		Lowest catches are obtained four days before and after the full moon.	Best temperatures are 18°C off Queenscliff and 16.5°C off Portland. When temperature 14°C and below, catches decline.	Good catches during years of strong westerlies.	Better catches in clear water.		
Jellies, Salps				Often found in cold water underneath the thermocline.				
Krill						When “black water” is around, you get a build up of krill off Jervis Bay.	Abundant during strong upwelling years.	
Blue-eye trevalla	Difficult to catch if the current is too strong.	More smaller fish (~2 kg) over summer.			Juveniles have been observed associated with floating kelp beds that are presumably created by large storms.			
Flathead – bottom trawl	If the EAC hits the shore then flathead are hard to catch. They sit just off the edge of a current front.	Better catches during spring/summer when the current is from the south.	Catches are better around the full moon.	Generally better catches when the thermocline is up on the shelf, with temperatures ~ 13°C in 100 fth depth.	If the wind swings from SW to NE then catch rates drop off on east coast. Catch rates drop off at Portland on an easterly or south-easterly wind.	In clear water catch rates are better at night, while in dirty water catch rates are better during the day.	Fish follow feed layers (juvenile cardinalfish or whitebait) which are in turn driven by tide/currents.	
Flathead – Danish seine					High catch rates during NE winds.		Fishers target the feed layer.	Danish seiners can’t catch flathead at night.
Redfish (east coast)	Catch rates drop when the current comes from the N or NE. Redfish follow meso-pelagics in with eddies spinning onto the shelf, and are found on the edge of eddies.	Highest catches during mid winter.		Highest catch rates from Eden north when SST is 16.5–16.8°C.			Redfish follow krill and lantern fish.	
Ling	Ling seem to follow the cooler water current from the south.	Catch rates are highest in winter/spring (during spawning runs in canyons).	Best catches are when the fish move in shallower around the full moon. They move out deeper with less moon.	In the west, the thermocline moves up onto the shelf, bringing deepwater species shallower.				
Blue grenadier		Move south in spring after spawning (mid winter), then head up east coast of Tasmania (late spring/early summer) before “vanishing” and then “reappearing” in western			The large recruitment event during 1993 coincided with screaming gales and huge spawning runs.	Blue grenadier are harder to find during wet years.		

Species	Currents/eddies	Season	Moon phase	Water temperature	Wind/storms	Water color/rainfall	Feed/Upwelling	Diurnal/tides
		Victoria in February.						
Silver warehou	Range extension north and south following cold water tongues.	Big spawning runs on the east coast (after gemfish) during early July.		Prefer bottom temperature of 12°C.				
Blue warehou		Seasonal catch rates.	Best catch rates during lead up to full moon.				Dependent on feed availability.	
Morwong			Highest catch rates during the week either side of full moon. During the new moon, catch rates are better in deeper water.	In the east, morwong catches are best in cold water 14–16°C. In the west, best catches seem to occur when the thermocline gets deeper, forcing shelf species out to the shelf break where they are more available		Best catches by Danish seiners are in milky/dirty water.		
Gummy shark		Catches seem to highest in the west (GAB) during winter.	Winter fishing improves on new and full moons.	Targeted by following changes in water temperature.		Some fishers look for dirtier water where there is generally more bait and therefore gummy shark. Need dirty water to catch them with trawl gear.	Fishers reported targeting the “feeding front”, just in front of a change in water temperature where food can be seen on the sounder.	
School shark				Generally caught in 16.5–18°C water. Temperature influences depth at which they are caught.				
Bight redfish	Cyclical trend in availability probably linked to Leuwin current and/or Bonnie upwelling.		Best catch rates on full moons.	Cooler water tends to force Bight redfish further inshore.				Better catch rates at night when they are near the bottom. They lift off the bottom in full daylight to feed.
Deepwater flathead	High catch rates at small eddy structures on either end of Bight which, attract bait.	Catches increase during November–December as Leuwin current strengthens and brings more warm water across the Bight.			Generally better catches when westerlies are blowing compared with northerly or easterlies.			
School whiting		More fish around during March–July.		Water temperature is only critical for fish quality.		May be worth investigating east coast rainfall trends against catch rates.		
Rock lobster			Better catches on specific moon phase.	Temperature?	Can’t fish in the west in rough water. At some places on east coast you will only find catchable lobster in rough weather.		Food?	Some times catchability is tide related.
Small pelagics and mackerel			Highest catch rates of shelf fish during the week before the moon and week of the full moon. The new moon is best for deep fish (especially in winter).	90% of target species caught in water temperatures of 14–16.5°C. Depth of thermocline determines the depth of fish.	In Tasmania, low catch rates during E or south-east winds.	Inshore species may be affected by river outflow and freshwater pooling on the surface.		

Note: EAC = East Australian Current

7.2 OCEANOGRAPHY: THE CIRCULATION OFF THE SOUTH-EAST OF AUSTRALIA

Ken Ridgway

7.2.1 Introduction

The south-east region of Australia represents an important 'gateway' between the Pacific and Indian Oceans. It is strongly influenced by the East Australian Current (EAC) from the north-east (Figure 2). This is a major western boundary current and it carries large volumes of warm, nutrient poor water southwards into the region. The EAC is highly variable and its flow is associated with large (300 km) eddies which also move southwards. Some of these features reach as far as Tasmania and drift into the Indian Ocean south of Australia. The waters around Tasmania are highly seasonal and surface currents bring warm water during winter on the west coast and in summer off the east coast.

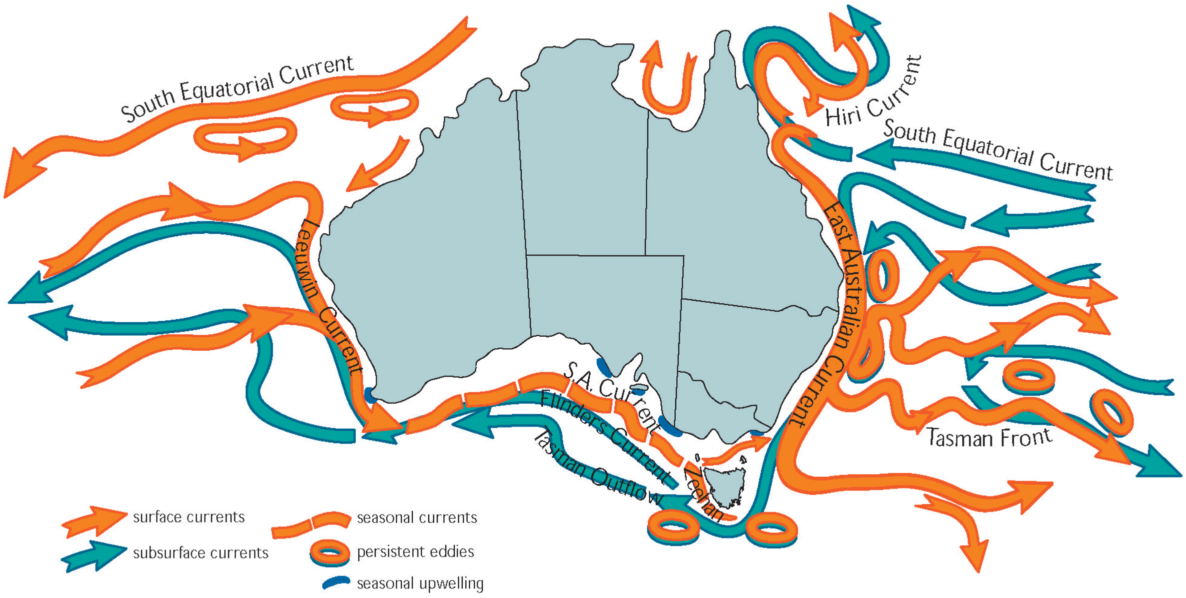

Figure 2. Schematic description of the surface and subsurface currents around Australia

7.2.2 Large-scale environment

The region is influenced by two major subtropical gyre systems — the South Pacific in the east and the Indian Ocean in the west (Figure 3 and Figure 4). These 'gyres' are the pathways followed by the flow in each ocean basin. They span the ocean basins and have an anticlockwise direction. These systems are connected to the south of Tasmania. Observations show that the greater gyre flow is squeezed into a narrow band of latitude between Tasmania and the eastward flowing Antarctic Circumpolar Current (ACC) in the south. The connection is formed when the residue of the East Australian Current (EAC) derived transport turns westward around Tasmania forming a 'Tasman Leakage' which penetrates into the Indian Ocean.

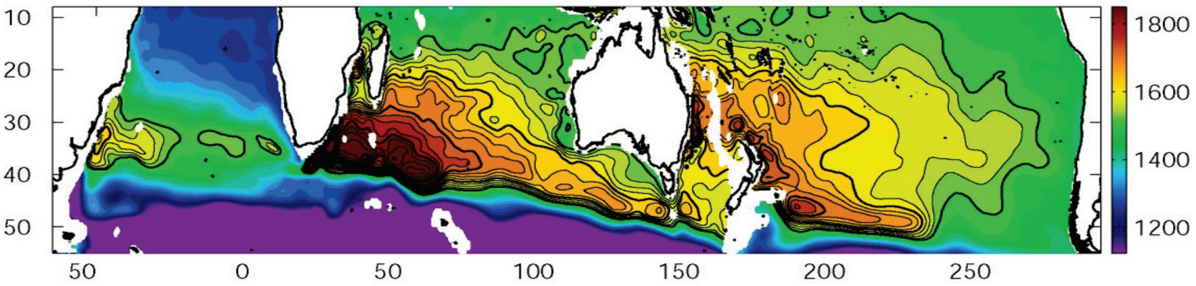

Figure 3. The interbasin gyre system for the Pacific and Indian Oceans as shown by the depth-integrated steric height (or mass transport function, P0/2000), derived from the T and S fields in CARS. The contour interval is 25 m^2.

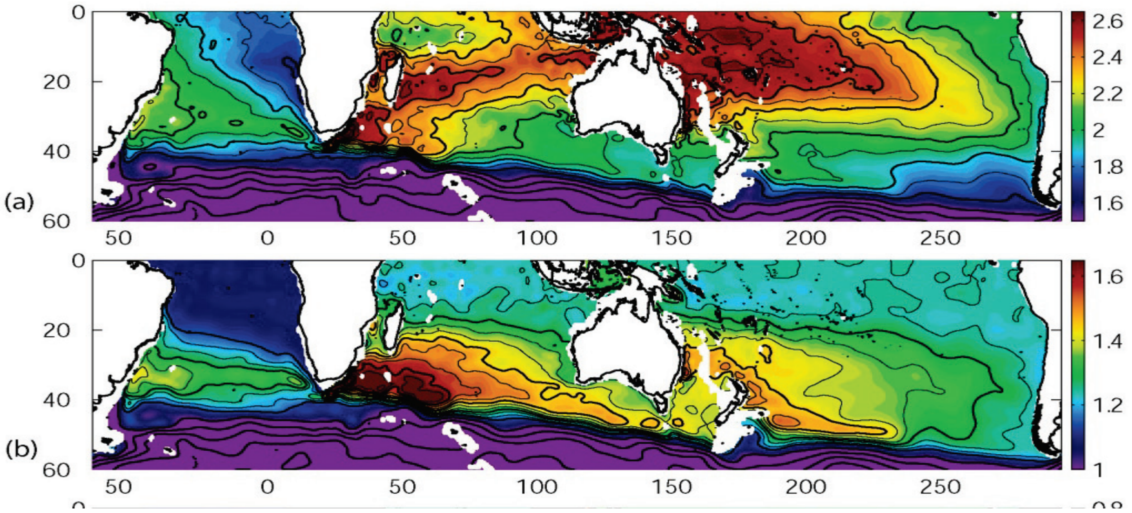

Figure 4. The flow at the (a) surface (contour interval 0.02 m) and (b) 900 m level (contour interval 0.01 m) as shown by the mean steric height.

7.2.3 East Australian Current (EAC)

The EAC provides both the western termination of the South Pacific Gyre and the linking element between the Pacific Ocean and Indian Ocean gyres. The current is accelerated, southward along the coastal boundary and then separates into north-eastward (STCC), eastward (Tasman Front) and residual southward (Tasman Outflow) components (Figure 5). Between latitudes 18ºS and 35ºS, the southward transport ranges from 25–37 Sv, the latter value includes a significant recirculation feature. A portion of the Tasman Front reattaches to the northern coast of New Zealand, forming the East Auckland Current and a sequence of semi-permanent eddies. The residue of the EAC transport continues southward along the Australian coast as far as Tasmania and then turns westward into the eastern Indian Ocean (Tasman Outflow).

Few modelling studies have focussed on the region. One recent study (Tilburg *et al.* 2001) suggested that gradients in wind stress curl control the current separation locations, non-linear dynamics induce the southward loop of the EAC as it separates from the coast and that the eastward meandering flow and quasi-permanent eddies are associated with upper ocean-topographic coupling.

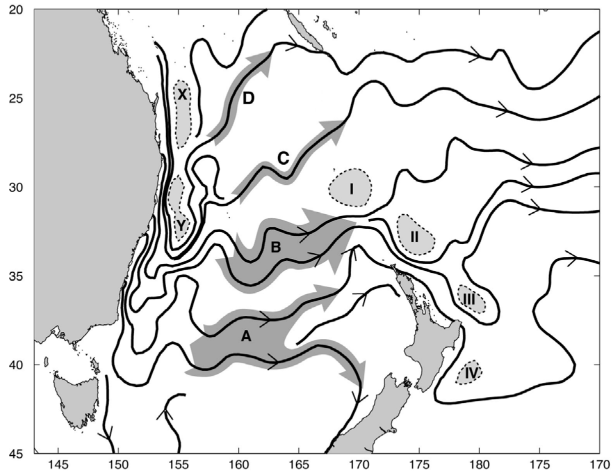

Figure 5. A schematic summary of the individual surface currents and eddies within the Tasman Sea. The four components of the separating EAC flow are given by A, B, C and D. Note that B represents the flow associated with the Tasman Front. The 4 quasi-permanent eddies surrounding New Zealand are I, Norfolk Eddy; II, North Cape Eddy; III, East Cape Eddy and IV, Wairapa Eddy. X and Y are 2 anticyclonic recirculation cells associated with the EAC flow within the Tasman Abyssal Basin.

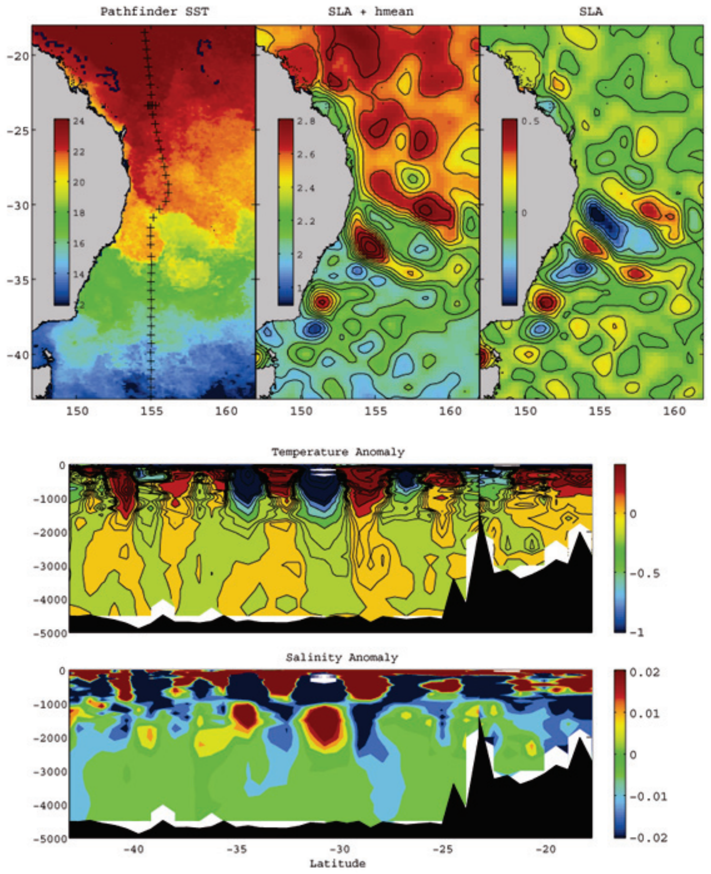

Figure 6. A 'snapshot' of the eddy field of the EAC. The upper panel shows the SST, sea level and sea level anomaly from satellite observations. The lower panel shows the cross-section of temperature and salinity anomalies along the indicated track from ship measurements.

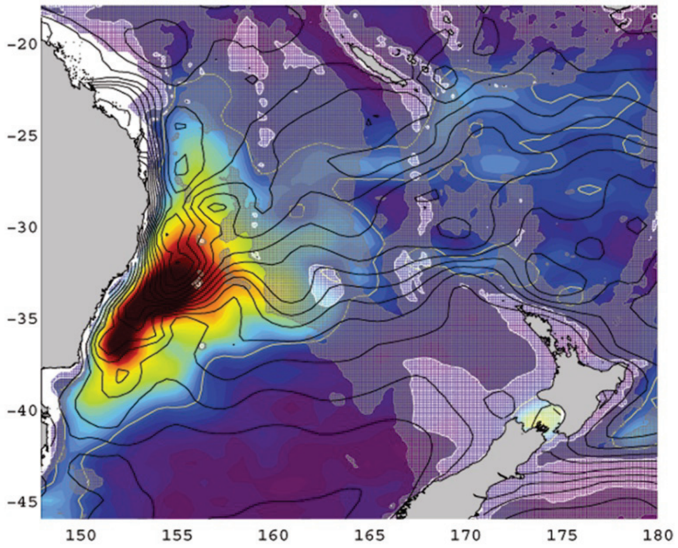

Figure 7. Variability of the EAC at the surface. The high variability region off eastern Australia represents the combined effect of the eddies seen in the snapshot in Figure 5.

7.2.4 Flow around Tasmania

The flow around Tasmania (Figure 8) shows distinctive mean and seasonal patterns. The mean temperature pattern (Figure 9a) shows the surface expression of the main EAC inflow off the eastern coast and the Zeehan Current and a southward flow on the west coast. The large scale advection of heat into the eastern waters establishes a substantial (1–2°C) temperature difference between the east and west coasts. The surface steric height topography (Figure 9b) has a clearer picture of the main boundary currents. Both the southward projection of the Tasmanian landmass and the South Tasman Rise (STR) leave an imprint on the major flow features. There are two large anticyclonic recirculation features or eddies either side of the STR at about latitude 46°S.

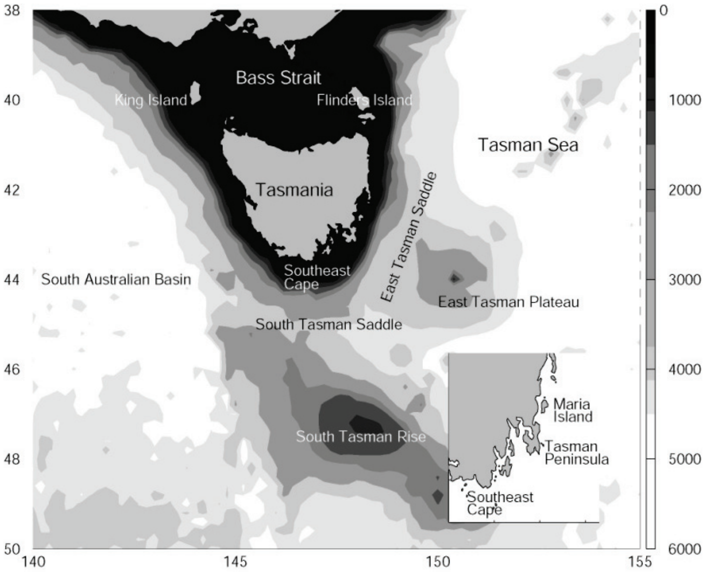

Figure 8. The waters around Tasmania showing both the main bathymetric features and other geographic features referred to in the text. Also shown is the location of the study domain in relation to the Australian continent.

At the surface the major inflow into the Tasmanian region is from the EAC. On the Tasmanian east coast the strongest flow is on the continental slope, but it is evident on the shelf as far south as latitude 43^{o}S (Tasman Peninsula). Here the flow of the Zeehan Current around southern Tasmania deflects it away from the coast and then follows a meandering poleward trajectory, finally looping to the east. The outflow straddles the eastern slope of the neck joining the Tasmanian continental shelf and the STR.

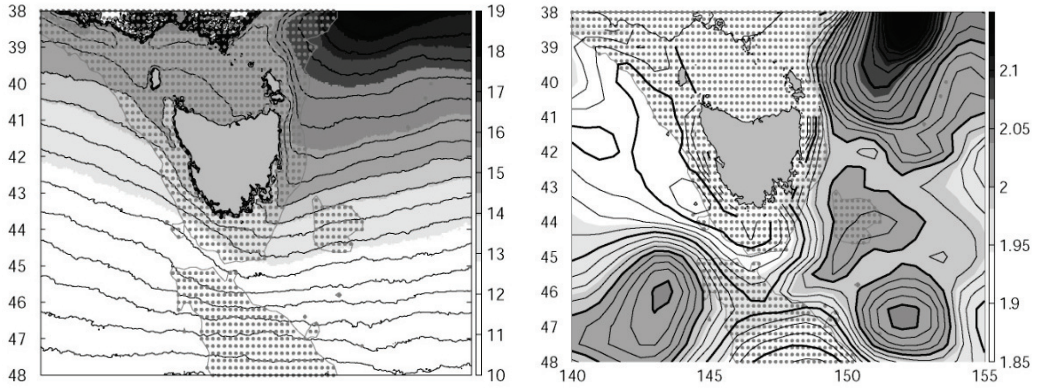

Figure 9. (a) The mean SST field (1993–2004) from a composite satellite product (contour interval 0.5°C). (b) The flow at the surface shown by the mean surface steric height, $\bar{h}$0/2000 (contour interval 0.01 m).

Southward current flow associated with the Zeehan Current is evident over both the continental shelf and slope. Figure 9b indicates that the poleward flow of the Zeehan Current actually forms the eastern side of a trough that extends to the north-west from the southern tip of Tasmania (the Western Tasmanian Low).

The surface variability is very different off the east and west coasts (Figure 10). Off the east coast the variability is related to the EAC, whereas, in the west it is weaker and arises from the seasonal rise and fall of coastal sea levels due to the seasonal reversing wind patterns. A high variability EAC tongue stretches polewards off the east coast between the major topographic structures.

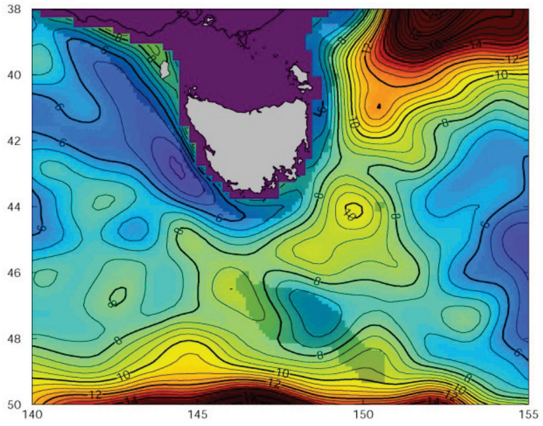

Figure 10. The surface height variability from an altimetry dataset (contour interval 0.01 m). The darkened regions represent where the water depth is less than 2000 m.

7.2.5 Seasonal flow

Summer and winter patterns of the surface circulation are influenced by the EAC and the Zeehan Current respectively. On the east coast in summer (January–March) there is a polewards flow of warm, saline water forced by an episodic coastal boundary flow (Figure 11). The cross-shelf pressure gradient driving this flow is formed from the difference between the seasonal changes in coastal sea level and the offshore eddies. There is a seasonal reversal of this flow in winter with cool, fresh, modified subantarctic surface waters drawn up from the south. Off the west coast, the Zeehan Current operates 180° out of phase with the EAC. Its strongest poleward flow is in winter when it projects warm, relatively saline waters down the west Tasmanian coast and around the southern tip of Tasmania. There is a sharp division between the EAC and Zeehan Current influence adjacent to the Tasman Peninsula off south-east Tasmania.

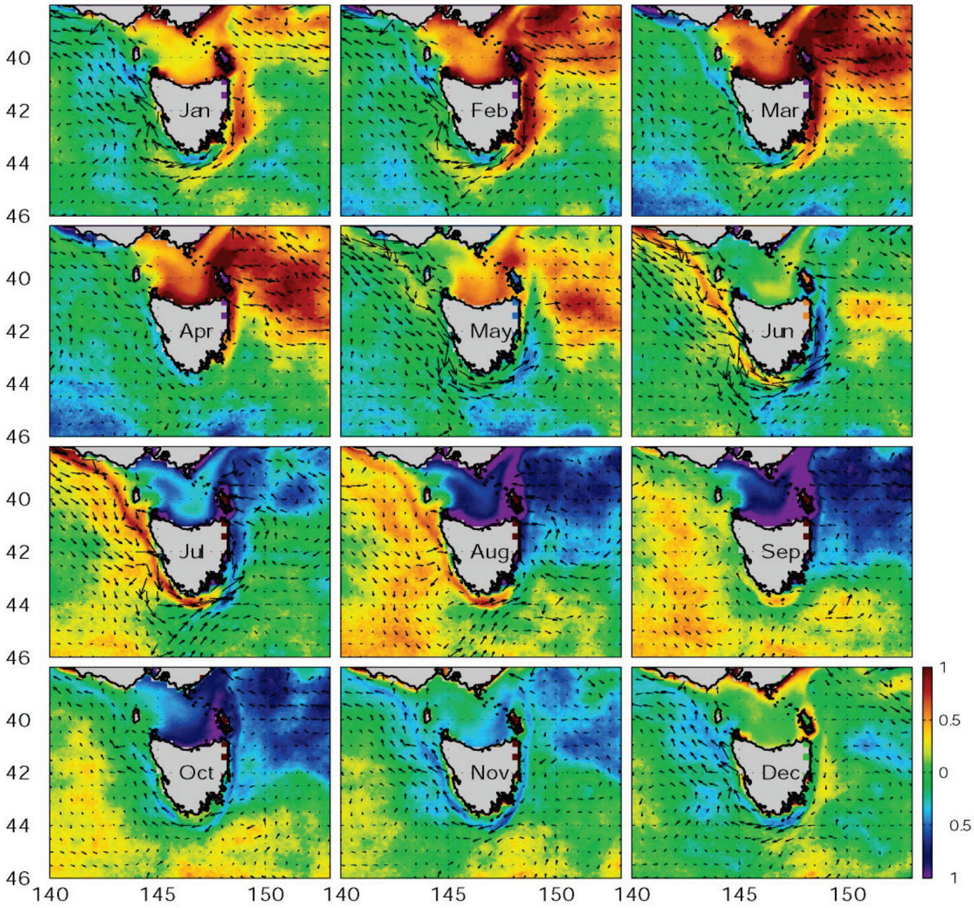

Figure 11. The monthly anomaly of SST from a composite SST product (1993–2003). We constructed the anomaly field by removing the annual mean SST from each grid-point and then removing a domain-wide seasonal anomaly.

Observations of seasonal variations of the EAC come from a station near Maria Island (at the 50 m isobath on the east coast of Tasmania). The time series of salinity and temperature shows a warm, saline pulse in summer, EAC water from the north (Figure 12). The peak T and S anomalies of 0.51°C and 0.19 PSU occur in early March (day 63) just as the nitrate cycle begins to increase from its minimum summer values (Figure 12c).

After summer the coastal water steadily cools over the following 5 months and reaches a minimum in July in phase with the peak nitrate value. Cool, nutrient rich water is drawn from the northern edge of the Subtropical Front (STF) located south of Tasmania.

Eddies are generated off eastern Australia and approximately one eddy per year travels westward around the deep channels south of Tasmania. Less than half of these eddies complete the journey into the Indian Ocean (Figure 13).

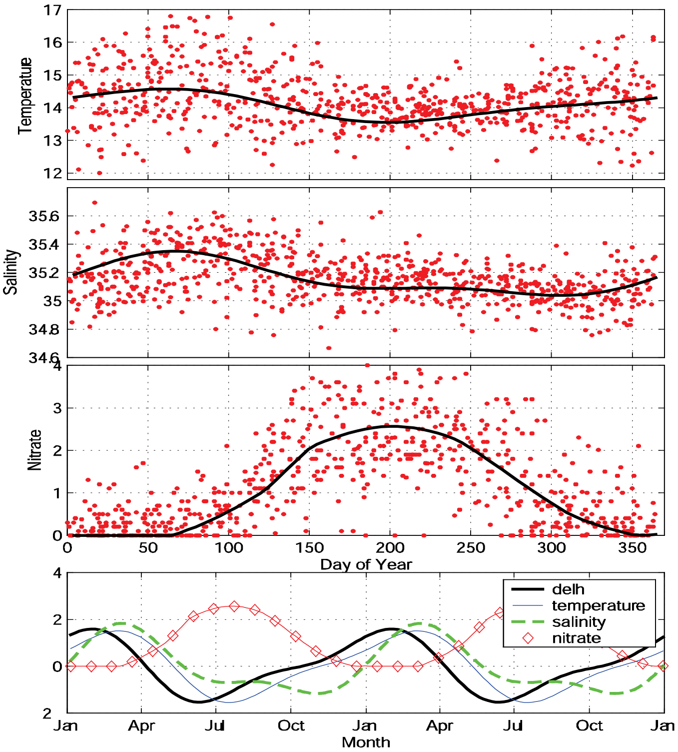

Figure 12. Individual samples from Maria Island plotted against day of year. The dots represent individual samples and the curves show the seasonal cycles. (a) Seasonally corrected temperature (°C), (b) salinity, (c) nitrate (μmol·kg^{-1}), (d) the seasonal temperature, salinity and nitrate cycles from (a–c), and sea level difference curves plotted over a 24 month period.

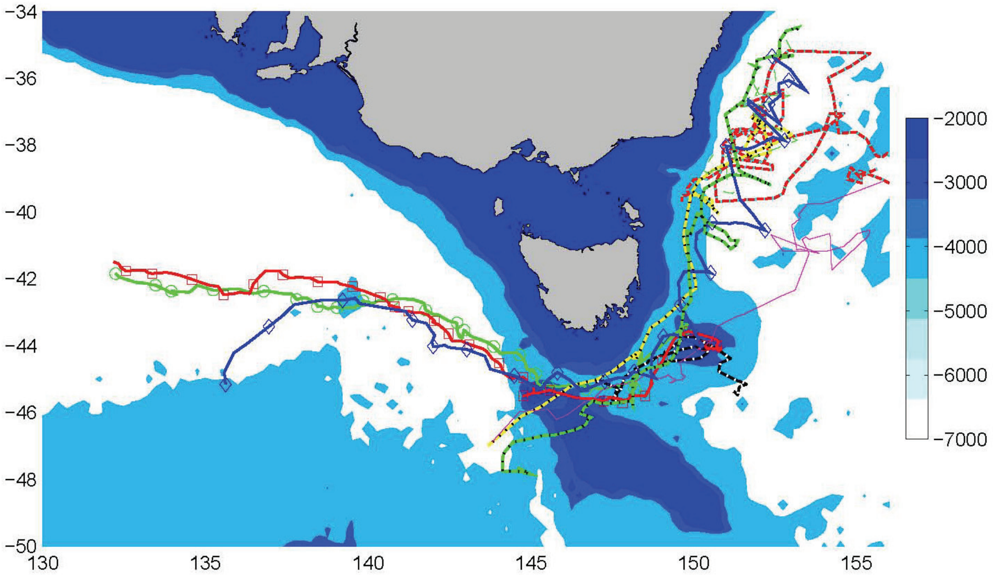

Figure 13. Eddy tracks obtained from altimeter maps for the period 1993–1999.

7.2.6 Southern Australian shelf

Seasonally reversing winds drive flow into the coast producing high/low sea level in winter/summer (Figure 14). An eastward downwelling slope current is generated along the southern shelf in winter in phase with the maximum flow of the seasonal Leeuwin Current on the west coast. A continuous boundary flow is created from North West Cape to southern Tasmania — a distance of 5500 km. This may be the longest coastal current in the world. This eastward flow forms the Zeehan Current upon entering the waters to the west of Tasmania.

During July, the outer flank of the high sea level becomes unstable and anticyclonic eddies are generated at 3 specific locations. These propagate westwards and the northernmost of these may reattach to the boundary current some 1500 km to the west. Similarly cyclonic features are created in the summer (Figure 15).

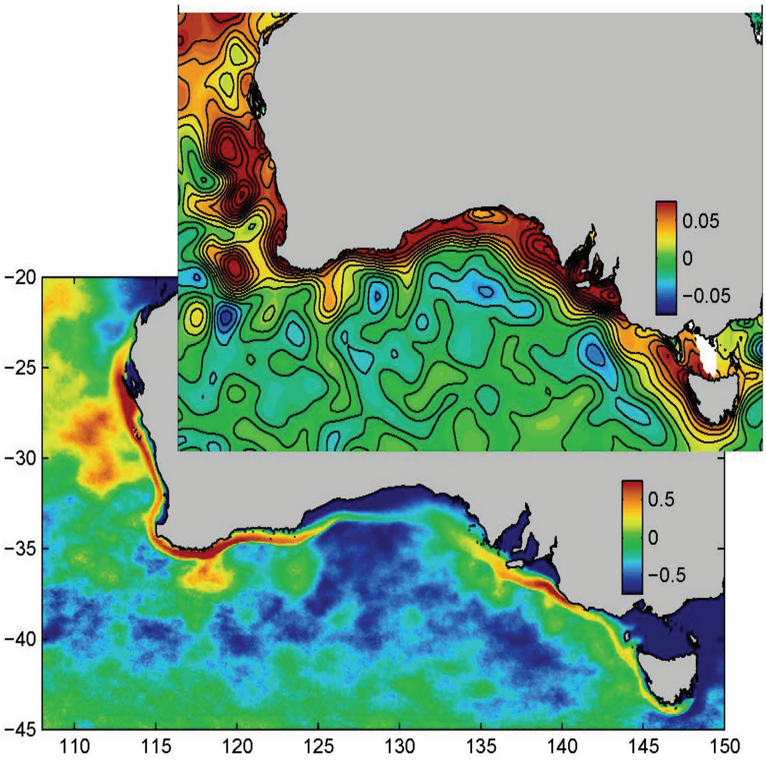

Figure 14. (a) SST anomaly for July from satellite data (b) SLA for July from altimetry.

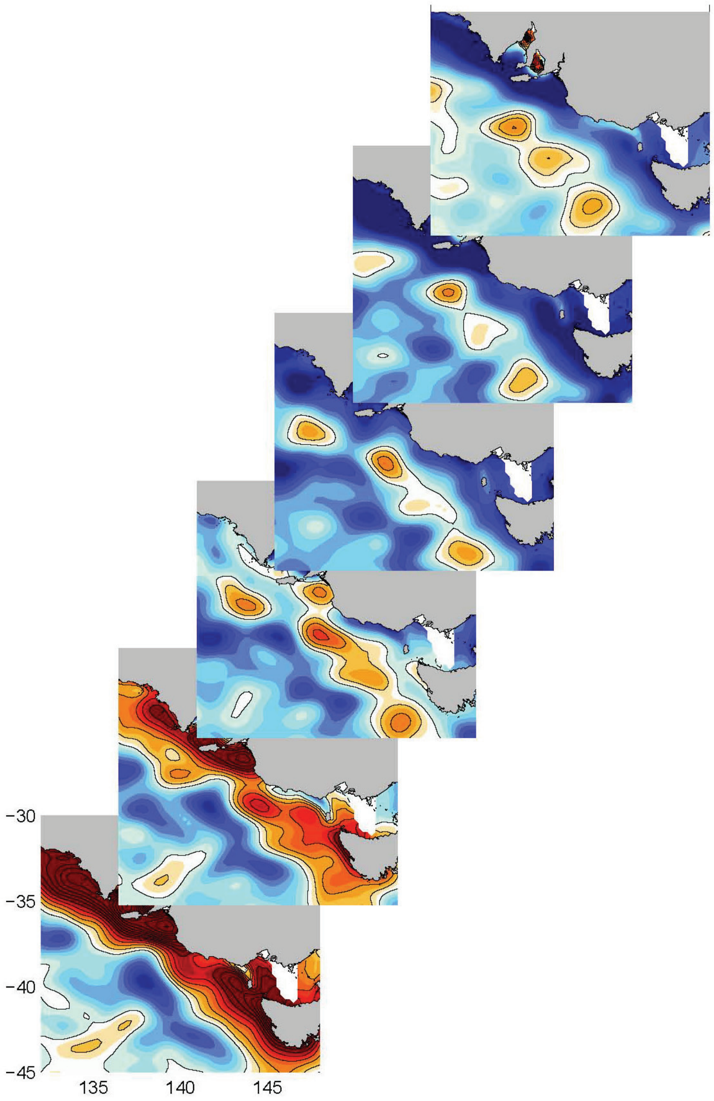

Figure 15. The evolution of eddies along the southern shelf as shown by sea level anomaly from satellite altimetry observations.

7.3 SEASONAL FLEET MOVEMENT

Jemery Day

7.3.1 Introduction and methods

Fishing fleets in the SESSF are known to shift effort seasonally, partly in response to environmental conditions, catch rates and market forces. This seasonal shift in fishing effort was examined for each of the species considered in this project and documented by initially plotting the latitude and longitude from all successful (with catches >1kg) shots in the period 1985–2006, and then splitting these plots into seasonal periods. The seasonal plots show all successful shots in two-month time intervals, (January and February, March and April, May and June, July and August, September and October, and November and December) with successful shots combined from shots in the period 1985–2006. This allows an easy visual comparison of the range of the fishing fleet in different seasons. To visualise this effort more effectively, contour lines were plotted on top of the raw shot data showing the positions of high and low densities of successful shots, for both the combined plot and seasonal plots.

All plots in this section include the raw data, plotted in grey dots, overlaid with a contour plot (in blue) to indicate the areas of high density and the coastline (in red). Note that these plots show density of shots where the target species was caught, and do not necessarily reflect the amount of catch in each shot. These plots reflect the number of successful shots for this target species rather than the amount of fish caught.

Seasonal movement varies considerably with each species and gear type. The blue grenadier non-spawning fishery has more effort off eastern Tasmania in the summer months and off NSW in the winter months (Figure 24). The western effort for blue grenadier is complicated by the definition of the spawning fishery off the west coast of Tasmania, but it appears that very little fishing effort occurs off the west coast of Tasmania in November and December, compared to the fishing effort for the rest of the year in this area. The pink ling trawlers increase their effort off eastern Tasmania in the summer months and decrease it in the winter months (Figure 27), whereas in the west the trends are not quite as clear, with the peak period for pink ling trawl effort in zone 50 (western Victoria) in March and April with the least effort in May and June in both zones 40 and 50, (western Victoria and western Tasmania, Figure 28). Redfish appears to have little seasonal shift in effort (Figure 30) with a similar pattern for Bight redfish, with just a little increase in effort in January and February in the south-east portion of the fishery (off the west coast of Eyre Peninsula, Figure 32). Silver warehou shows a clear increase in effort off eastern Tasmania in the summer months (Figure 35), but in the west the patterns are less clear (Figure 36), with a peak in effort in zone 40 (western Tasmania) from January through to April and a drop in the effort in zone 50 (western Victoria) in July-August and November-December.

7.3.2 Flathead Danish seine

The data for tiger flathead caught by the Danish seine fleet is concentrated off the coast of Eastern Victoria, with some fish occurring between Cape Otway and Wilsons Promontory (Figure 16, Figure 18). There is little seasonal movement of the Danish seine fishing effort for tiger flathead (Figure 17), and even at a fine spatial scale (in the area having the most effort) the distribution of fishing is fairly constant, decreasing slightly on offshore grounds during May–June (Figure 19).

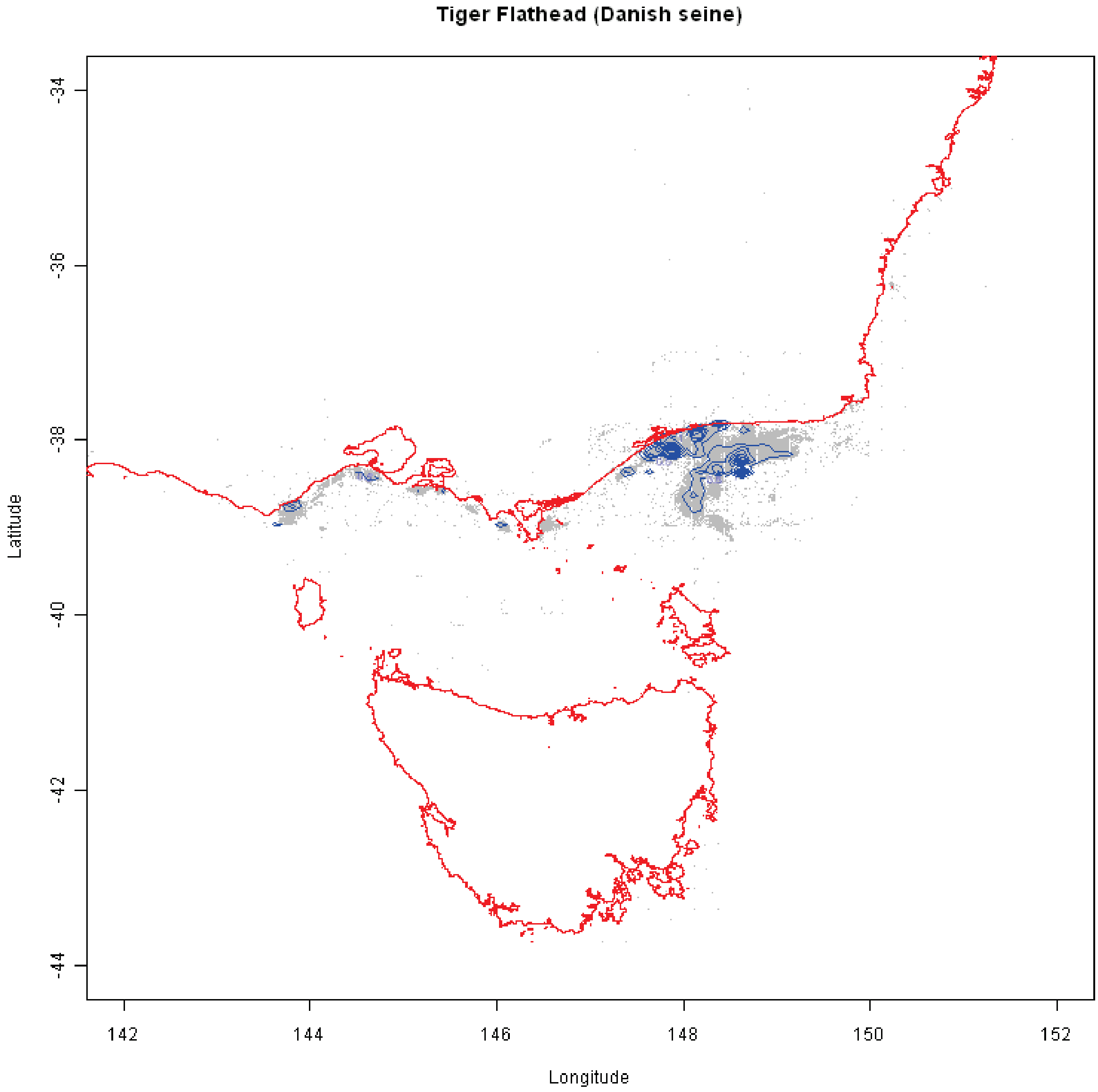

Figure 16. Tiger flathead (Danish seine) shots combined for all years and all seasons. Note the high density of shots near Lakes Entrance, in eastern Victoria.

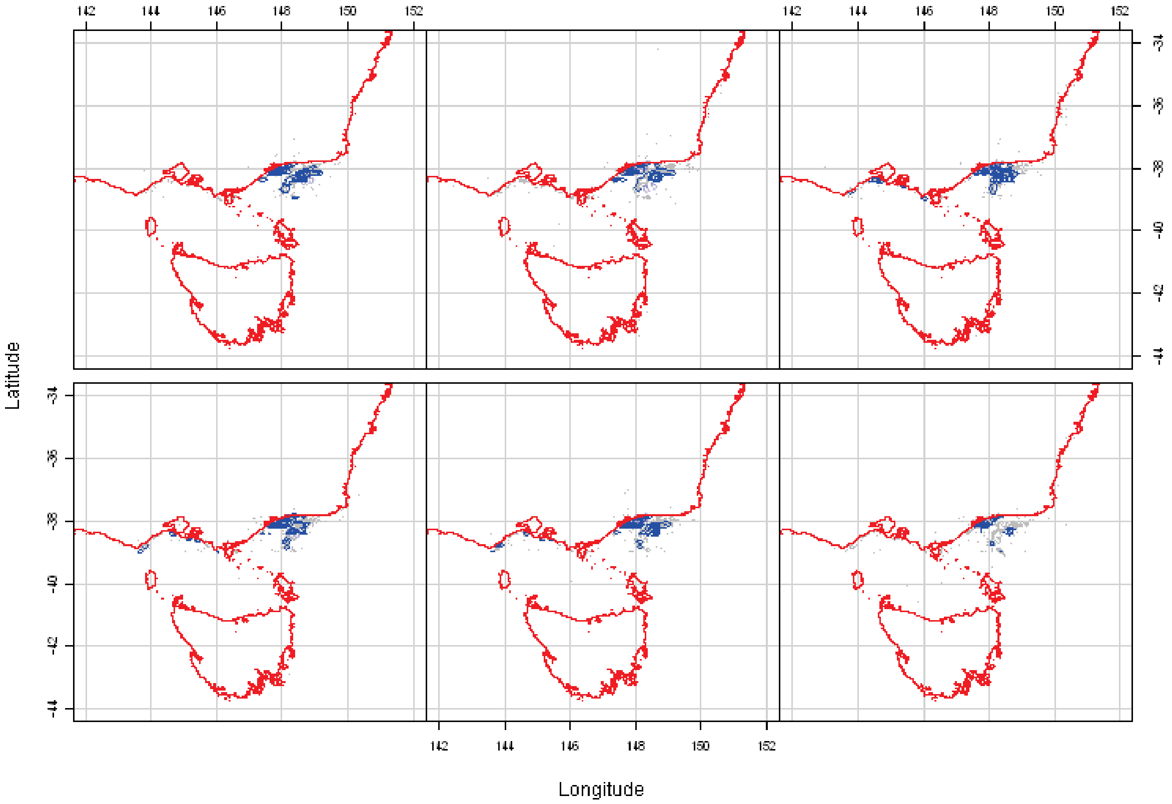

Figure 17. Tiger flathead (Danish seine) shots combined for all years separated into two month periods with January and February combined in the lower left corner, then March and April (lower middle), and progressing left to right along each row with November and December shown in the top right corner. The top panel indicated the two month period covered in each figure, with the left had bar relating to the figure in the top left, the 2nd bar from the left relating to the figure in the top center, and the bar on the far right hand side relating to the bottom right figure.

Figure 18. Tiger flathead (Danish seine) shots combined for all years and all seasons for a restricted geographic range, near Lakes Entrance, in eastern Victoria.

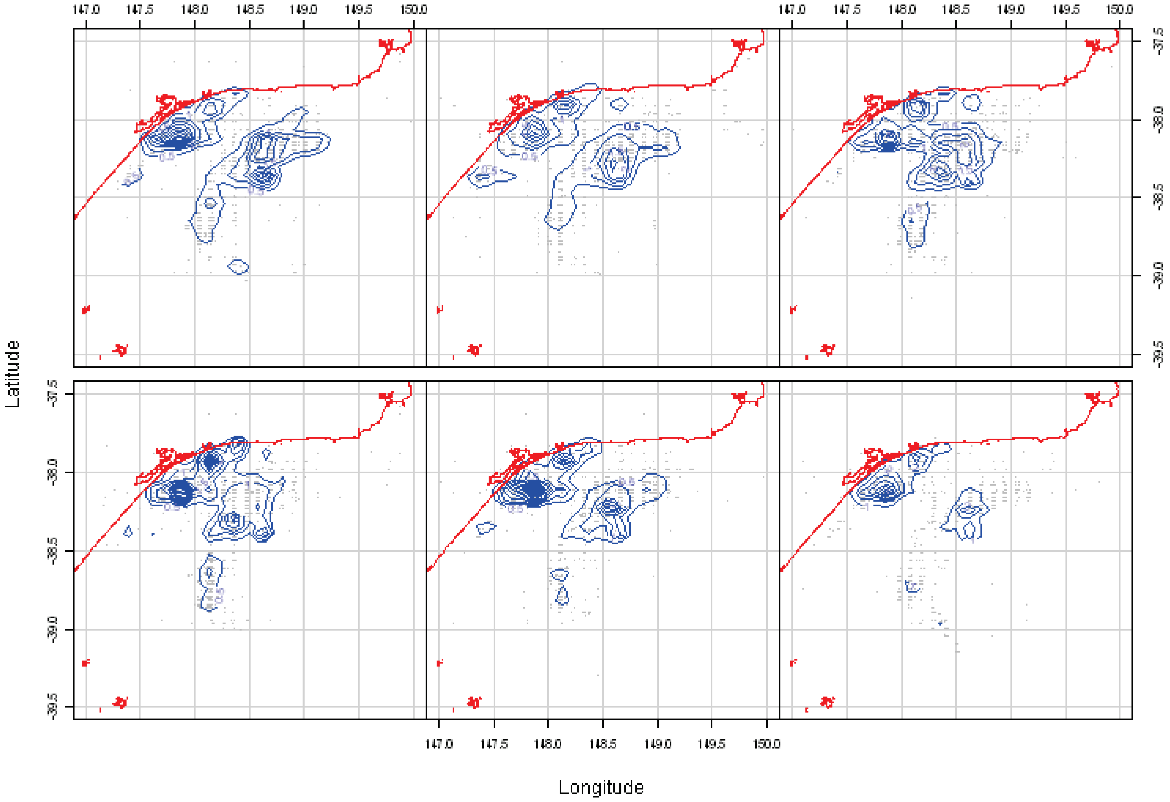

Figure 19. Tiger flathead (Danish seine) shots combined for all years, for a restricted geographic range, near Lakes Entrance, in eastern Victoria, separated into two month periods with January and February combined in the lower left corner, then March and April (lower middle), and progressing left to right along each row with November and December shown in the top right corner.

7.3.3 Flathead otter trawl

Effort targeting tiger flathead by the otter trawl fleet is more widely distributed than for the Danish Seine fleet. Fishing is concentrated off eastern Victoria, but a high proportion of the effort also takes place along the New South Wales coast (Figure 20). A considerable amount of fishing also occurs off eastern Tasmania and western Victoria. Plots of the distribution of effort show that throughout late autumn, winter and early spring the southern range of effort appears heavily concentrated off southern NSW. During November-December, the otter trawl fleet, many vessels of which are based out of Eden and Lakes Entrance, begins to move further south to fish longer trips more off eastern Tasmania during summer and early autumn months (Figure 21) before returning north again in autumn.

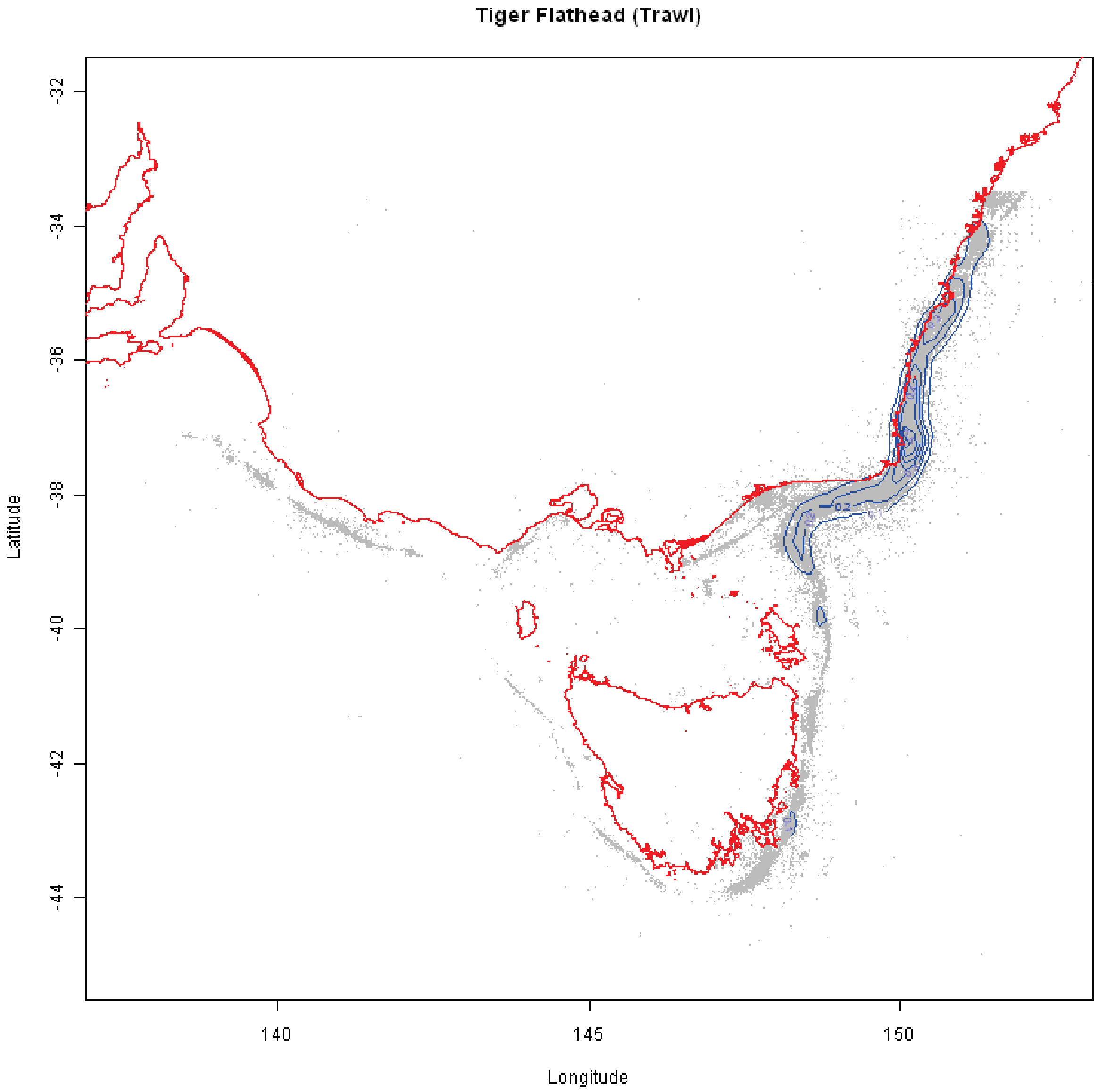

Figure 20. Tiger flathead (otter trawl) shots combined for all years and all seasons. Note the high density of shots in the eastern regions, in particularly in zones 10 and 20.

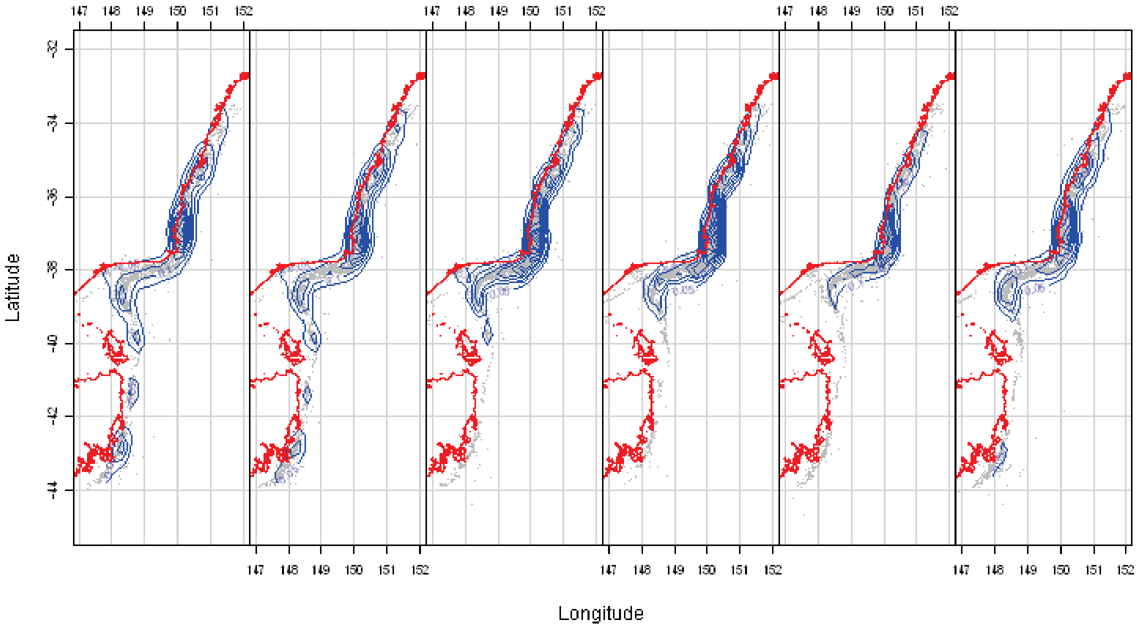

Figure 21. Tiger flathead (otter trawl) shots combined for all years, for a restricted geographic range of south-east Australia, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

7.3.4 Blue grenadier (non-spawning)

Most of the effort targeting non-spawning blue grenadier is concentrated off eastern Victoria, and western Victoria, and western Tasmania (Figure 22). Some spatial and temporal patterns were revealed in effort distribution plots. Effort off western Victoria drops off during winter, when presumably, vessels move to target the spawning population. Shots targeting spawning blue grenadier (June–August off western Tasmania) are not included in these plots resulting in the lack of effort off western Tasmania during May-June and July-August plots. Effort off NSW and eastern Victoria drops greatly during March-April and then moves north up the NSW coast during winter and spring before retracting south in January-February when there is a concentration of effort off eastern Tasmania (Figure 24).

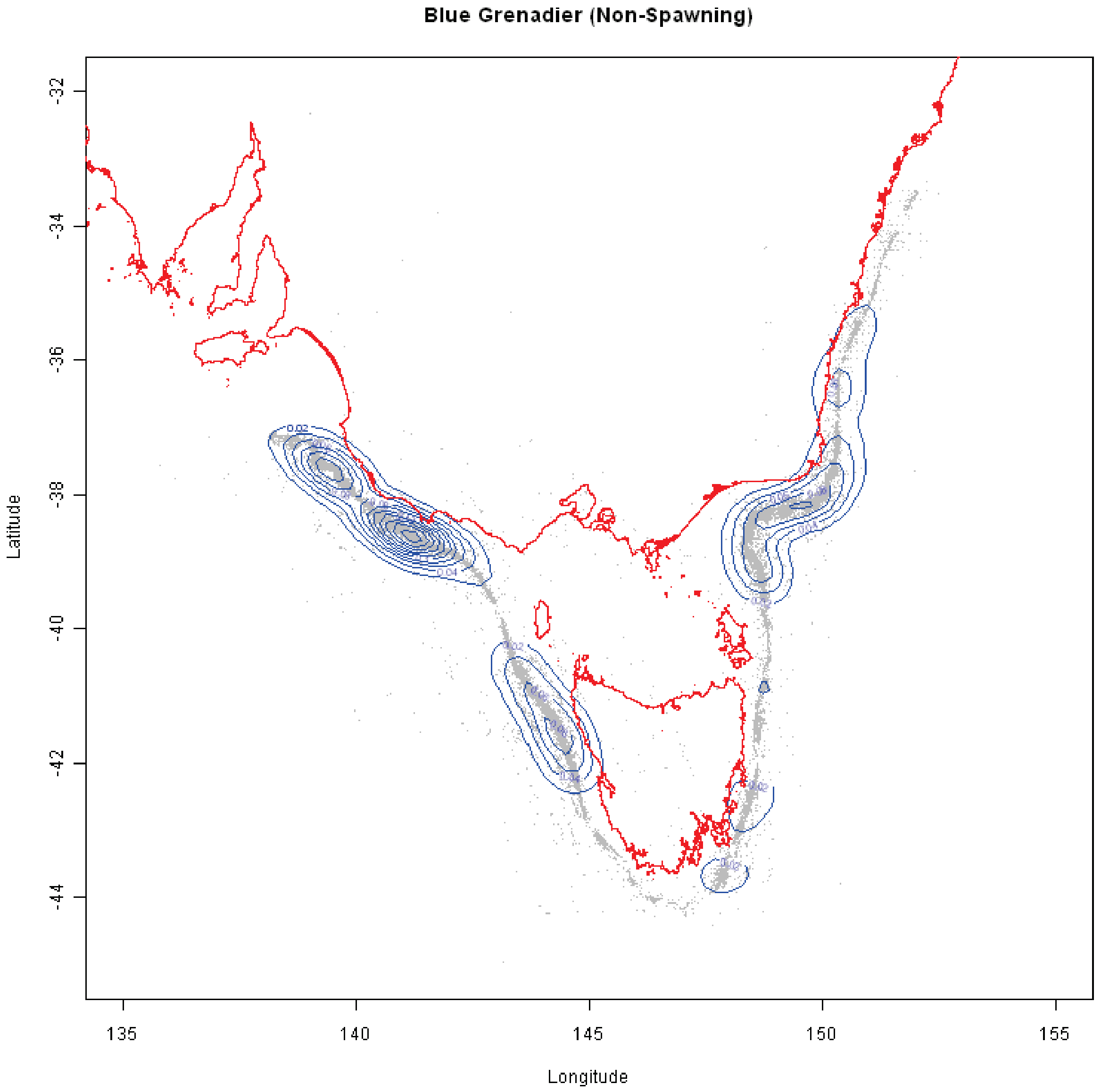

Figure 22. Blue grenadier (non-spawning) shots combined for all years and all seasons. Note the high density of shots in the western regions – in particular in zones 20, 40 and 50.

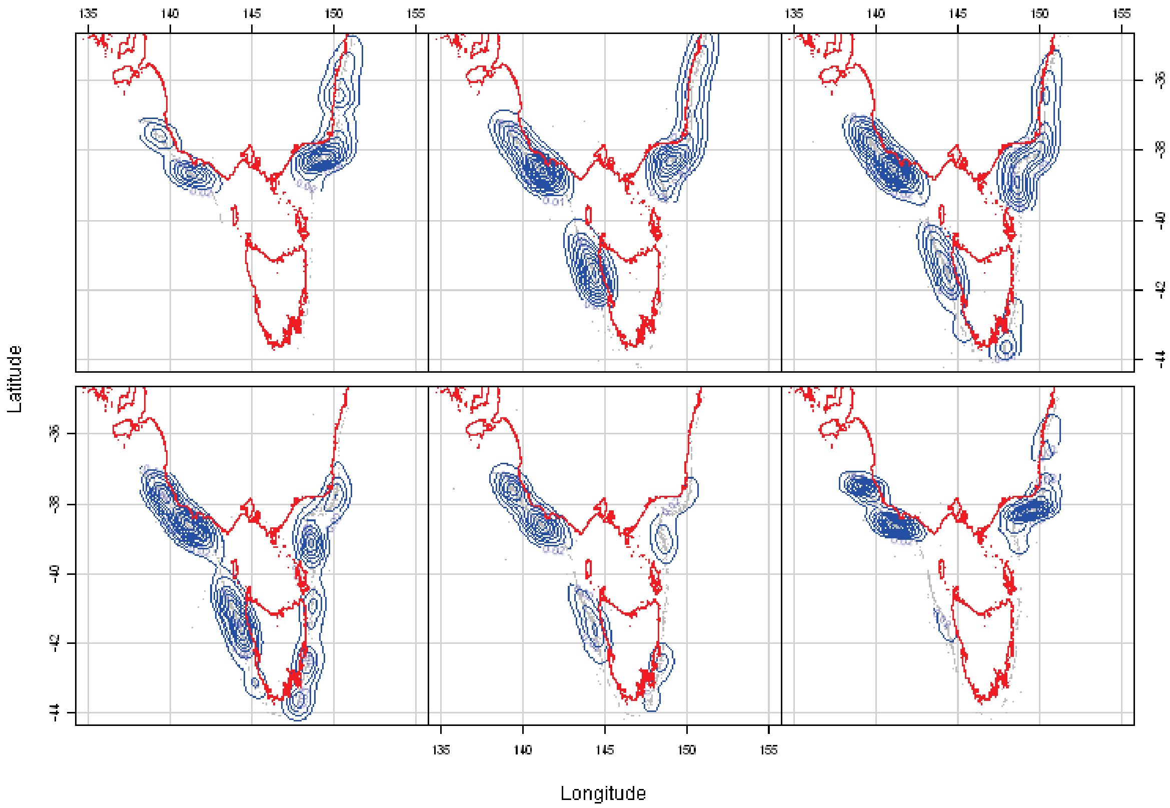

Figure 23. Blue grenadier (non-spawning) shots combined for all years, separated into two month periods with January and February combined in the bottom left panel, then March and April (bottom row, middle panel), and progressing left to right with November and December shown in the top right panel.

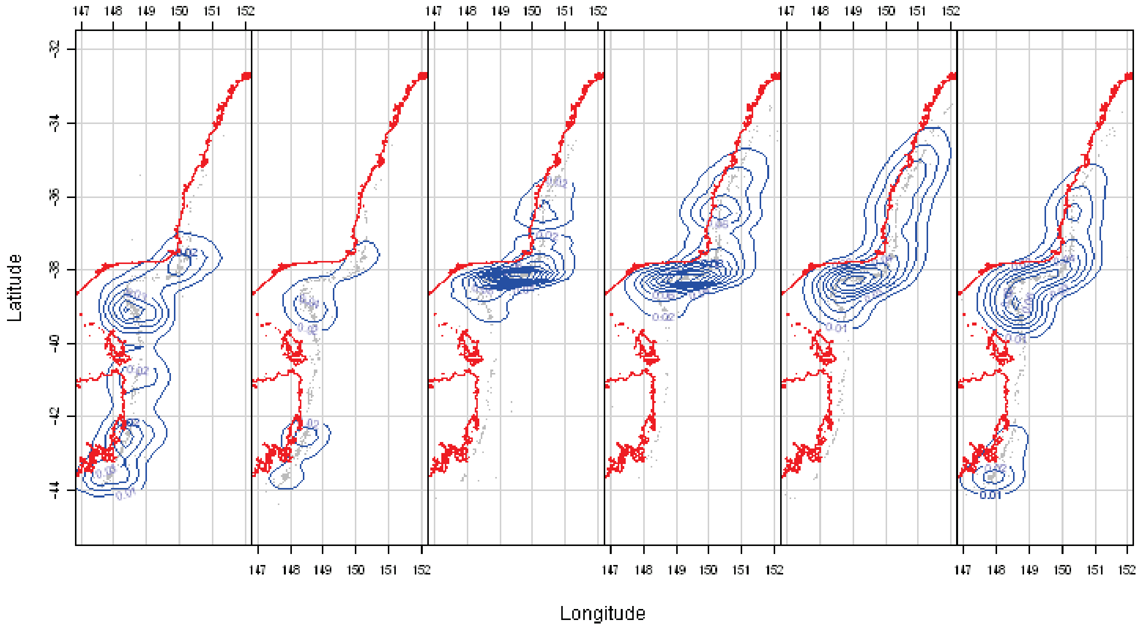

Figure 24. Blue grenadier (non-spawning) shots combined for all years in the east only, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

7.3.5 Pink ling

The distribution of effort for pink ling is shown in the following series of plots. Effort is distributed throughout south-east Australia, with particularly high concentrations right along the NSW and eastern Victorian coast, and off western Tasmania and western Victoria (Figure 25). On the east coast, there is a reduction in effort off Tasmania during May-June (Figure 26) when there also appears to be a restriction of effort over a narrower depth range off NSW and eastern Victoria than in other months (Figure 27). Effort returns to eastern Tasmania over the summer months. There is limited seasonal movement in the geographical distribution of the effort for ling off western Victoria and Tasmania, however, effort is reduced in these regions during winter months (Figure 28).

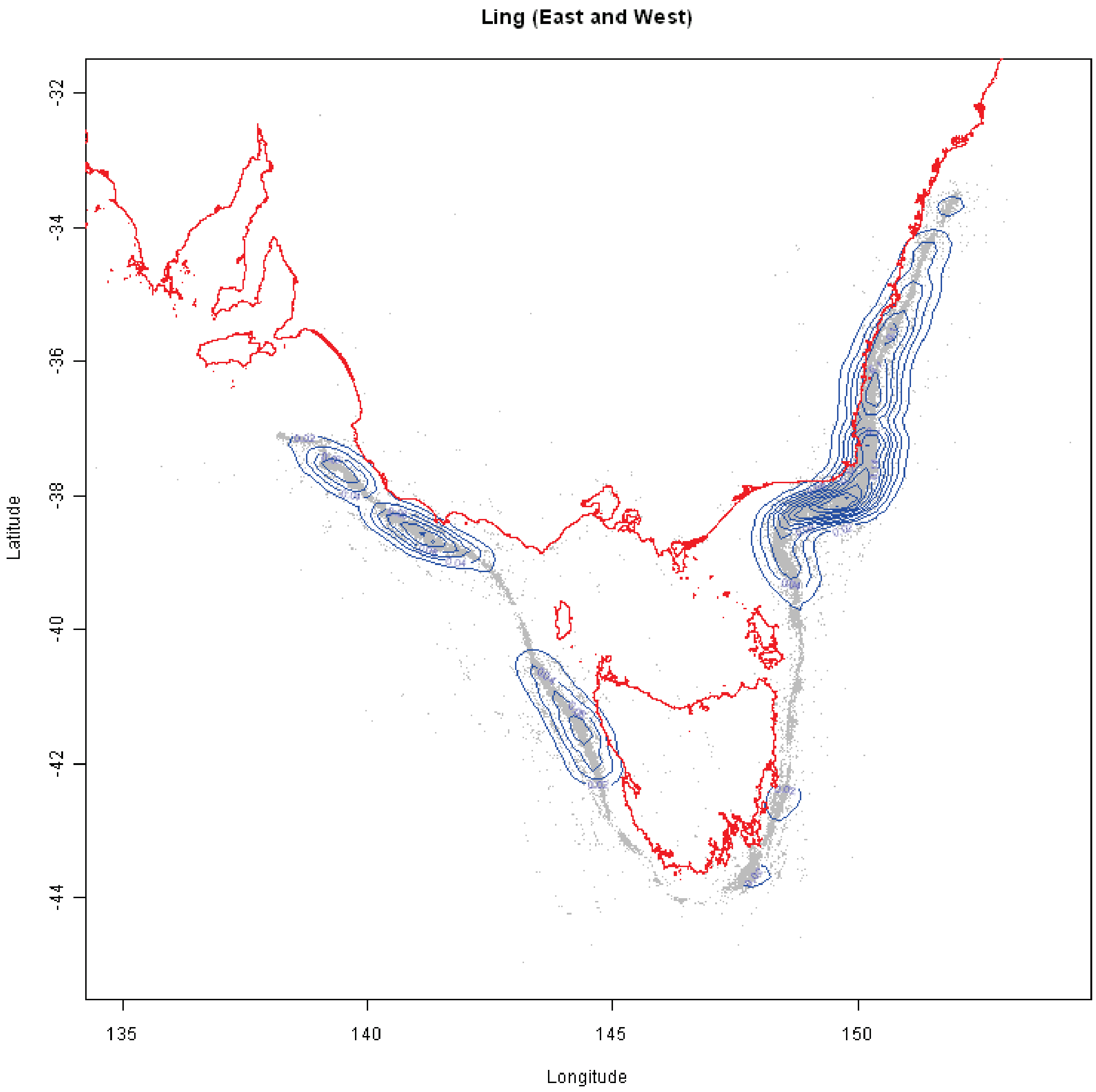

Figure 25. Pink ling (east and west combined) shots combined for all years and all seasons.

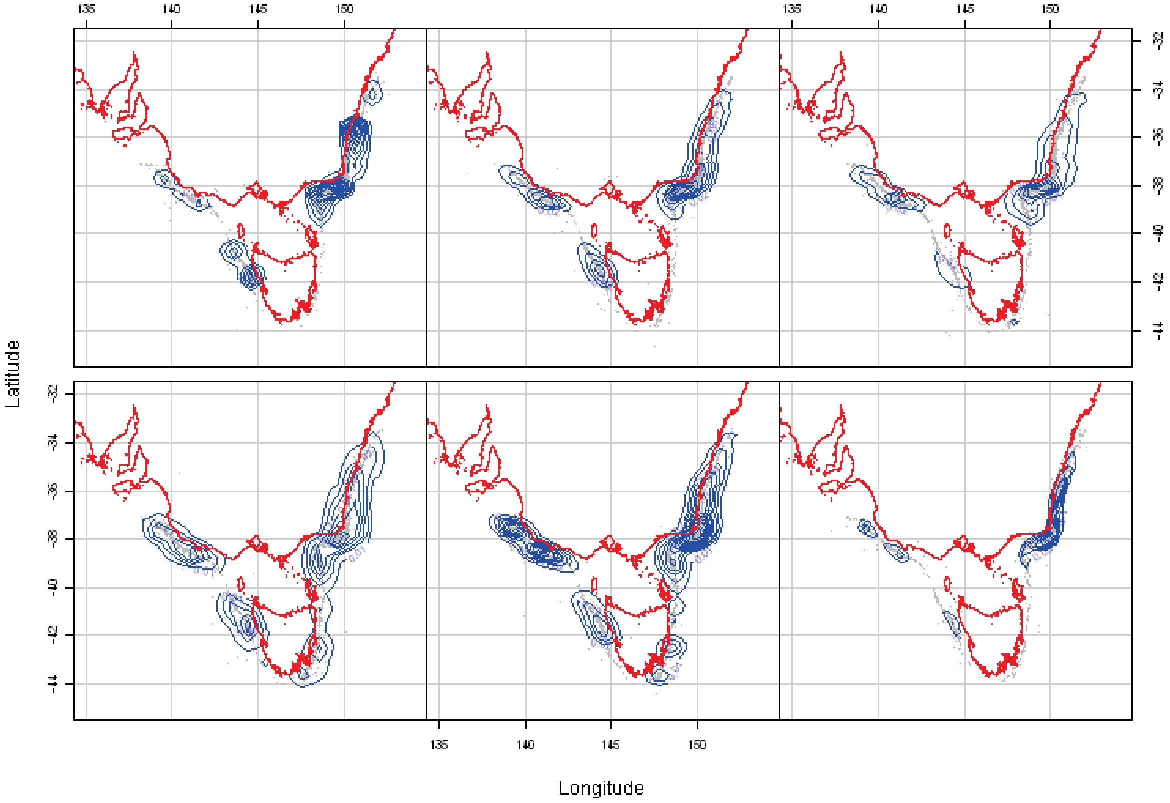

Figure 26. Pink ling (east and west combined) shots combined for all years separated into two month periods with January and February combined in the bottom left panel, then March and April (bottom row, middle panel), and progressing left to right with November and December shown in the top right panel.

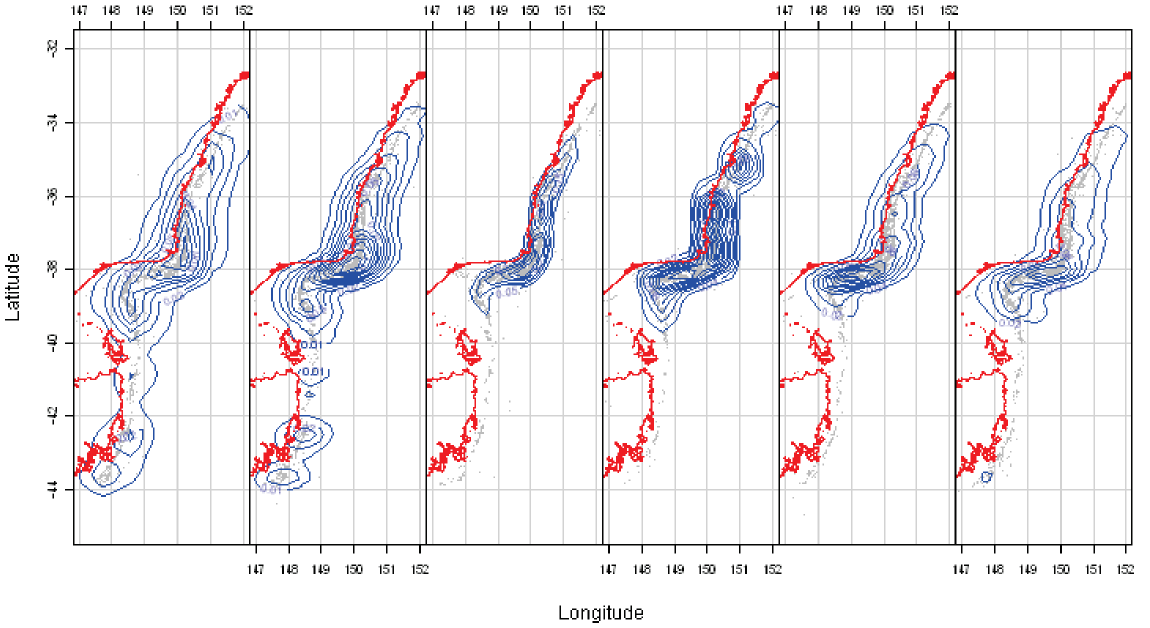

Figure 27. Pink ling shots combined for all years in the east only, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

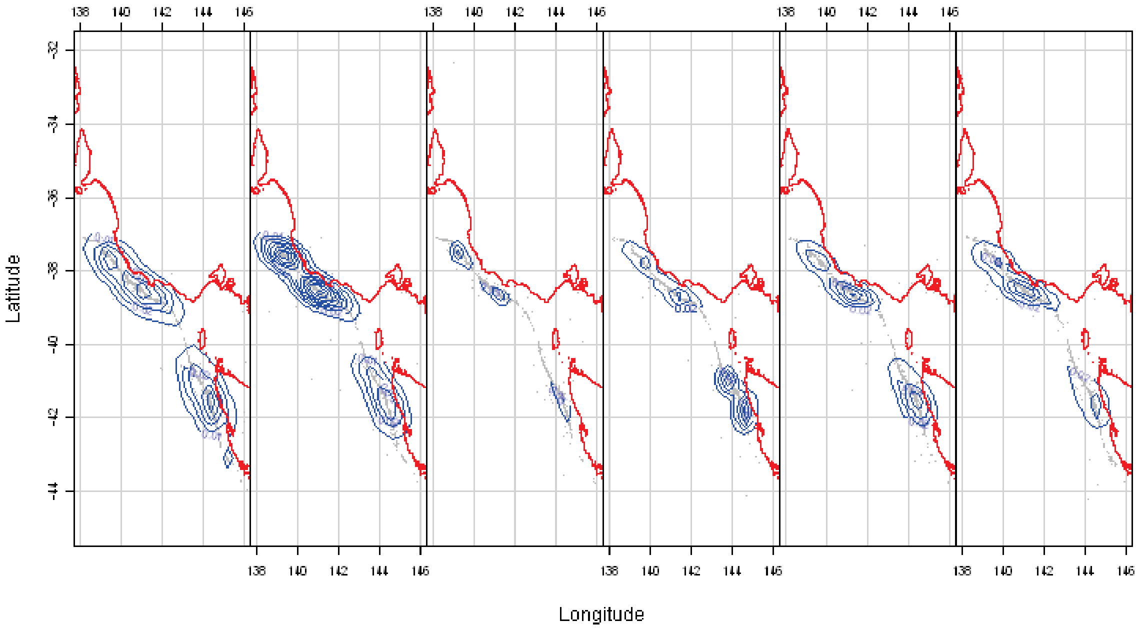

Figure 28. Pink ling shots combined for all years in the west only, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

7.3.6 Redfish

The distribution of effort for redfish is almost entirely off NSW and eastern Victoria (Figure 29). There is no obvious seasonal movement in the geographical distribution of the effort for this species (Figure 30).

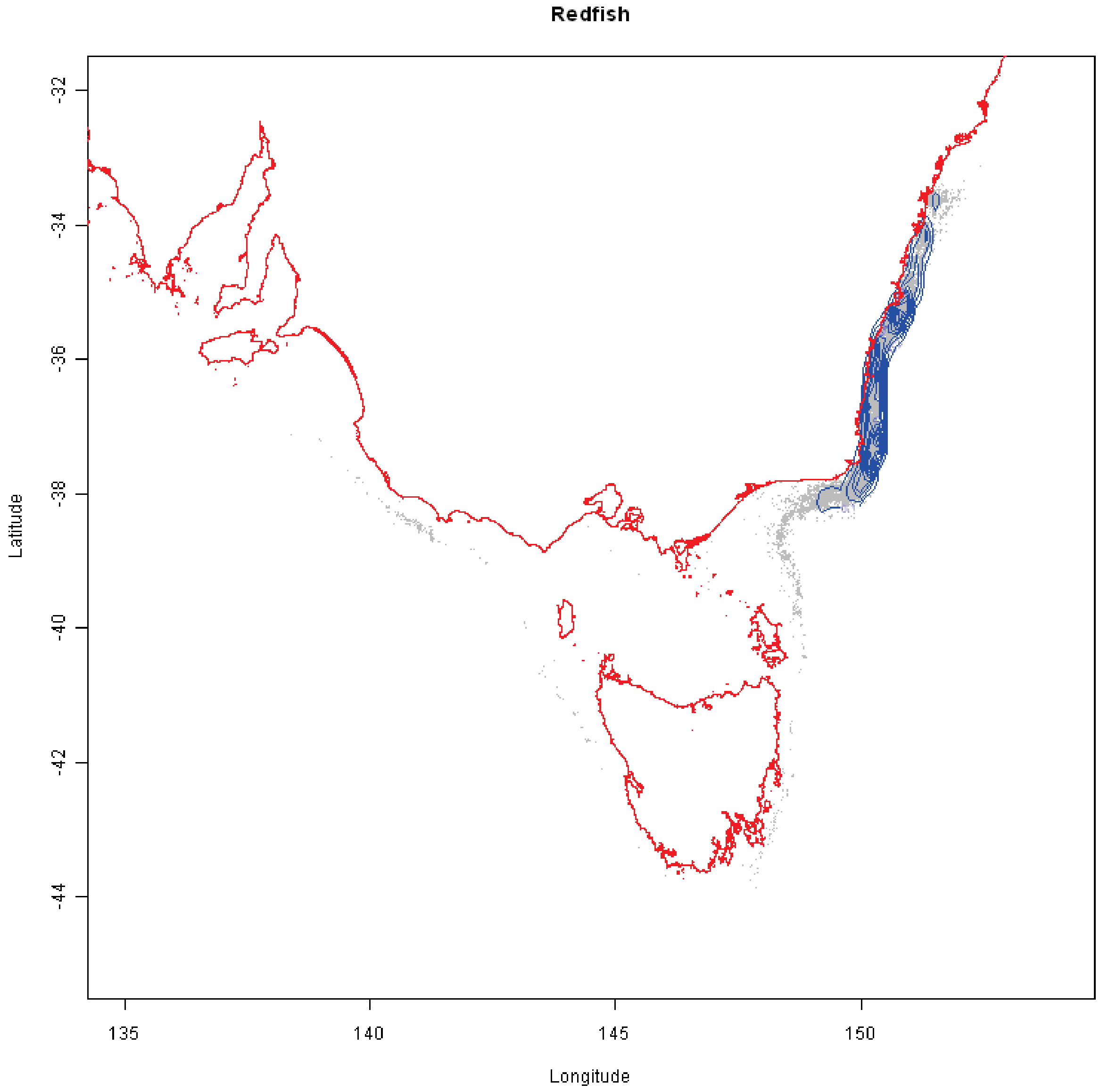

Figure 29. Redfish shots combined for all years and all seasons.

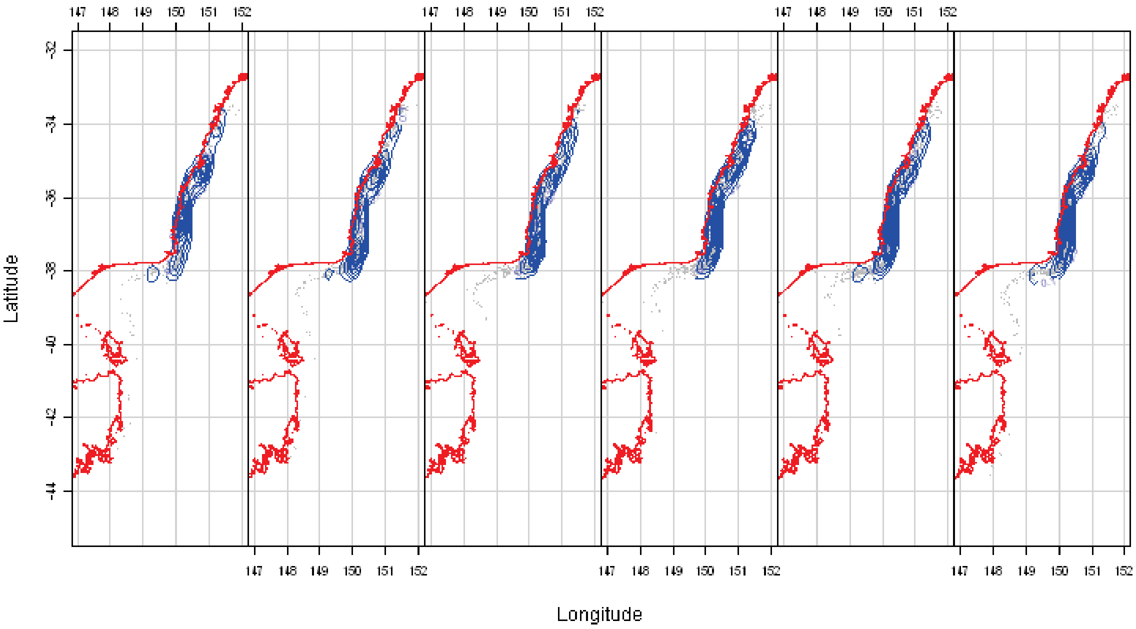

Figure 30. Redfish shots combined for all years in the east only, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

7.3.7 Bight redfish

The distribution of effort for Bight redfish is shown concentrated along a narrow band along the length of the Great Australian Bight (Figure 31). There appears to be some small south-east movement in the distribution of effort during January-February (Figure 32).

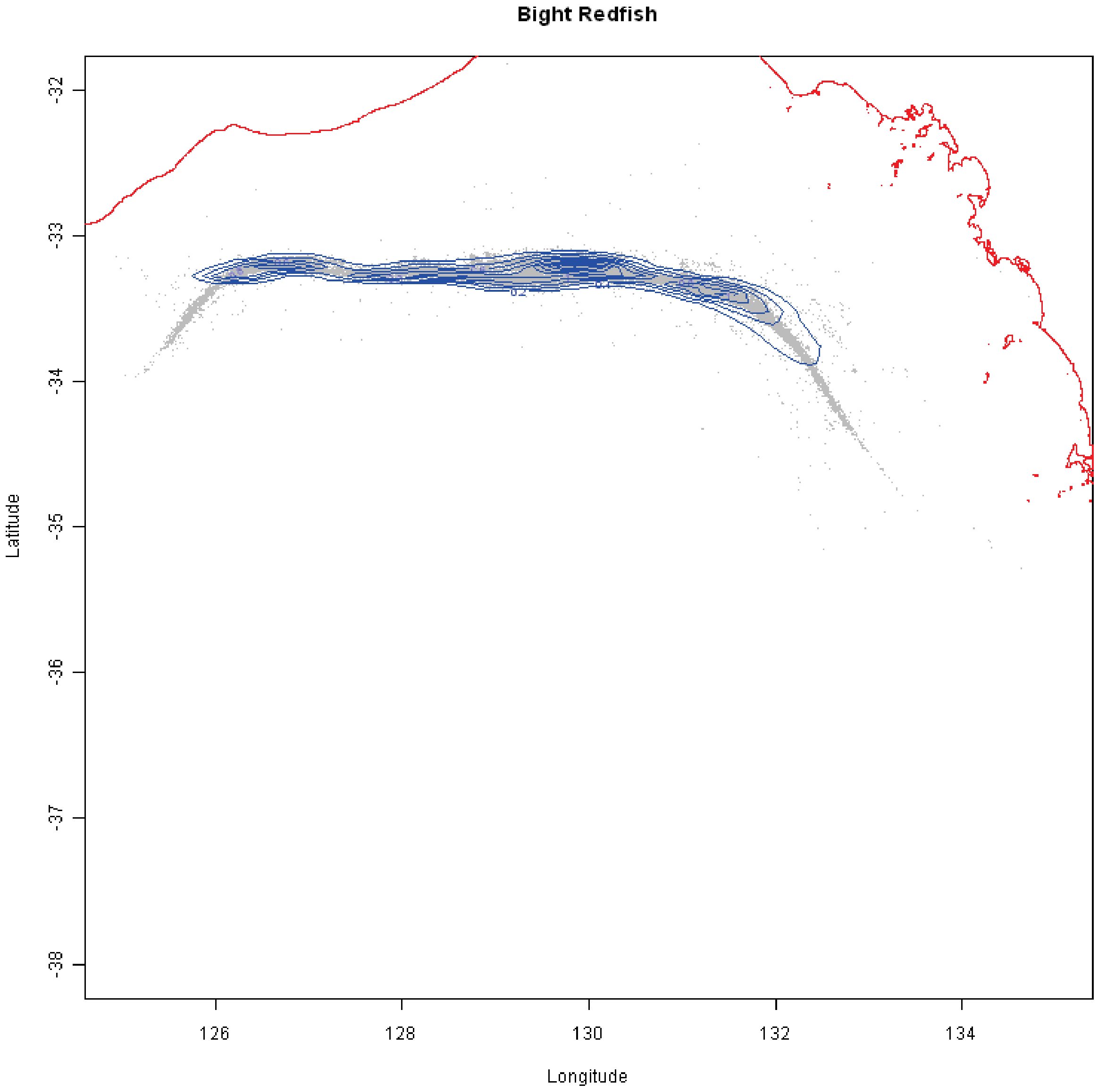

Figure 31. Bight redfish shots combined for all years and all seasons.

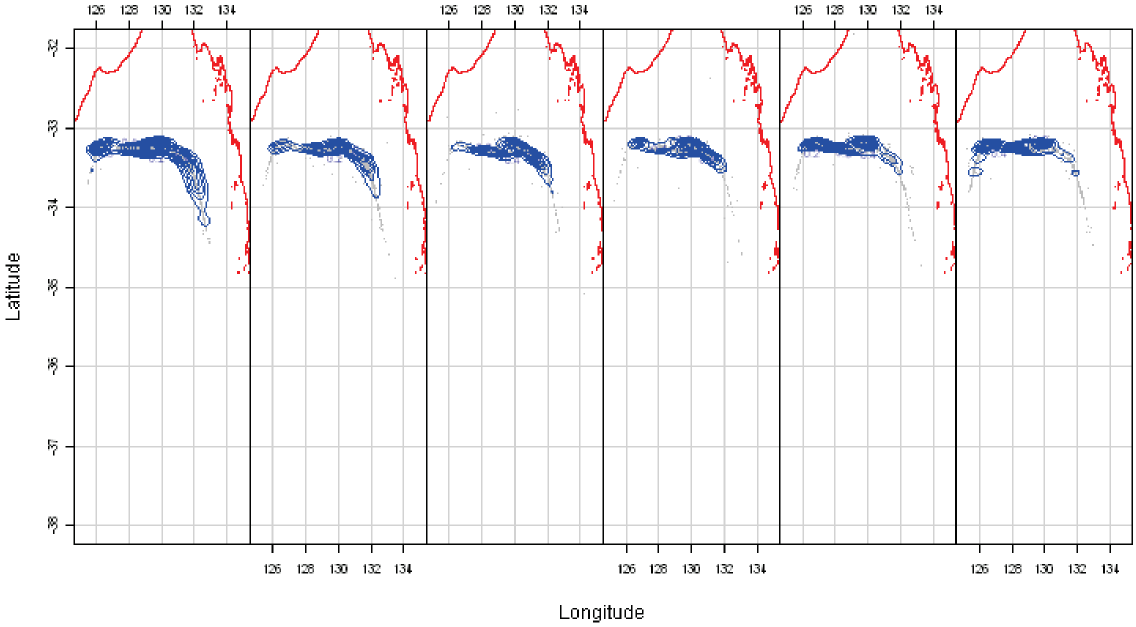

Figure 32. Bight redfish shots combined for all years separated into two month periods with January and February combined in the bottom left panel, then March and April (bottom row, middle panel), and progressing left to right with November and December shown in the top right panel.

7.3.8 Silver warehou

Concentrations of effort targeting silver warehou can be seen off western Victoria, western Tasmania, eastern Tasmania, eastern Victoria and southern NSW (Figure 33). Some seasonal changes in the distribution of effort were observed (Figure 34), particularly off eastern Tasmania where the pattern was similar to that for pink ling and blue grenadier — increasing in summer months and being nearly non-existent during winter months (Figure 35). The distribution of effort in the west was also similar to that observed for pink ling, with limited seasonal movement in the geographical distribution but some seasonal changes in fishing intensity, increasing over the summer months (Figure 36).

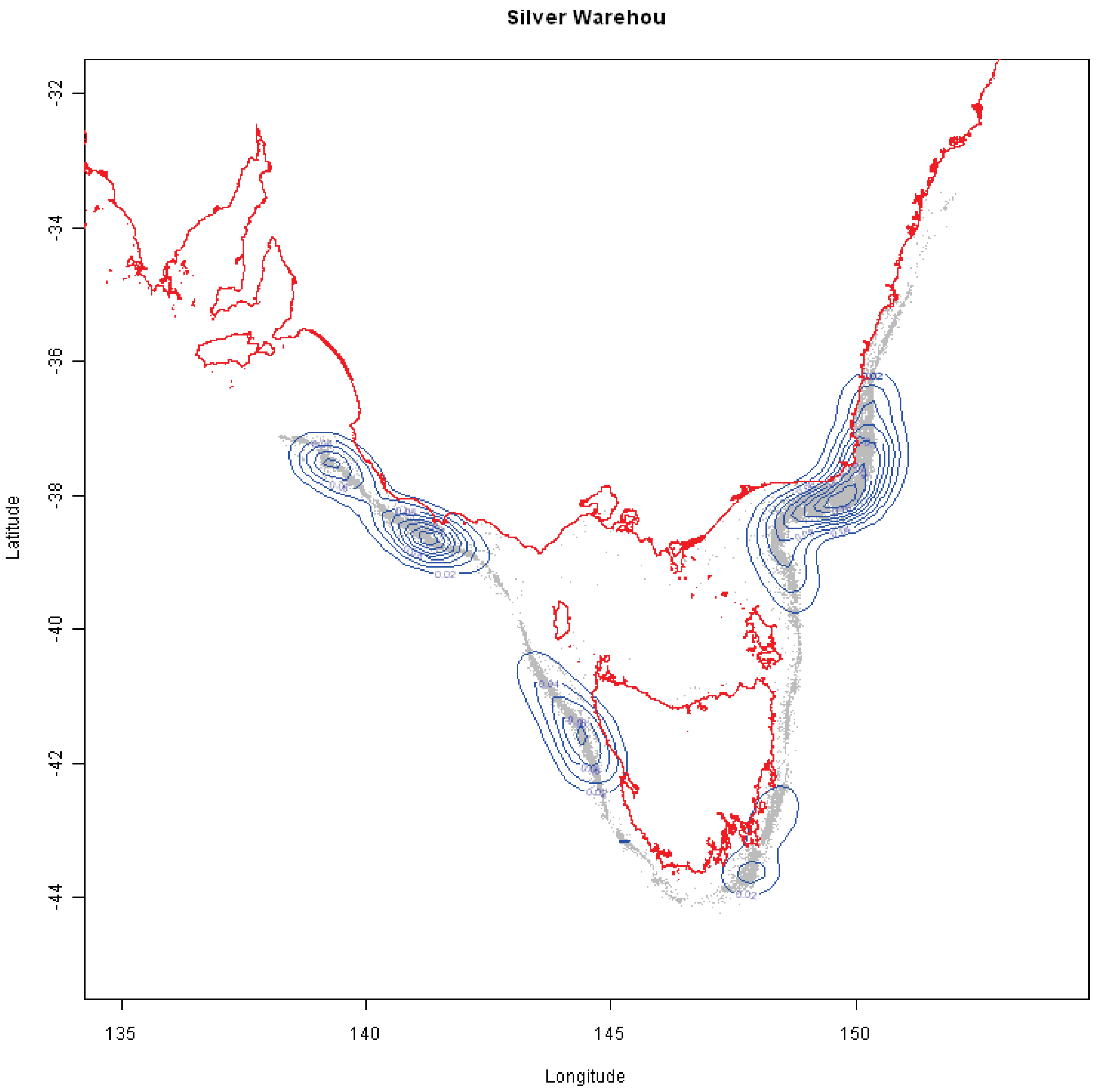

Figure 33. Silver warehou (east and west combined) shots combined for all years and all seasons.

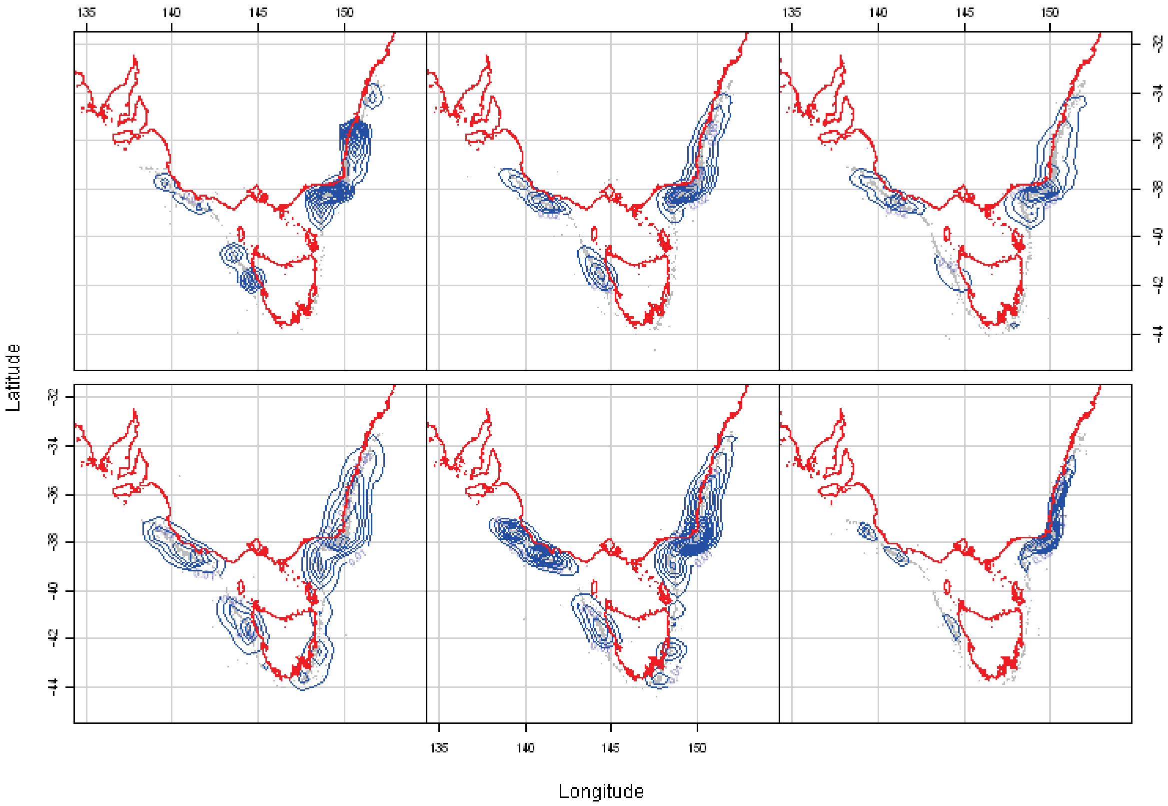

Figure 34. Silver warehou (east and west combined) shots combined for all years separated into two month periods with January and February combined in the bottom left panel, then March and April (bottom row, middle panel), and progressing left to right with November and December shown in the top right panel. There appears to be some seasonal movement in the geographical distribution of the effort for this fishery, with variation in effort both north-south and east-west.

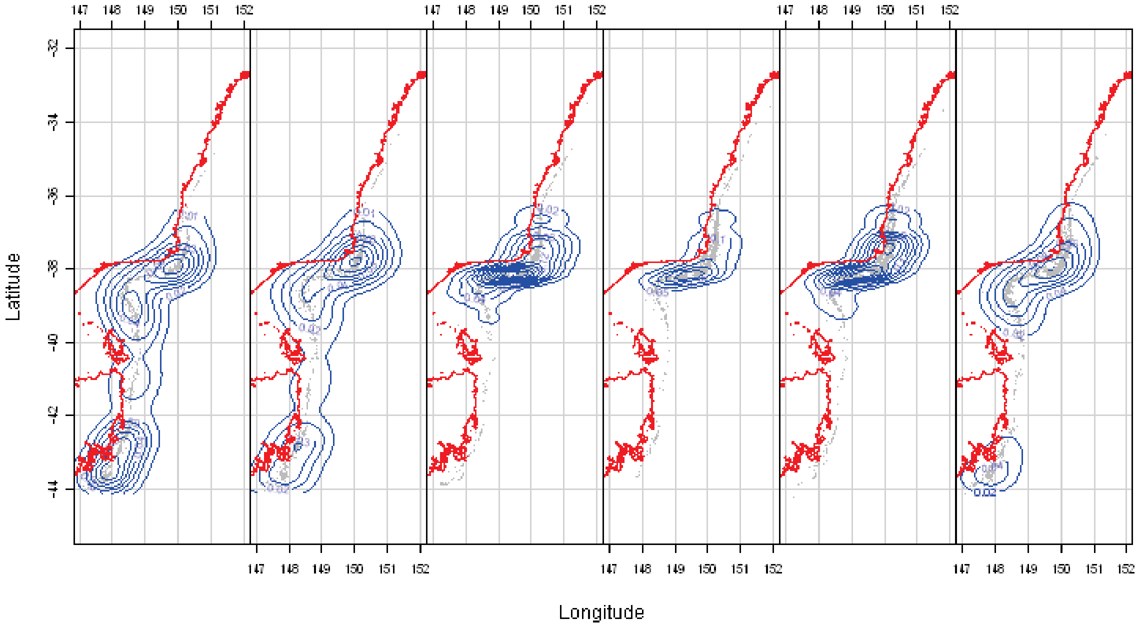

Figure 35. Silver warehou shots combined for all years in the east only, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

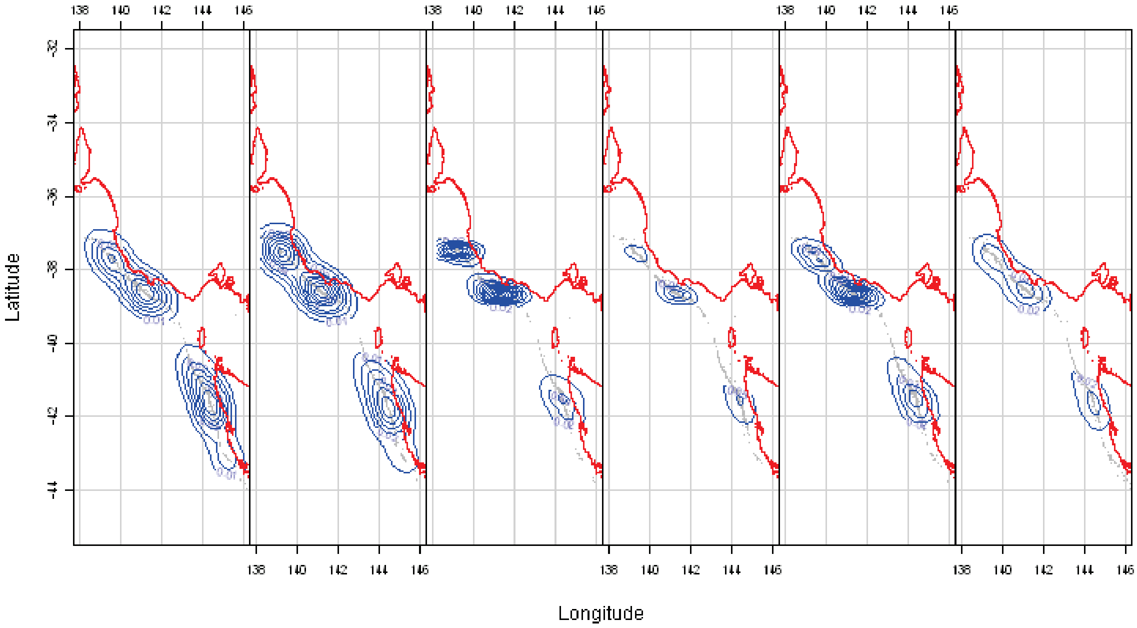

Figure 36. Silver warehou shots combined for all years in the west only, separated into two month periods with January and February combined in the left panel, then March and April (2nd panel), and progressing left to right with November and December shown in the right panel.

7.4 LITERATURE REVIEW – CONNECTIONS BETWEEN ENVIRONMENTAL AND OCEANOGRAPHIC VARIABLES AND FISH POPULATION DYNAMICS

Jemery Day

7.4.1 Time scales of climate variability

The links between environmental conditions and fish population dynamics have been examined on a number of time scales ranging from hundreds of thousands of years (Sharp, 2003), through to hundreds of years and decades (Francis and Hare, 1994; Lluch-Cota *et al.*, 1997; Klyashtorin, 2001; Tian *et al.*, 2004a; Tian *et al.*, 2004b; Pershing *et al.*, 2005).

A range of direct and indirect techniques are used to examine data over short and long time scales. Numerous examples show that fisheries dynamics involve much more than isolated fish stocks and fishing mortality because oceans and hence fisheries are connected to larger scale dynamic forces and processes (Sharp, 2003). One well known case demonstrates a strong relationship over a period of several decades between upward sea surface temperature trends off coastal Japan and population increases in three species of sardine from different regions in the Pacific Ocean (Kawasaki *et al.*, 1991; Sharp, 2003). This same example shows population declines apparently related to ocean cooling through along-shore, wind-driven upwelling periods.

The El Niño-Southern Oscillation (ENSO) is probably the best known mechanism of global climate variability, and is considered to have large impacts on marine ecosystems and particularly on populations of small pelagic species. However, major changes in abundance and species composition of small pelagic species tend to occur on an interdecadal scale, rather than the interannual variability normally associated with ENSO. Statistical relationships investigated between small pelagic populations, both climate regimes and ENSO activity indicate possible parallel behaviour, with global climate signals lagging about a decade behind variations of populations of small pelagic species (Lluch-Cota *et al.*, 1997). In contrast, Brodziak and O'Brien (2005) showed that the North Atlantic Oscillation (NAO) index, forward-lagged by 2 years had the largest correlation with recruits per spawner anomalies of New England groundfish.

The search for long-term datasets showing variability in fishery populations and environmental fluctuations has resulted in the examination of a diverse range of long-term data such as glacial ice cores, tree rings and fish scale diversity in ocean sediments. Klyashtorin (2001) found evidence suggesting that fish populations and environmental variables oscillated on a 50–70 year time scale. Spectral analysis of up to 150 years of global air surface temperature anomaly (dT), Atmospheric Circulation Index (ACI), and Length Of Day (LOD) data showed a clear 55–65 year periodicity. Similar results were also obtained from longer-term datasets. Air surface temperatures over a 1500 year period, reconstructed from analysis of glacial ice core samples and tree rings, also showed a 55–60 year periodicity. Similarly, the analysis of a 1600 year time series of sardine and anchovy biomass, reconstructed from fish scales in varved sediment cores in a Californian upwelling, revealed a regular 50–70 year fluctuation. Likewise, the spectral analysis of catch statistics of commercial species for the last 50–100 years showed cyclical fluctuations of about 55 years (Klyashtorin, 2001).

A number of authors have investigated more recent effects of climate change on fisheries. They looked at the implications of warming climates and future climate change on fishery management (Cook and Heath, 2005; Drinkwater, 2005; Fried-land *et al.*, 2005; Köster *et al.*, 2005; Poulard and Blanchard, 2005; Rose, 2005; Rothschild *et al.*, 2005). Historical catches of salmon, cod, and halibut from the 17th and 18th centuries have been examined and correlations were found between temperature records and catches and catch weights (Lajus *et al.*, 2005).

7.4.2 Linking environmental variables and fish population dynamics

There is a large number of potential environmental and oceanographic variables that may be linked to fish population dynamics and recruitment success, including: temperature, upwelling, freshwater discharge, phytoplankton concentration, transport, wind mixing, salinity, and dissolved oxygen. Selecting the most appropriate environmental and oceanographic variables and establishing whether the links are causal or merely coincidental is a major challenge.

Many relationships have been identified between environmental factors and either recruitment success or other impacts on fish abundance (Leggett *et al.*, 1984; Drinkwater and Myers, 1987; Skreslet and Borja, 2003; Hunt and Megrey, 2005; Möllmann *et al.*, 2005). However, the complexity of the marine ecosystem and the inherent non-linearities often cause apparent relationships to fail when retested with additional data (Myers, 1998).

The most common environmental factor identified as influencing fish population dynamics is temperature and correlations between temperature and aspects of population dynamics have been examined in numerous studies (Ellertsen *et al.*, 1989; Planque and Frédou, 1999; van der Veer and Witte, 1999; O'Brien *et al.*, 2000; Beaugrand *et al.*, 2003; Cook and Heath, 2005; Drinkwater, 2005; Greve *et al.*, 2005; Hansen *et al.*, 2005; Megrey *et al.*, 2005; Orlova *et al.*, 2005; Rätz and Lloret, 2005). While data on temperature is relatively easy to measure or to obtain from other sources, temperature has obvious links to physiological processes, and it can also be a good proxy for other oceanographic mechanisms.

Stock-environment recruitment models were fitted for Norwegian herring to a long time series of spawning stock, recruitment, and temperature data extending back to 1907 (Fiksen and Slotte, 2002). This work shows a strong relationship between temperature and both spawning stock biomass and recruitment. Including sea temperature in the stock-recruitment model increases the explanatory ability and removes autocorrelation from the residual variability.

While temperature is often used, in some cases other environmental variables seem to be more important. The relationship between the catch-per-unit-effort of fisheries targeting juvenile North Atlantic albacore and several environmental variables was studied by Goñi and Arrizabalaga (2005). A significant negative relationship occurred between catch-per-unit-effort (CPUE) of age 2 albacore and both the average agitation of the sea and the duration of insolation. No clear relationship was found between CPUE and sea surface temperature, precipitation, NAO or Gulf Stream Index. Goñi and Arrizabalaga (2005) suggest that this highlights the importance of considering environmental variables in the standardisation of CPUE series used for stock assessment.

7.4.3 Appropriate choice of spatial scale: spatial correlation of environmental variables

While in some cases, broad scale indices can be correlated with fish population dynamics over wide geographical scales (Kawasaki *et al.*, 1991), there are some cases when there is a need to consider appropriate spatial boundaries.

Spatial correlations for the three coastal variables sea surface temperature (SST), sea surface salinity (SSS) and an upwelling index were examined by Mueter *et al.* (2002b). They postulated that these environmental variables may affect juvenile salmon during their early marine life. Both the upwelling index and coastal SST were characterised by strong positive correlations with juvenile salmon mortality at short distances. The SSS had much weaker and more variable correlations. Mueter *et al.* (2002b) conclude that the coastal marine environment is dominated by regional scale variability of several hundred to a thousand kilometres and that this variability in coastal SST can help explain covariation across space in survival rates among salmon stocks.

Mueter *et al.* (2002b) emphasise the need to seek spatial correlations in addition to temporal correlations to avoid finding spurious correlations. This avoids problems using environmental variables that may be correlated among themselves at various spatial scales, problems using environmental or fish population variables averaged over a variety of temporal or spatial scales or problems associated with using various time lags. If different populations respond similarly to environmental forcing, environmental variables can only explain changes in fish population variables if their correlation scales are similar to those seen in the fish populations. Furthermore, similarity in correlation scales can lend strong support to observed correlations between environmental and population variables for individual fish stocks.

The need to consider appropriate regional scales was also highlighted in a study estimating the effects of ocean temperature on survival rates of three species of Pacific salmon (Mueter *et al.*, 2002a). The estimated effects were examined across 120 stocks and they differed between northern and southern stocks, but were consistent across stocks within species and areas. Warm anomalies in coastal temperatures were associated with increased survival rates for stocks in Alaska and decreased survival rates for stocks in Washington and British Columbia, suggesting that different mechanisms determine survival rates in the two areas. Regional-scale sea surface temperatures were a better predictor of survival rates than large-scale climate anomalies, suggesting that survival rates are primarily linked to environmental conditions at regional spatial scales.

Consistent with previous studies, Mueter *et al.* (2005) found that correlations between the survival rates of pink or sockeye salmon in Alaska and sea surface temperature have opposite signs from correlations for stocks in British Columbia and Washington at most lags and at both regional and large spatial scales. In general, however, the measures of coastal ocean conditions that they examined explain a relatively small proportion of the environmentally induced variability in salmon survival rates.

Others also suggest that the temporal-spatial response scale of a specific regional oceanic ecosystem is generally smaller than that of a climatic regime shift (Tian *et al.*, 2004a; Chiba *et al.*, 2005). Hence, it is important to identify the regional variation pattern in the specific oceanic environment which affects the dynamics of the fish stocks and ecosystem.

7.4.4 Environmental impacts on juvenile survival

Different environmental and oceanographic variables may affect a population at various life stages. Some of these impacts on the population dynamics may be more significant for some life stages than others. In many cases, environmental impacts on juvenile mortality can have critical consequences for effective recruitment and population dynamics.

Given the postulated effect of environmental conditions on juvenile survival, Mueter *et al.* (2005) tested the hypothesis that survival rates from spawners to recruits in three species of Pacific salmon are related to coastal ocean conditions during migration to the sea and soon after. They correlated measures of survival rate for 110 stocks of salmon with regional-scale indices of coastal sea surface temperature, sea surface salinity, and upwelling as well as with a large-scale index of ocean climate. Survival rates were related to ocean temperatures just prior to, during, and after out-migration, which are indicative of the early marine conditions experienced by juvenile salmon. However, for two of the three species studied, survival was most strongly correlated with marine conditions prior to out-migration, during freshwater residency. No evidence was found for any relationship between the survival rates of salmon and coastal upwelling conditions.

Changes in the climate and oceanography of the north-east Pacific influence the recruitment of walleye pollock and other groundfishes in the Bering Sea (Hollowed *et al.*, 2001; Mueter *et al.*, 2006). However, the observed relationships between environmental variables and survival or recruitment were relatively weak and explained only a moderate proportion of the variability in recruitment (Mueter *et al.*, 2006). In particular, recruitment of strong year-classes was often greatly underestimated. Nevertheless, environmental effects at the larval stage, such as the estimated effects of surface transport, have been included in current stock assessment models.

7.4.5 Do correlations imply mechanisms?

It can be difficult to establish clear connections between variability in the environment and recruitment and there are mixed feelings about the benefits of drawing strong conclusions based on correlative studies. Walters and Collie (1988) criticise correlative environment-recruitment studies as futile because of biases, measurement error, and the near certainty of spurious correlations. Similarly, Cook and Heath (2005) argue that when correlations between recruitment and the environment are discovered, the mechanism driving the relationship is usually a matter of speculation. In contrast, others (Kope and Botsford, 1990; Tyler, 1992) claim that correlative studies provide information on patterns that lead to the formulation of testable hypotheses. Mueter *et al.* (2002b) emphasise the need to avoid spurious correlations.

7.4.6 Coexistence and modelling environmental variability

Several authors show that fluctuations between good and poor environmental conditions can actually promote coexistence for a range of species, or have a positive influence for an individual species. Using a modelling approach Pitchford *et al.* (2005) show that variance in an individual's environment significantly increases the probability of recruitment. This has similarities to earlier work on the intermediate disturbance hypothesis (Connell, 1978) and coexistence theory, mediated by variable environmental conditions (Chesson, 2000).

7.4.7 Regime shifts

Population dynamics and environmental conditions can be relatively stable on decadal scales, during periods called regimes. A regime implies a characteristic behaviour of a natural phenomenon over time. A shift suggests an abrupt change from one characteristic behaviour to another. Although climate variability occurs across a broad spectrum of spatial and temporal scales, a regime spans a decade or more, whereas a shift occurs within a period of a year or so (Hare and Mantua, 2000; McFarlane *et al.*, 2000).

Ecological regime shifts occurred in the North Sea and the central Baltic Sea synchronously in the late 1980s (Alheit *et al.*, 2005). These shifts seem to have been a response to the North Atlantic Oscillation (NAO), the winter index of which was characterised by elevated temperatures and stronger westerly winds. The regime shift resulted in a reduction in recruitment of North Sea cod, whereas Baltic sprat started to thrive, both of which had strong impacts on fisheries and landings of both species. Temperature, which is highly correlated with NAO variability, seems to be the key physical variable impacting phytoplankton, zooplankton and fish species in both systems. However, indirect effects also appear to be triggered by increasing air and sea temperatures. Significant correlations between climate indices and biological processes are consistent with climate variability forcing changes in biological variables and processes but Alheit *et al.* (2005) note that these observations do not prove causal relationships. Regime shifts have also been reported in the north-east Pacific (McFarlane *et al.*, 2000; Tian *et al.*, 2004a) and the north-west Pacific (Tian *et al.* 2004a), with significant impacts on fish populations in these regions and in some cases the management of fisheries (Hare and Mantua, 2000).

7.4.8 Connections to south-east Australian fisheries

While many of these studies of the connections between environmental and oceanographic variables and fish population dynamics are based in the northern hemisphere, the general principles still apply to south-east Australian fisheries. A selection of examples relevant to this region is included below.

Tuna

Both the influence of sea surface temperatures and response to thermoclines are used in stock assessments for a range of tuna species (Brill, 1994; Block *et al.*, 1997; Schick *et al.*, 2004) and their response to temperature is well known (Block and Stevens, 2001). In Australia, warm core eddys have been associated with aggregations of yellowfin tuna (Young *et al.*, 2001).

Tiger flathead

Tiger flathead are known to have had cycles in catches and catch rates over the last twenty years (Cui *et al.*, 2004). Significant positive correlations between catches and catch rates and the sea surface temperature were evident in many cases and accounted for between 25–50% of the variation in catches or catch rates. Significant positive correlations were also apparent between the Southern Oscillation Index (SOI - lagged 2 years) and catch rates in all sectors/areas of the fishery. These correlations explained 40–70% of the variation in catch rates. The mechanisms behind these correlations have yet to be explained.

Gemfish

Winter aggregations of eastern gemfish in south-east Australia are thought to be influenced by cold bottom currents from the south and east flowing up onto the shelf; the edge of warm-core eddies, and topographic features along the shelf break (Prince and Griffin, 2001). However, Rowling (2001) disputes these conclusions and claims that observations of spawning gemfish have been few in the history of the fishery. Based on model estimates that indicate recruitment during the last 25 years has been relatively weak compared to the period from the 1970's to mid 1980's (eg. Little and Rowling 2009), eastern gemfish are also one species for which a "regime shift" has been suggested. There is little evidence outside of the gemfish assessment itself to support this contention, and if it has occurred, the cause or mechanism behind such a shift remains unclear.

Blue grenadier

Intermittent spawning of blue grenadier in New Zealand has been directly linked to oceanographic conditions (Francis *et al.*, 2005). Cyclic recruitment of blue grenadier also occurs in south-east Australia although the environmental drivers have yet to be determined (Tuck *et al.*, 2004).

Orange roughy

The pattern of recruitment of orange roughy off Tasmania possibly reflects the 50 year fluctuations in bottom water temperature (Koslow and Thresher, 1999).

7.5 BLUE GRENADIER BIOMASS CYCLES IN ATLANTIS SE

Beth Fulton and Geoff Tuck

7.5.1 Introduction

Blue grenadier are found from New South Wales, around southern Australia to Western Australia, including the coast of Tasmania. They are a moderately long-lived species with a maximum age of about 25 years and an age at maturity of 4–5 years. Spawning occurs predominantly off western Tasmania between late May and early September. Adults migrate to the spawning area from throughout south-east Australia, with large fish arriving earlier in the spawning season. Spawning fish have also recently been caught off the east coast of Australia.

Episodic observations of large cohorts of small fish, interspersed with extended periods of relatively poor recruitment, are a characteristic of this stock. Stock assessments have consistently shown this trend, with cohorts with magnitude well above mean levels evident in years 1978–79, 1985–87, 1994–95 and 2003–04 (Figure 37; Tuck, 2009). An application of the Atlantis SE ecosystem software was used to explore the cyclic nature of recruitment in this stock.

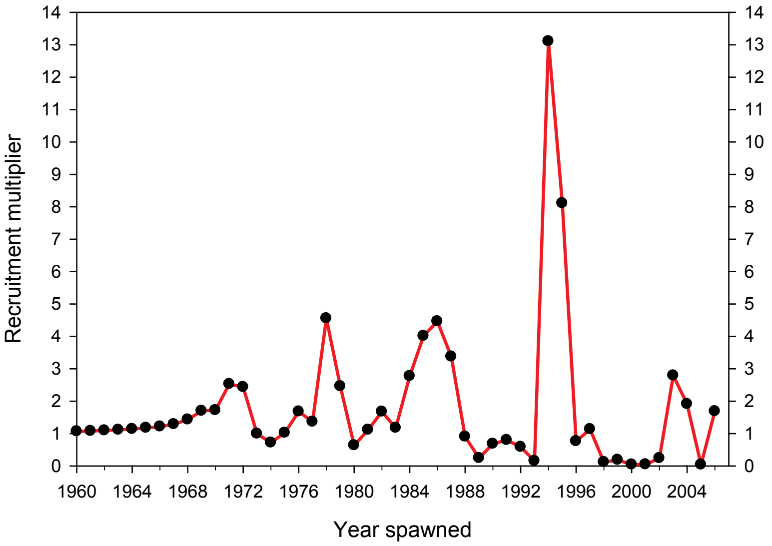

Figure 37. Estimated recruitment multipliers (the amount by which the recruitment deviated from that predicted by the stock-recruit relationship) versus year of spawning (from Tuck, 2009).

7.5.2 Methods and results

Atlantis SE contains the capacity to force biomass-impacting mechanics, such as recruitment, with a forcing pattern to produce periodic strong year classes. However, in some cases this kind of dynamic is predicted by the model rather than forced on it. This is the case for some parameterisations of the Atlantis SE model. The parameterisation that best fit both the historical blue grenadier and the broader south-east ecosystem (in particular the demersal fish fauna) biomass trajectories contained a quasi-periodic cycle in blue grenadier abundance and total biomass (Figure 38). Under alternative parameterisations this cycle could be a good deal weaker, or even absent. The cycle was also weaker through the prediction (2000–2020) simulations, particularly for biomass — though the cycles were still present when abundance was considered, especially the abundance of new settlers. The sensitivity of the cycles to the parameter set used and the system condition indicate that if the model is in any way capturing the mechanics driving the real cycles[1] then it is likely to only be capturing a small part of the real story (this will be explained more below).

The cycles predicted by Atlantis SE result from the interaction of many model components on a number of scales and of a number of different types. Beginning amongst the model's physical components, the flows between cells (as well as the temperature and salinity in each cell) is forced using either 5 or 10 year time series from the BLUElink hydrodynamics model. In simulations which span more than 10 years this BLUElink time series is simply repeated in a cyclic manner (a water temperature example is given in Figure 39).

As the rate parameters used in Atlantis SE are temperature dependent, this time series can have direct effects on the biological dynamics in the biophysical model. However, the strongest action of this environmental state is its contribution to cycles in the biological components, particularly the primary producers (Figure 40) and other basal food web components.

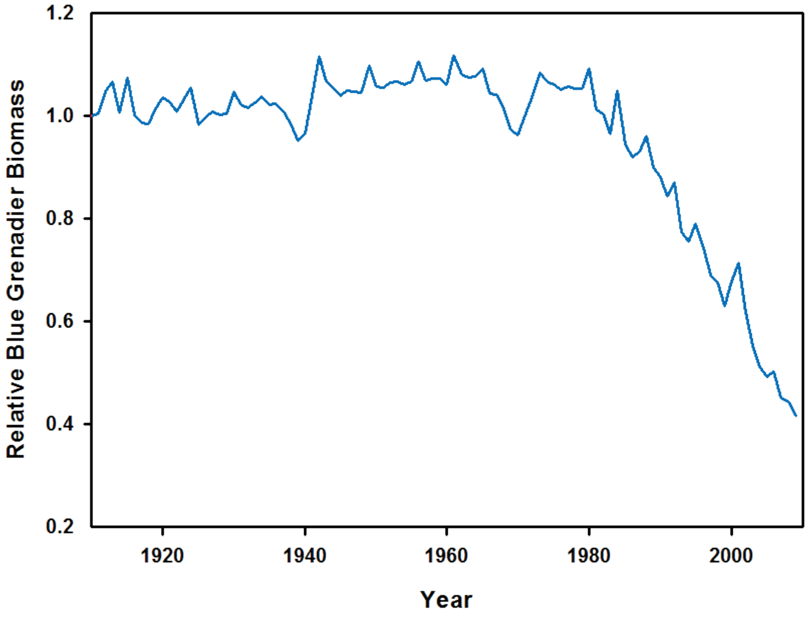

Figure 38. Biomass trajectory predicted for blue grenadier by Atlantis SE

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[1] It is very important to remember that ecosystem models give you more scope than ever to be "right for the wrong reasons" and all model results must be treated with caution.

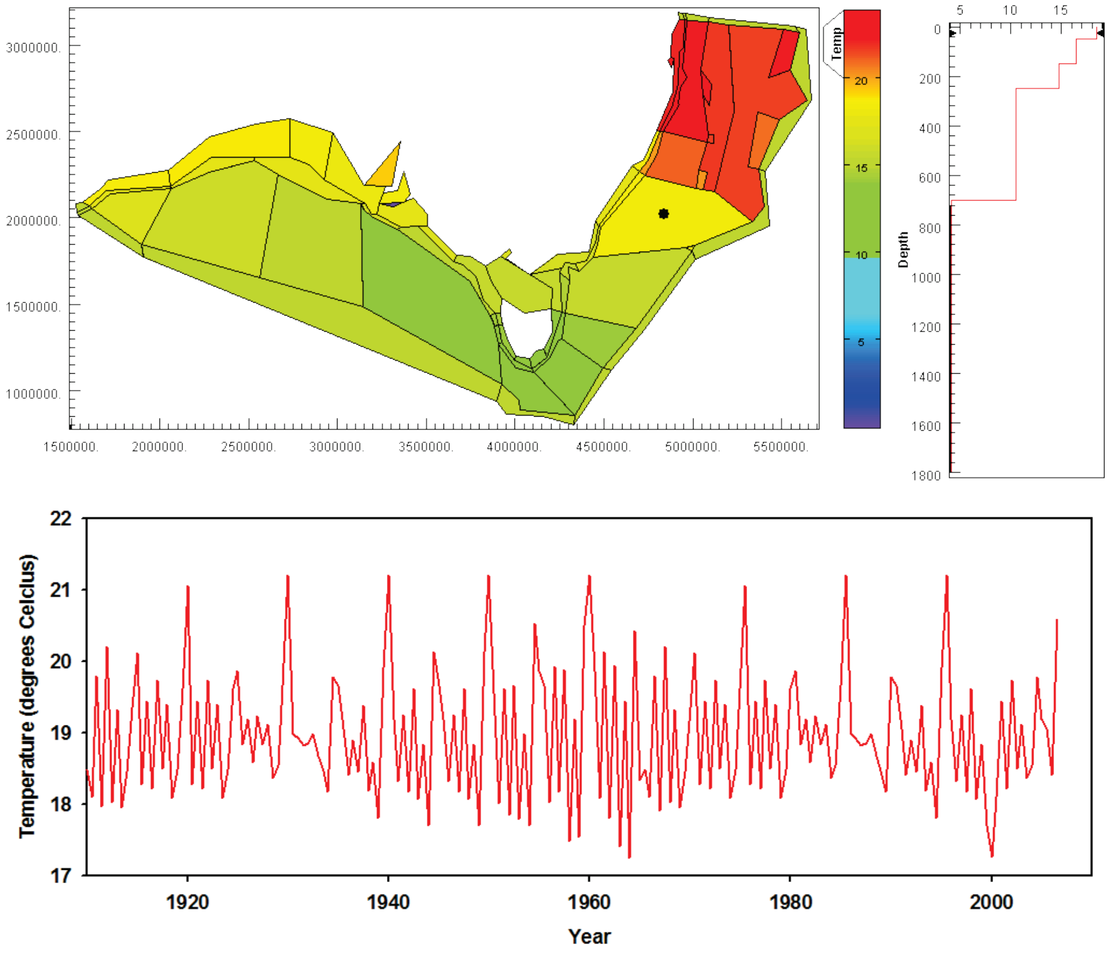


Figure 39. Example of a temperature map and time series generated by the BLUElink model and used in Atlantis SE — the profile by depth and the time series both come from the cell off the east coast of Australia that is marked with a black dot.

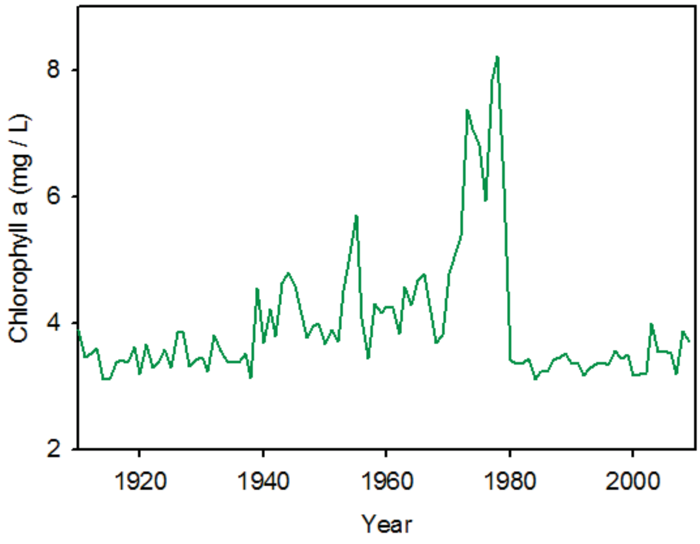


Figure 40. Time series of overall Chlorophyll levels from the Atlantis SE model parameterisation that predicts cycles in blue grenadier biomass and abundance.

Trophically, both predators and prey of blue grenadier also contribute to the cycles. Some of the major prey groups of the blue grenadier, particularly the prey of the youngest age classes, show a quasi-cyclic pattern in biomass levels (Figure 41), though these cycles may be imposed on longer-term trends in prey biomass (see the overall prey biomass available to blue grenadier in Figure 42). The variability in the prey biomass available to juvenile blue grenadier is stronger than the impacts of adult prey availability. Nevertheless, the latter is not negligible as it leads to changes in adult condition, which in turn impacts upon the levels of spawn produced.

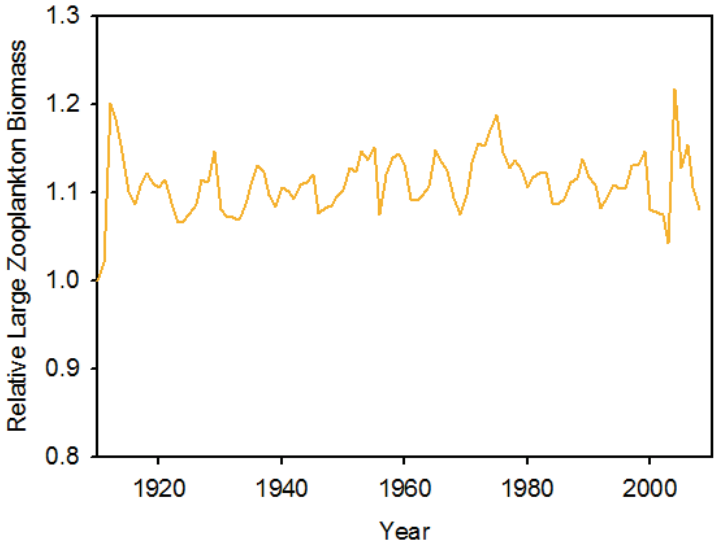


Figure 41. Time series of overall biomass for zooplankton available to juvenile blue grenadier.

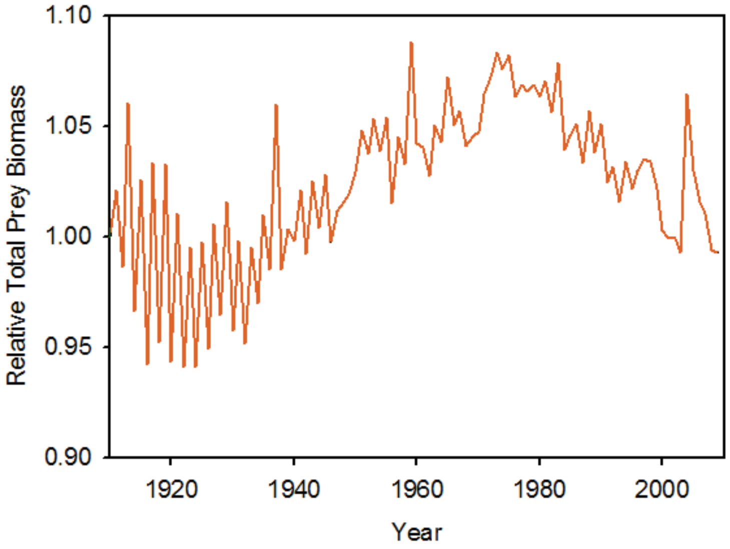


Figure 42. Time series of overall prey biomass available to blue grenadier in Atlantis SE.

The variability of biomass of predators also impacts upon the biomass of blue grenadier. Again this primarily acts through the small juveniles (via survivorship of this age group), but there is a moderate contribution for the adult age classes, as it impacts the spawner population size (but the impact is much smaller than predation on juveniles). The cycles in predators (Figure 43) are not as strong as the cycles in prey groups, but total predator biomass remains important for helping determine the form/strength of the blue grenadier cycle.

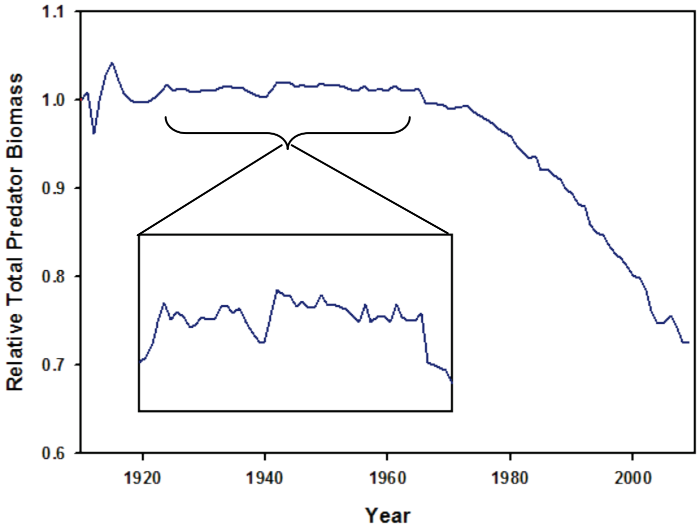


Figure 43. Biomass trajectory of overall biomass of blue grenadier predators.

7.5.3 Concluding remarks

Drawing this together, these cycles act together to produce the quasi-periodic cycles observed in the blue grenadier biomass, abundance and recruitment index (Figure 44). The environment acts directly on the rate parameters, but also via the cycles it creates in the basal trophic levels, which in turn flow up through the web to create cycles in the prey groups. The cycles in prey biomass impact blue grenadier in two ways, the first by impacting survival (a lack of prey can lead to starvation) and the second by impacting individual condition ("good" years are partly a result of fatter fish not just more fish). Meanwhile, cycles in predator biomass impact abundance of blue grenadier, particularly the smallest, most vulnerable age classes. When a peak in prey availability coincides with a trough in predation pressure the highest peaks in the blue grenadier cycles occur, weaker peaks occur when the cycles do not match as fully, and troughs can occur when high predation pressure coincides with poor environmental and prey conditions. Lags in the system (as pressures feed through the food web) mean that the cycle is not exactly regular and does not simply match the cycling of the environmental forcing.

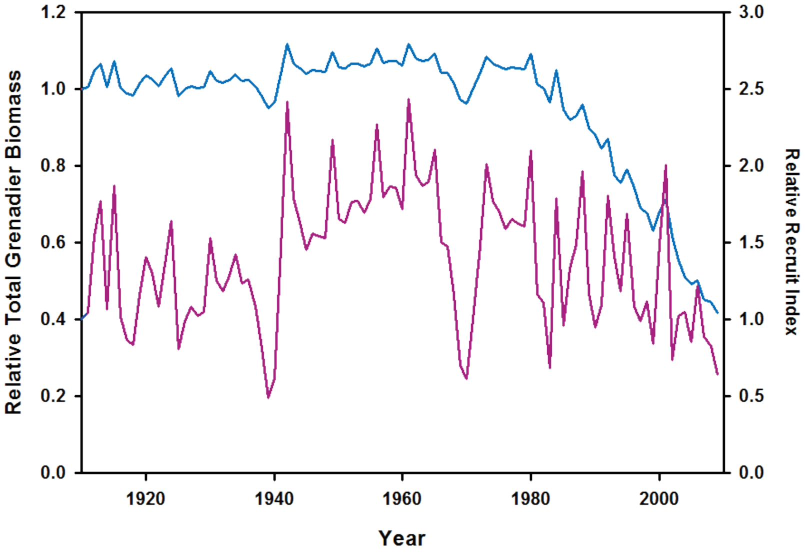


Figure 44. Time series of overall blue grenadier biomass (blue) and recruitment index (purple) from the Atlantis SE model.

As mentioned above, the model predicted cycling in blue grenadier biomass may not be true in reality, however they pose interesting hypotheses to explore and it can be used to gain further insights into the dynamics of the stock. Moreover, the model is unlikely to include all the components contributing to the cycles seen in reality, where larval dynamics are no doubt a key component. This is suggested by the fact that cycles in the model are much smaller in magnitude than those observed in reality (Figure 37).

7.6 QUANTIFYING THE EFFECTS OF ENVIRONMENTAL FACTORS ON CATCH RATES IN SOUTH-EAST FISHERIES: 1986 TO 2006

Min Zhu and Jemery Day

7.6.1 Introduction

The primary focus of this section is to investigate the effect of including environmental variables on the standardised CPUE analyses in the Southern and Eastern Scalefish and Shark Fishery (SESSF) from 1986 to 2006. Figure 45 shows the location of fishing zones referred to in this chapter, and Table 2 lists the species and gear types analysed.

The report begins with a description of the datasets used in Section 7.6.2, followed by a discussion and outline of the statistical methods used for data analysis in Section 7.6.3. Section 7.6.4 presents results of the analysis by species. Section 7.6.5 includes a discussion of the major results. In addition, we outline limitations and suitable extensions to the statistical analyses presented in this report.

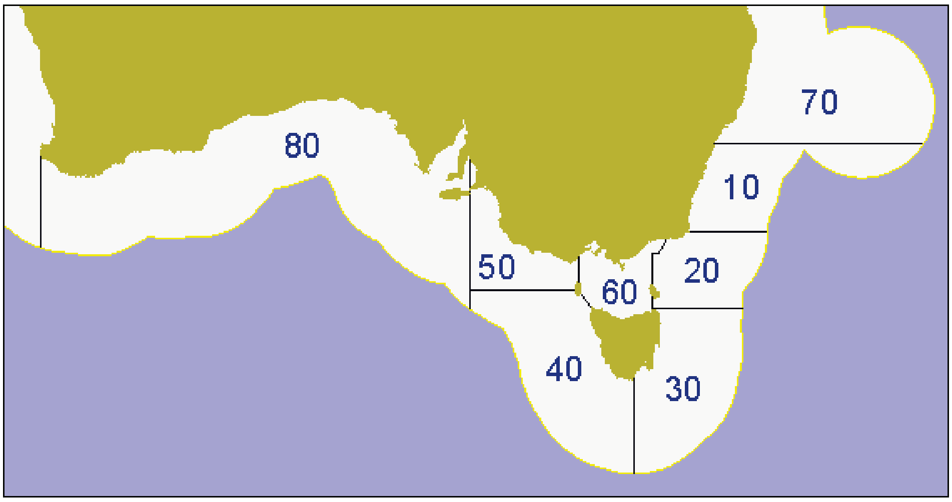


Figure 45. Map showing fishing zones of the SESSF.

Table 2. Fish species investigated and their fishery, gear type and fishing zones.

Species	Fishery-ID	Gear-type	Zone
Flathead – otter trawl	South East Trawl (SET)	Trawl (TW)	Zone 10, 20, 30, 50, 60
Flathead – Danish seine	SET	Danish Seine (DS)	Zone 10, 20, 30, 50, 60
Blue grenadier – spawning fleet	SET	TW	Zone 40 only restricted to the months of June July and August
Blue grenadier – non-spawning fleet	SET	TW	Zones 10, 20, 30, 50 and 60 for all months, and zone 40 for all months except June, July and August.
Ling – east	SET	TW	Zones 10, 20, 30
Ling – west	SET	TW	Zones 40, 50
Redfish	SET	TW	Zones 10, 20, 30, 50, 60
Bight redfish	Great Australian Bight (GAB)	TW	Zone 80
Silver warehou	SET	TW	Zones 10, 20, 30, 50, 60

7.6.2 The data

The data comprise a number of fields including: fishing location (latitude and longitude), catch weight (kg), average fishing depth, effort (in hours or shots), fishing vessel, and information on environmental variables from a range of sources covering both physical and chemical aspects of the environment. Many of the environmental variables come from the *CSIRO Atlas of Regional Seas (CARS).* Table 3 lists and describes the variables used in analyses.

Table 3. Variable used to quantify the effects of environmental factors on catch rates.

Variable	Description
LatMid	Latitude for the midpoint of the shot (or the start or end point if one value is missing)
LongMid	longitude for the midpoint of the shot (or the start or end point if one value is missing)
date	Shot date
eDay	The day of a year. Ranging from 1 to 365. A derived variable from date
eTime	Elapsed days from Jan 1, 1986. A derived variable from date
NewMoon	Cos(2π MoonAge/29.53) Moon age is the time that has elapsed since the last preceding conjunction of the sun and moon. Day 0 corresponds to new moon, day 7 is the first quarter moon, day 15 full moon and day 22 is the last quarter moon. Correspondingly, the value = 1 if this variable corresponds to a new moon, -1 for a full moon, and a value of 0 for either the first quarter or the last quarter
SprMoon	Cos(4π MoonAge/29.53)
Gear code	"TW" for trawl, "DS" for Danish Seine
Zone	SEF zone: geographical fishing zones ranging from 10 to 80
Vessel	Vessel name
Effort	Time for each shot in decimal hours for trawl and Danish seine
Fishery ID	South-east Trawl (SET) or Great Australian Bight (GAB)
Trawl_depth	Average trawl depth (in metres)
AGSO_bathymetry	Depth of the sea floor at latMid and longMid using bathymetry from AGSO database
CARS_bathymetry	Depth of the sea floor at latMid and longMid using bathymetry from CARS database
CARS_depth_temp	Temperature at average shot depth from CARS database
CARS_depth_sal	Salinity at average shot depth (psu) from CARS database
CARS_depth_DO	Dissolved oxygen at average shot depth (ml/l) from CARS database
CARS_depth_SiO2	Silicon dioxide at average shot depth (umol) from CARS database
CARS_depth_PO4	Phosphate at average shot depth (umol) from CARS database
CARS_depth_NO3	Nitrate at average shot depth (umol) from CARS database
CARS_surf_temp	Temperature at surface from CARS database
CARS_surf_sal	Salinity at surface (psu) from CARS database
CARS_surf_DO	Dissolved oxygen at surface (ml/l) from CARS database
CARS_surf_SiO2	Silicon dioxide at surface (umol) from CARS database
CARS_surf_PO4	Phosphate at surface (umol) from CARS database
CARS_surf_NO3	Nitrate at surface (umol) from CARS database
CARS_surf_Chlo	Chlorophyll A at the surface from SeaWIFS (mg/m^3) from CARS database
CARS_depb_temp	Temperature at sea bed at shot latMid and longMid from CARS database
CARS_depb_sal	Salinity at sea bed at shot latMid and longMid (psu) from CARS database
CARS_depb_DO	Dissolved oxygen at sea bed at shot latMid and longMid (ml/l) from CARS database
CARS_depb_SiO2	Silicon dioxide at sea bed at shot latMid and longMid (umol) from CARS database
CARS_depb_P04	Phosphate at sea bed at shot latMid and longMid (umol) from CARS database
CARS_depb_NO3	Nitrate at sea bed at shot latMid and longMid (umol) from CARS database
SST_3day	Sea surface temperature – 3 day composite from NOAA AVHRR satellite data
SST_6day	Sea surface temperature – 6 day composite from NOAA AVHRR satellite data
Temp_depth	Temperature at trawl depth – hindcasting data from SynTS system
Temp_depth_NRT	Temperature at trawl depth – near real time data from SynTS system
Temp_depb	Temperature at sea bed from SynTS system
SeaWiFS_Turbidity	Turbidity from the SeaWiFS satellite
SeaWiFS_Chlo_A	Chlorophyll A from the SeaWiFS satellite
MODIS_Turbidity	Turbidity from the MODIS satellite on a 4km scale
MODIS_Chlo_A	Chlorophyll A from the MODIS satellite on a 4km scale (daily)
Altimetry	Sea surface height (m) based on satellite altimetry
Wind speed	Wind speed (m/s) NCEP data
Wind speed u	Wind speed in direction u (m/s) NCEP data
Wind speed v	Wind speed in direction v- perpendicular to wind direction u (m/s) NCEP data
Magnetic_Anomaly	Magnetic anomaly
SST_frontal_density	Sea surface temperature frontal density
MLD_synTS	Mixed layer depth (MLD) from the CSIRO Mixed-layer Depth Atlas – hindcasting data
MLD_synTS_NRT	Mixed layer depth (from the CSIRO Mixed-layer Depth Atlas) – near real time data
SOI	Southern Oscillation Index – monthly scale
DAY_NIGHT	A categorical variable with 4 levels: D day time shots; N night time shots; M mixed shots (starting in daylight and finishing at night or vice versa); U unknown

Considering the complex nature of these large datasets, considerable effort was required to ensure the environmental data was matched to the fisheries data and used appropriately. The following procedures were used to validate, filter and in some cases exclude data from further analysis:

1. The shot date was replaced by the variables eDay and eTime, which represent the day of a year and the elapsed number of days since January 1st 1986 respectively.
2. The phase of the moon was expected to be important in explaining catch rate variation. Two related variables, NewMoon and SprMoon were used to represent different aspects of moon phase.
3. Trawl_depth lists the average trawl depth of each shot. If the average trawl depth was deeper than the bathymetry, then the bathymetry depth was used instead to prevent attempts to collect environmental data from below the sea floor.
4. CARS_bathymetry was used instead of AGSO_bathymetry as the CARS data is a more complete dataset.
5. There was considerable missing data for the CARS depth nutrient variables when attempting to match the shot data used. Some of this missing data came about because the mean depth and midpoint of the shot were used. Depending on the trawl track and the bathymetry, the mean trawl depth may not be appropriate to use at the mid point of the trawl (as the mean depth may be either below the sea floor or just above the sea floor). The following rules were used to substitute nutrient values from the sea floor in these cases to extend this dataset:
    a. The default depth for all CARS data at depth was average trawl depth. If the average trawl depth recorded was deeper than CARS_bathymetry (below the sea floor), the CARS depth variables were derived using the bathymetry depth instead.
    b. If the CARS data at depth values were missing and the average shot depth was shallower than the CARS_bathymetry with a difference between them less than 10 m (so less than 10 m higher than the sea floor), the CARS depth variables were derived using the bathymetry depth instead.
6. Any CARS nutrient variables (both at depth and at the surface) with negative nutrient concentrations were assumed to be zero.
7. Due to the high correlation between SST_3day and SST_6Day (correlation > 0.9), the variable SST_3day was excluded from the analysis. The 6 day time frame generally gives more reliable results due to a reduction in the gaps in coverage, resulting from cloud cover.
8. Due to the high correlation between SeaWiFS_Turbidity and SeaWiFS_Chlo_A (correlation > 0.9), the variable SeaWiFS_Turbidity was excluded from the analysis. Chlorophyll A is more closely related to primary productivity than turbidity so is a better choice if only one of these two variables is to be used.
9. The two MODIS variables were excluded from the analysis due to the short time period for which data from this satellite was available.
10. Three wind speed related variables (Wind speed, Wind speed u and Wind speed v) have missing data from September 2005 onwards. Given the low correlation of these wind speed variables with catch rates (r <0.02), these variables were also excluded from the analysis.

11. For the SynTS (Synthetic Temperature and Salinity) temperature-at-depth variable, Temp_depth, if the value of Trawl_depth was deeper than CARS_bathymetry, the depth used for this temperature-at-depth value was the depth at the sea floor (Temp_depb).
12. For both SynTS and MLD, the fields with "NRT" were calculated in near real time. These NRT values are less accurate but much faster to compute than the values calculated using the time and computationally intensive hindcasting process, used for values prior to 2006. The values Temp_depth and MLD_synTS were used by preference, but if these values were not available, the NRT (Near Real Time) equivalents were used instead.

Table 4 lists further data filters used in the project for removing invalid shots. If any of these data fields were missing, the whole record was discarded.

Table 4. Reasons for filtering (discarding) shot records based on shot or catch details.

Reason code	Invalid range
LatMid	Latitude of shot missing
LongMid	Longitude of shot missing
Date	Date missing
Zone	SESSF zone 10, 20, 30, 40, 50, 60 fishery ID SEF SESSF zone 10, 20, 30, 40, 50, 60, 80 for fishery ID GAB
Vessel	Vessels with only a few non-zero shot records
Effort	If method is trawl and hours < 0.5 if depth fished is shallower than 500 m, or hours = 0 otherwise; and if method is trawl and hours > 10
CARS_bathymetry	Shots deeper than 1500 m or shallower than 10 m
Avdep	Trawl average depth fished shallower than 10 m or deeper than 2000 m, Danish seine average depth deeper than 200 m
FLT	Tiger flathead catch in average depth deeper than 550 m
GRE	Blue grenadier catch in average depth shallower than 50 m blue grenadier catch per shot > 100,000 kg
RED	Redfish catch in average depth deeper than 600 m
MOW	Jackass morwong catch in average depth deeper than 600 m
TRT	Blue warehou catch in average depth deeper than 800 m
TRS	Silver warehou catch in average depth deeper than 800 m
LIG	Pink ling catch in average depth deeper than 1000 m

One of the difficulties with the datasets used in this project was the different time frame used for the collection of data for each environmental variable. Environmental variables were categorised into one of six groups according to the period of time in which they were available (as shown in Table 5). Many of the environmental variables of interest (Category 2 to 6) were only available in the later years.

Table 5. Categories describing the period of time for which each environmental variable was available.

Category	Variables	Period available
Category1	Zone, Vessel, DAY_NIGHT, Trawl_depth, CARS_depth_temp, CARS_depth_sal, CARS_depth_DO, CARS_depth_SiO2, CARS_depth_PO4, CARS_depth_NO3, CARS_surf_temp, CARS_surf_sal, CARS_surf_DO, CARS_surf_PO4, CARS_surf_SiO2, CARS_surf_NO3, CARS_surf_Chlo, eTime, NewMoon, SprMoon, SOI, Magnetic_Anomaly	all 21 years 1986 to 2006
Category2	Altimetry	Oct. 1992 to 2006
Category3	Temp_ depth	Jan. 1993 to 2006
Category4	SST_6day	Oct. 1993 to 2006
Category5	SST_frontal_density, MLD_synTS	Jan. 1994 to 2006
Category6	SeaWiFS_Chlo_A	Sep. 1997 to 2006

7.6.3 Statistical methods

7.6.3.1 Mixed-effects model

The approach used for CPUE analyses was a linear mixed-effects modelling framework. The general form of the mixed-effects model follows:

$$G(x) = \propto + \beta_1 f_1(\text{seasonal}) + \beta_2 f_2(\text{longterm}) + \beta_3 f_3(\text{ENV}) + \text{re(vessel)} + \text{error}$$

In this representation of the function $G(x)$, $\propto$ is the constant term and β_1, β_2 and β_3, are all vectors of regression coefficients. In total 8 periodic terms (cosine and sine terms) were used to model the seasonal trend in CPUE. So β_1, is of dimension 8, one for each cosine or sine term used to represent the seasonal component. The non-linear trend of the long-term effect was approximated through applying natural cubic splines on eTime. The dimension of β_2, is equal to the degrees of freedom of the splines. The environmental component consists of spatial and environmental factors to be investigated. The contribution of fishing vessels to the CPUE fluctuations was modelled as a random effect as denoted in the fifth term. As CPUE varied greatly, we used a log scale and assume a normal error distribution with variance σ^2 for log transformed CPUE, which is a common practice in CPUE standardisations.

Natural cubic splines were also used to model the contribution of average trawl depth to CPUE fluctuations. The use of splines allows the relationships between certain variables and CPUE to be more complicated than a linear relationship. However, most of the environmental variables considered in the model were assumed to have a linear relationship with the log-scale CPUE.

The following sections discuss a range of issues which needed to be addressed when standardising catch rate.

7.6.3.2 Seasonal effect and long-term trend

CPUE varied from year to year, and from season to season within a particular year. These variations can be partially explained by fluctuations in environmental factors and other factors such as the fishing effectiveness of different fishing vessels. However, there was still a substantial amount of uncertainty remaining after adjustment by these variables, and we used a seasonal effect and long-term trend to explain this uncertainty. Two variables eDay and eTime were used for this purpose. The seasonal effect was modelled via periodic terms (cosine and sine functions) on eDay. In total, 8 periodic terms (cosine and sine terms) were used to model variations in CPUE at different times during a year. The long-term trend was modelled using splines on eTime with the number of degrees of freedom determined by the data. Using smoothing splines instead of categorizing each year with discrete jumps between December and January (as is used in most standardisations for fishery stock assessments) was an alternative method of modelling the long-term trend. Treating year as a categorical variable introduces gaps between years, suggesting that the fish abundance on Dec 31st can make a sudden jump on January 1st of the next year.

7.6.3.3 Vessel effect

The question of how to model vessel effect (if there was any) in CPUE standardisation was also important. Using the Danish seine tiger flathead dataset as an example, the vessel effect can be shown by:

1. fitting a simple linear model *m0* using all the variables except vessel;
2. fitting another linear model *m1* using variables including vessel as a categorical variable;
3. Anova (*m0, m1*).

Analysis of Variance Table

	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)
m0	133362	180987				
m1	133323	177367	39	3620	69.771	< 2.2e-16 ***

This analysis of variance table shows that there was very strong evidence for vessel to vessel differences. As a result, we treated vessel as a random effect rather than a fixed effect, allowing more general predictions about catch rates from vessels other than the restricted set of those vessels operating in the fishery when the data was collected.

7.6.3.4 Variable selection

Variable selection is a difficult problem for a large dataset with many variables, some with very little influence and with high correlations between some variables. Model selection approaches using likelihood-based criteria such as AIC or BIC do not perform well for these very large datasets. In these cases, AIC or BIC only exclude terms with non-significant *p*-values. For a very large dataset, almost every candidate regression term is statistically significant, but in this case statistical significance may not relate to practical importance. For this analysis we decided to exclude those terms for which the effects are too small to matter, thereby summarizing the results using a relatively simple but effective model.

A goodness-of-fit statistic of a mixed-effect model, denoted r^2, was employed for our model selection purposes. It is proposed by Xu (2003) and measures the variation in the response explained by the covariates. The statistic r^2 makes direct use of the estimated variances and is comparable to traditional R^2 for linear models. Denoting n as the total number of observations, y_i the observed value for the i^{th} observation and $\overline{y}$ is the average of the total observed values, the explained variation in a linear mixed-effects model can be estimated by $r^2 = \frac{\hat{\sigma}^2}{\hat{\sigma}_0^2}$, where $\hat{\sigma}^2$ is the estimate of error variance σ^2 from the model and $\hat{\sigma}_0{}^2 = \frac{1}{(n-1)}\sum_{i=1}^{n}(y_i - \overline{y})^2$ is an estimate of var(Y). As pointed out by Xu (2003), r^2 takes into account the different degrees of freedom under the full model and under the null model and therefore corresponds to the adjusted R^2.

Unlike hypothesis testing, where the *p*-values can be heavily influenced by sample size, the measure r^2 consistently estimates the proportion of the explained variation in the population. In assessing the importance of a covariate, it also overcomes the limitation of the regression coefficient which depends on the scale. With the aim of choosing the most influential terms, we used a two part variable selection procedure.

Step 1: Use the BIC criterion to do the initial variable selection which can be implemented by the R function stepAIC. To enable the use of stepAIC, which can not be performed on a model with random effects, the random effect of vessel estimated by a mixed-effects model was subtracted from the response (log transformed CPUE), to get a new response variable, and the stepAIC procedure was then performed on the linear model for the new response variable with the same explanatory variables as in the mixed-effects model except for vessel.

Step 2: Use r^2 to assign a relative score to the remaining variables after stepAIC on the basis of their influence on the dependent variable and exclude those terms for which the effects are too small, thereby summarising the results using a simple but effective model. This step is subjective as it requires a choice of threshold for determining how much extra variation explained is "too small" to allow the addition of one more explanatory variable.

7.6.3.5 Evaluation of models

Different models were evaluated by examining the following criteria:

- the residual plots of the fitted models for normal error assumption,
- the random effect terms in each model, and
- the percent variation explained by each model.

7.6.4 Analysis by species

The standardised CPUE analyses were carried out for each species using the variables from Category 1 to Category 6 (see Table 5). Among these variables, CARS_depth_temp, CARS_surf_temp and CARS_surf_Chlo describe the same information as the variables Temp_depth, SST_6day and SeaWiFS_Chlo_A, but the latter variables include yearly as well as seasonal data. Hence the CARS variables CARS_depth_temp, CARS_surf_temp and CARS_surf_Chlo were excluded from any analysis when the alternative variables were available.

The standardised CPUE analyses for each species were carried out in two steps.

Analysis I: the model was constructed for the period 1986 to 2006 using the predictors from Category 1 (Table 5);

Analysis II: the model was constructed for the period from Sep 1997 to 2006 using all the predictors from Category 1 to 6 with CARS_depth_temp, CARS_surf_temp and CARS_surf_Chlo removed.

In both analyses, any records with missing data were removed.

As stated in Section 7.6.3.4, the variable selection had two steps:

Step 1: initial variable selection based on BIC. Variable selection was based on BIC criterion with both "forward" and "backward" directions, using the R function stepAIC with direction set to "both".

Step 2: the forward variable selection was made using the statistic, r^2, the variation explained by the model for the remaining variables after Step 1. The total amount of variation explained by the model was tabulated as variables were added, with the order specified by selecting the variable with the greatest explanatory power from the remaining variables at each step. If the variance explained increased by less than 0.1% when an additional term was added, all remaining variables were excluded.

To illustrate the data further, additional summary statistics are listed in Appendix 8, including:

1. a summary of variables in each zone;
2. highly correlated variable pairs with Spearman rank correlation greater than 0.7;
3. the correlation of each of the variables with log CPUE;
4. the correlation of each of the variables with the average trawl depth;
5. the correlation of each of the variables with the seasonal trend from Analysis I;
6. the correlation of each of the variables with the long-term trend from Analysis I.

In addition to these summary statistics, residuals and contributions of season and depth to the fits were plotted for each species.

7.6.4.1 Tiger flathead Danish seine

This section gives the results of the analysis of catches of tiger flathead by Danish seine (DS) in the south-east trawl (SET) region.

Given that there were poor records for shot duration for many of the early records for Danish seine, with a default shot duration of 1.5 hours recorded when no information was available, catch rates for Danish seine were analysed as catch per shot rather than catch per hour of effort. Hence the unit of effort used for Danish seine shots was the number of shots.

Analysis I – Jan 1986 to Dec 2006

A CPUE standardisation analysis was performed for 133,409 records collected over 21 years using 21 explanatory variables from Category 1.

The advantages of smoothing all possible terms (by applying splines) were explored initially and compared to a model where there were only two smoothed variables, *Trawl_depth* and date *(eTime)*, with the degrees of freedom, deviance explained and AIC all compared in Table 6. Given that the added complexity of smoothing all terms does not explain much more deviance, the simpler of these models was chosen with all variables except for *eTime* and *Trawl_depth* modelled as linear terms.

Table 6. Smoothing table.

	Effective DF	Deviance explained	AIC
Smoothing eTime and Trawl_depth only	62	40%	410139
Smoothing all possible terms	135	41.7%	406879.2
	Increase 118%	Increase 1.7%	Increase 0.8%

Step 1 of variable selection, based on the BIC criterion with both "forward" and "backward" directions, resulted in four environmental variables being excluded: *CARS_surf_PO4, Magnetic_Anomaly, SOI* and *SprMoon.* A mixed-effects model was fitted using the remaining variables. The long-term trend was modelled using splines with 16 degrees-of-freedom.

To begin step 2, the baseline model with *long-term trend* and *Trawl_depth* as fixed effects and *Vessel* as a random effect explained 35.70% of the variation. All other variables were selected sequentially with one variable being added to the baseline model at each iteration, with the variable selected based on the largest increase in variance explained. As an example, adding seasonal effect explained 37.38% of the variation, the largest increase in variance explained when combined with baseline model. Table 7 lists the order of the variables selected in step 2, and the right column lists the total variance explained.

Table 7. Tiger Flathead Danish seine variance explained (1986–2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	35.70%
+ seasonal effect	37.38%
+ DAY_NIGHT	38.68%
+ CARS_depth_temp	39.48%
+ CARS_depth_sal	40.39%
+ Zone	40.54%
+ CARS_surf_DO	40.61%
+ CARS_depth_SiO2	40.69%
+ CARS_surf_NO3	40.72%
+ NewMoon	40.75%
+ CARS_surf_sal	40.78%
+ CARS_surf_temp	40.81%
+ CARS_surf_Chlo	40.84%
+ CARS_depth_NO3	40.87%
+ CARS_depth_DO	40.87%
+ CARS_depth_PO4	40.88%
+ CARS_surf_SiO2	40.88%

As Table 7 shows, after the variable *CARS_surf_DO* is added, there is no single variable which increases the amount of variance explained by the model by more than 0.1%. Clearly the variables *Trawl_depth*, *seasonal effect*, *long-term trend* and *Vessel* are the most influential variables in explaining fluctuations in CPUE for the period from 1986 to 2006. The variables *DAY_NIGHT, CARS_depth_temp, CARS_depth_sal* and *Zone*, explain a further 3.17% of the variance and the remaining ten regression terms only explain 0.34% of the variance. Although these variables are all statistically significant, largely due to the very large number of records in this dataset, excluding those terms has little impact on effectively summarising the past 21 years of CPUE data. The final model is a relatively simple but effective model with eight terms.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + DAY_NIGHT + CARS_depth_temp + CARS_depth_sal + Zone

Table 8 lists the parameter estimates of the final model. The intercept absorbs the effects of the first level of categorical variables in the model. Therefore the intercept of the model (119.494) represents the joint effect of Zone10 and DAY_NIGHTD. These estimates can be interpreted to say that catch rates were highest in Zone 20 (the estimate 0.727 is the largest for this zone and exp(0.727) = 2.069, which suggests that catch rates are expected to be twice as high in Zone 20 than in Zone 10) during the day (the other categories, Night, Mixed and Unknown all have negative estimates so the multiplier =exp(estimate) is less than 1) when the temperature at shot depth is warmer (estimate = 0.321) and salinity at shot depth is lower (estimate = -3.448). The parameter values for the periodic trend do not have a simple interpretation but are included in Appendix 8.

Table 8. Tiger Flathead Danish seine parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	119.494	3.158	0
Zone20	0.727	0.2	0
Zone30	-1.134	0.381	0.003
Zone50	0.493	0.201	0.014
Zone60	0.458	0.2	0.022
DAY_NIGHTM	-0.283	0.014	0
DAY_NIGHTN	-0.63	0.013	0
DAY_NIGHTU	-0.177	0.01	0
CARS_depth_temp	0.321	0.006	0
CARS_depth_sal	-3.448	0.089	0

For this analysis and for every subsequent analysis (for each species/gear type combination examined), plots were constructed to show the histogram of residuals, allowing the assumption of a normal distribution for these residuals to be verified. In addition, plots were also produced to show the residuals for vessels, the contribution of the seasonal trend to the model fit to log-scaled CPUE and the partial contribution of average trawl depth to the model fit to log-scale CPUE. These plots are included in Appendix 8 for completeness.

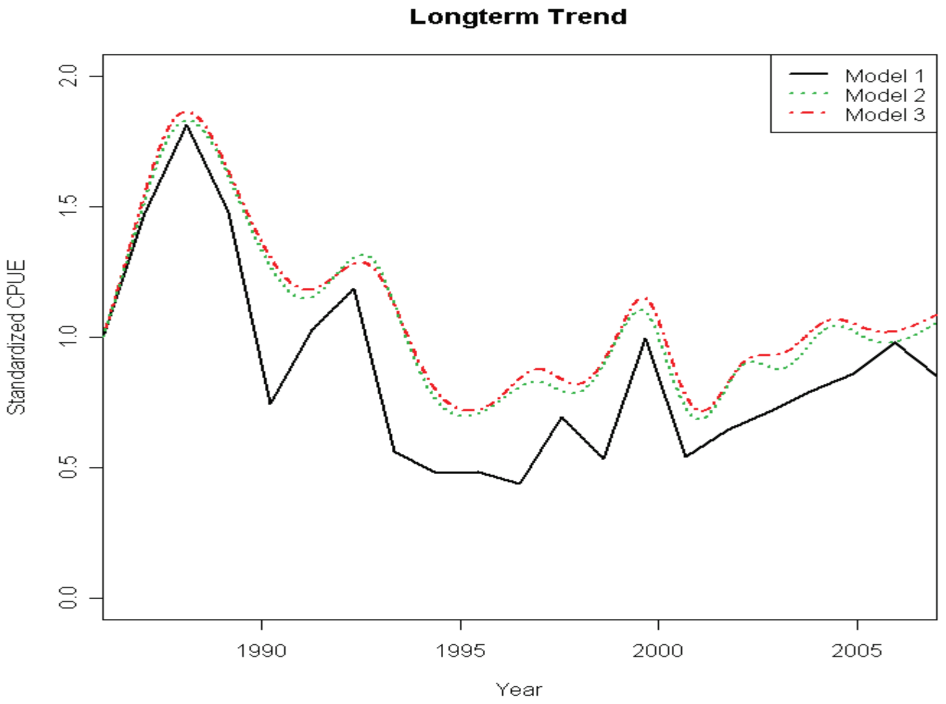


Figure 46. The standardised CPUE for tiger flathead taken by Danish seine relative to catch rates in 1986, as represented by the discrete model (Model 1), the smoothed model (Model2) and the optimal smoothed model (Model3).

Figure 46 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model for standardised CPUE analysis for the SESSF (Haddon 2007, SESSF Document 2007/10). The model was

log(CPUE) = Year+Month+Trawl_depth+Zone+Vessel,

in which *vessel*, *year* and *month* were treated as categorical variables, and the relationship between *Trawl_depth* and *CPUE* was assumed to be linear.

Model 2: the smoothed version of Model 1. Periodic terms were used to replace the variable *Month*. Splines were used for *year* effect and *trawl_depth* and *Vessels* were treated as a random-effect instead of a fix-effect in the model. This model explains 39.52% of the CPUE variation.

Model 3: the final model in Analysis I. This model explains 40.54% of the CPUE variation.

Model 1 (illustrated by the black solid line in Figure 46) represents the standard form of CPUE standardisations used for stock assessments in the SESSF currently (Haddon 2007), with year treated as a categorical variable and a range of standard explanatory variables. Model 2 (illustrated by the green dotted line in Figure 46) is a continuous version of Model 1. Model 1 and Model 2 cannot be compared directly because of their different assumptions, but they do tend to show similar behaviour in general. Model 3 (illustrated by the red dash-dotted line in Figure 46) is directly comparable to Model 2 and shows the impact of including environmental variables on the standard form of the standardised catch rate.

As seen in Figure 46, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 47,947 records collected from Sep. 1997 to 2006 using 25 explanatory variables from Categories1–6. These data included no shots from zone 30 and small numbers of shots from zones 10 and 50. Zone 10 was merged with neighbouring zone 20, and zone 50 was merged with zone 60 for this analysis as there were few records in these two zones. Therefore, only zones 20 and 60 were considered in this analysis.

The variables SprMoon, CARS_surf_PO4, CARS_depth_DO, SeaWiFS_Chlo_A, Altimetry, Zone, SST_frontal_density, and MLD_synTS were excluded from the model in step 1 (using BIC).

Table 9. Tiger Flathead Danish seine variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	25.13%
+ seasonal effect	26.43%
+ CARS_surf_NO3	27.19%
+ DAY_NIGHT	27.68%
+ Temp_depth	27.90%
+ CARS_depth_SiO2	28.01%
+ CARS_depth_NO3	28.07%
+ NewMoon	28.10%
+ Magnetic_Anomaly	28.13%
+ CARS_surf_DO	28.18%
+ CARS_surf_sal	28.18%
+ CARS_depth_PO4	28.15%
+ CARS_depth_sal	28.17%
+ SOI	28.19%
+ SST_6day	28.20%
+ CARS_surf_SiO2	28.21%

To begin step 2, the baseline model with *long-term trend* and *Trawl_depth* as fixed effects and *Vessel* as a random effect explains 25.13% of the variation. Adding seasonal effect explains 26.43% of the variation, the largest increase in variance explained when combined with the baseline model. Table 9 lists the order of the variables selected in step 2, and the right column lists the total variance explained.

After the variable *CARS_depth_SiO2* was added, there was no single variable which increases the amount of variance explained by the model by more than 0.1%. Clearly the variables *Trawl_depth*, *long-term trend, Vessel,* and *seasonal effect* are the most influential variables in explaining fluctuations in CPUE for the period from 1997 to 2006. The variables *CARS_surf_NO3, DAY_NIGHT, Temp_depth,* and *CARS_depth_SiO2* explain a further 2.58% of the variance is explained and the remaining ten regression terms only explain 0.20% of the variance.

Final Model:

Trawl_depth + Vessel + long-term trend + Seasonal effect + CARS_surf_NO3 + DAY_NIGHT + Temp_depth + CARS_depth_SiO2

Table 10 lists the parameter estimates for the final model.

Table 10. Tiger Flathead Danish seine parameter estimates (1997 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	-2.449	0.164	0
DAY_NIGHTM	-0.177	0.021	0
DAY_NIGHTN	-0.475	0.028	0
DAY_NIGHTU	-0.014	0.016	0.051
Temp_depth	0.096	0.007	0
CARS_depth_SiO2	0.138	0.019	0
CARS_surf_NO3	0.285	0.016	0

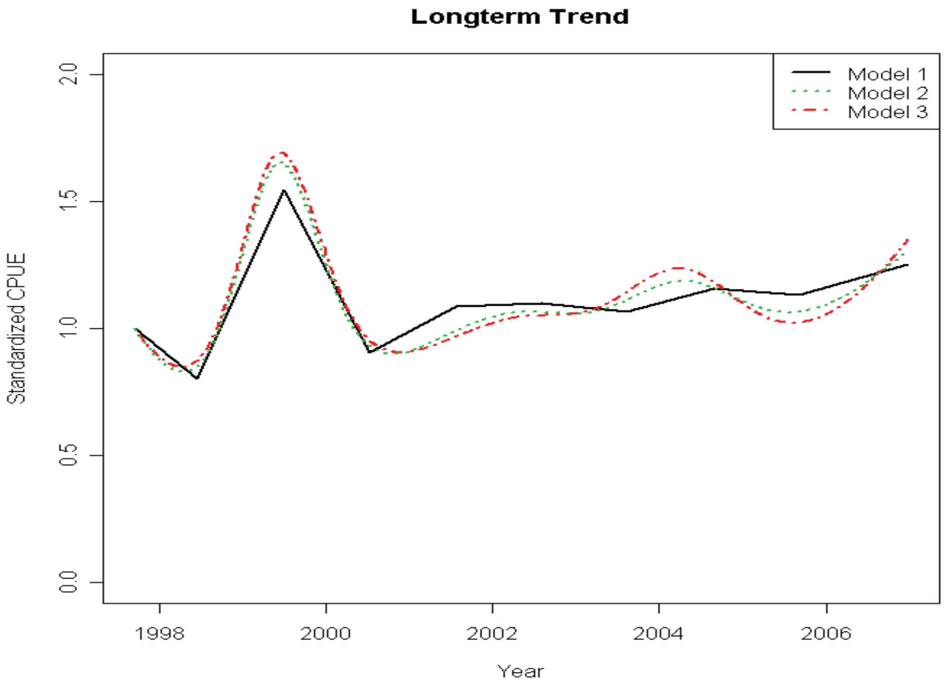


Figure 47. The standardised CPUE for tiger flathead taken by Danish seine relative to catch rates in 1997, as represented by the discrete model (Model 1), the smoothed model (Model2), and the optimal smoothed model (Model3).

Figure 47 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 27.68% of the variation.

Model 3: the final model in Analysis II. This model explains 28.01% of the variation.

As seen in Figure 47, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

7.6.4.2 Tiger flathead otter trawl

This section presents the results of the analysis of catches of tiger flathead using otter trawl in the south-east trawl region.

Analysis I – Jan 1986 to Dec 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 211,507 records collected over 21 years.

Two variables *SOI* and *SprMoon* were excluded in step 1 by the BIC criterion. Table 11 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 11. Tiger flathead otter trawl variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	17.76%
+ Zone	18.97%
+ Magnetic_Anomaly	19.39%
+ seasonal effect	19.75%
+ CARS_surf_PO4	20.05%
+ CARS_surf_temp	20.15%
+ CARS_depth_temp	20.42%
+ CARS_depth_sal	20.80%
+ CARS_surf_sal	21.16%
+ CARS_surf_NO3	21.30%
+ CARS_depth_DO	21.42%
+ CARS_depth_NO3	21.56%
+ CARS_depth_SiO2	21.65%
+ DAY_NIGHT	21.73%
+ CARS_surf_DO	21.78%
+ CARS_depth_PO4	21.81%
+ CARS_surf_SiO2	21.84%
+ CARS_surf_Chlo	21.86%
+ NewMoon	21.87%

The last variable chosen in step 2 was *CARS_depth_NO3*.

Final model:

Trawl_depth + Vessel + long-term trend + Zone + Magnetic_Anomaly + Seasonal effect + CARS_surf_PO4 + CARS_surf_temp + CARS_depth_temp + CARS_depth_sal + CARS_surf_sal + CARS_surf_NO3 + CARS_depth_DO + CARS_depth_NO3

Table 12 lists the parameter estimates for the final model.

Table 12. Tiger flathead otter trawl parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	56.825	2.845	0
Zone20	0.049	0.009	0
Zone30	-0.101	0.025	0
Zone40	-0.769	0.049	0
Zone50	0.092	0.032	0.003
Zone60	-0.427	0.022	0
Magnetic_Anomaly	-0.001	0	0
CARS_surf_PO4	0.416	0.062	0
CARS_surf_temp	-0.227	0.006	0
CARS_depth_temp	0.224	0.006	0
CARS_depth_sal	-3.526	0.089	0
CARS_surf_sal	2.089	0.067	0
CARS_surf_NO3	0.211	0.008	0
CARS_depth_DO	-0.653	0.027	0
CARS_depth_NO3	-0.054	0.003	0

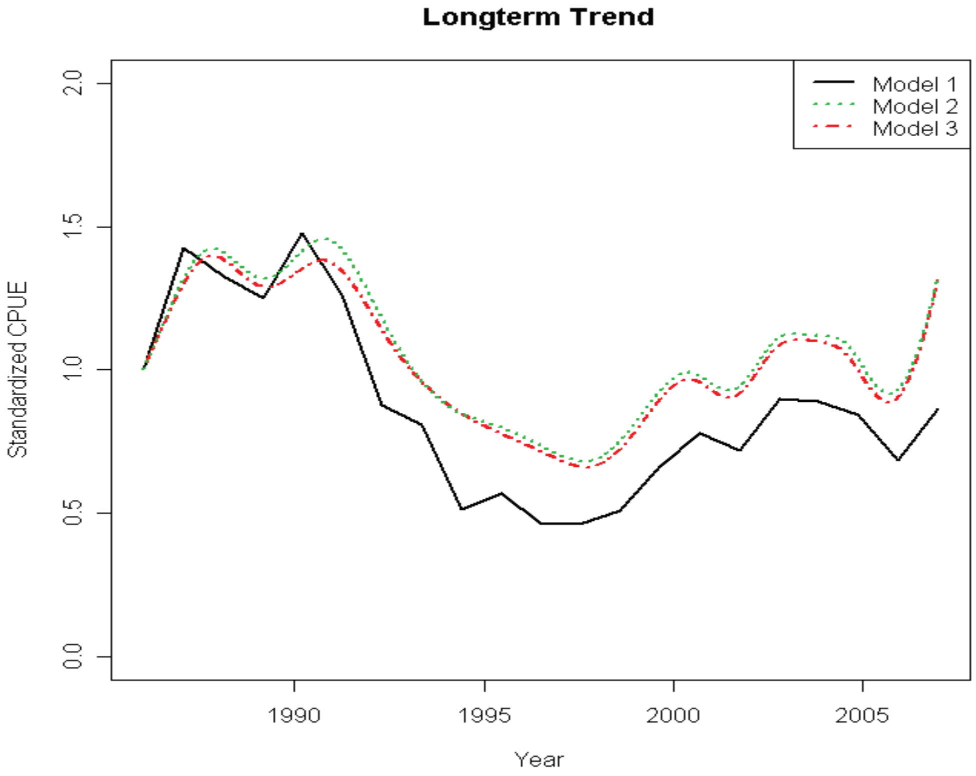


Figure 48. The standardised CPUE for tiger flathead taken by otter trawl relative to catch rates in Jan 1986, as represented by the discrete model (Model 1), the smoothed model (Model2) and the optimal smoothed model (Model3).

Figure 48 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 20.19% of the variation.

Model 3: the final model in Analysis I. This model explains 21.56% of the variation.

As seen in Figure 48, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 65,822 records collected from Sep 1997 to 2006. The variables *CARS_surf_PO4, SprMoon, Altimetry,* and *SeaWiFS_Chlo_A* were excluded from the model in step 1 by BIC. Table 13 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 13. Tiger flathead otter trawl variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	25.09%
+ Zone	26.44%
+ MLD_synTS	27.44%
+ seasonal effect	27.83%
+ CARS_surf_DO	28.08%
+ CARS_surf_NO3	28.23%
+ CARS_depth_NO3	28.50%
+ CARS_depth_sal	28.80%
+ CARS_surf_sal	28.96%
+ Temp_depth	29.10%
+ SST_6day	29.32%
+ DAY_NIGHT	29.42%
+ NewMoon	29.51%
+ CARS_depth_PO4	29.57%
+ CARS_depth_DO	29.65%
+ SST_frontal_density	29.70%
+ Magnetic_Anomaly	29.74%
+ CARS_depth_SiO2	29.77%
+ CARS_surf_SiO2	29.80%
+ SOI	29.81%

The last variable chosen in step 2 was *DAY_NIGHT*.

Final Model:

Trawl_depth + Vessel + long-term trend + Zone + MLD_synTS + Seasonal effect + CARS_surf_DO + CARS_surf_NO3 + CARS_depth_NO3 + CARS_depth_sal + Temp_depth + CARS_surf_sal + SST_6day + DAY_NIGHT

Table 14 lists the parameter estimates for the final model.

Table 14. Tiger flathead otter trawl parameter estimates (1997 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	51.898	4.743	0
Zone20	-0.012	0.021	0.55
Zone30	-0.231	0.041	0
Zone40	-1.48	0.071	0
Zone50	-0.12	0.073	0.099
Zone60	-0.494	0.04	0
MLD_synTS	0.007	0	0
DAY_NIGHTM	-0.027	0.01	0.009
DAY_NIGHTN	-0.126	0.013	0
DAY_NIGHTU	-0.052	0.081	0.522
CARS_depth_sal	-3.244	0.135	0
CARS_depth_NO3	-0.097	0.004	0
CARS_surf_sal	1.712	0.113	0
CARS_surf_NO3	0.229	0.011	0
CARS_surf_DO	0.743	0.067	0
Temp_depth	0.11	0.007	0
SST_6day	-0.074	0.005	0

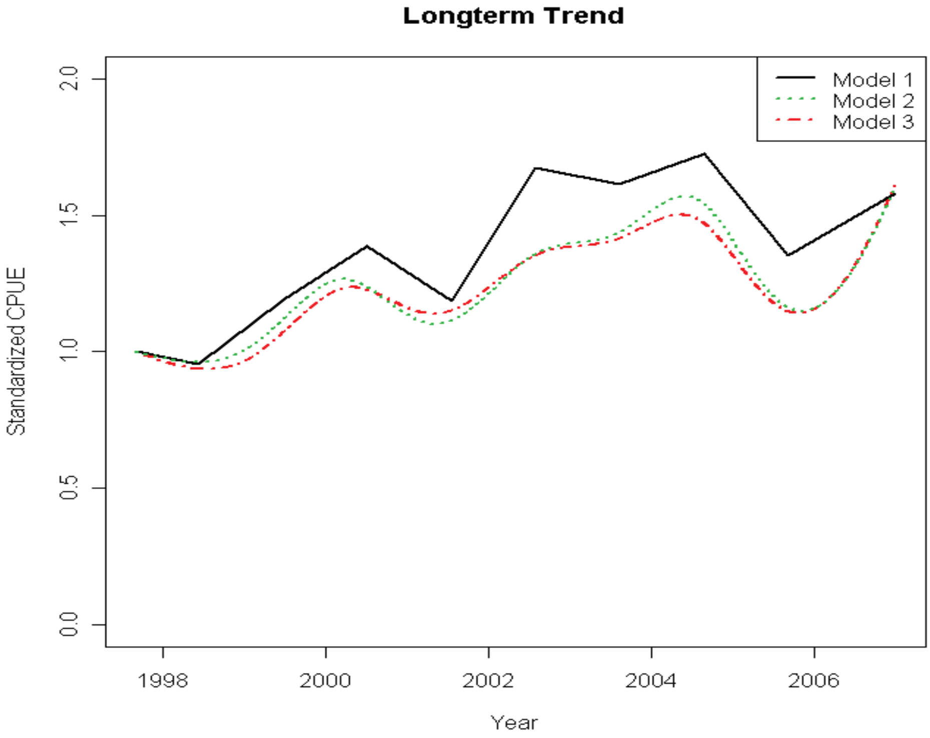


Figure 49. The standardised CPUE for tiger flathead taken by otter trawl relative to catch rates in September 1997, as represented by the discrete model (Model 1), the smoothed model (Model2) and the optimal smoothed model (Model3).

Figure 49 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 27.34% of the variation.

Model 3: the final model in Analysis II. This model explains 29.42% of the variation.

As seen in Figure 49, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

7.6.4.3 Spawning blue grenadier

This section presents the analysis of catches of blue grenadier from Zone 40 in the months June, July and August. As we were considering CPUE for part of the year only, modelling seasonal and year affects using splines was no longer appropriate. Instead, treating *Year* and *Month* as categorical variables for temporal trend made more sense for this dataset.

Analysis I – 1986 to 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 8,828 records collected over 21 years.

Ten variables Magnetic_Anomaly, CARS_depth_NO3, NewMoon, SprMoon, CARS_surf_temp, CARS_surf_Chlo, CARS_depth_temp, CARS_depth_DO, CARS_depth_PO4, and CARS_surf_PO4 were excluded in step 1 by the BIC criterion. Table 15 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 15. Spawning blue grenadier variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + Year	53.58%
+ DAY_NIGHT	57.56%
+ MONTH	58.66%
+ CARS_depth_sal	59.17%
+ CARS_surf_sal	59.46%
+ CARS_surf_SiO2	59.69%
+ CARS_surf_NO3	59.82%
+ CARS_surf_DO	59.90%
+ SOI	59.98%
+ CARS_depth_SiO2	60.02%

The last variable chosen in step 2 was *CARS_surf_NO3*.

Final model:

Trawl_depth + Vessel + YEAR + MONTH + DAY_NIGHT + CARS_depth_sal + CARS_surf_sal + CARS_surf_SiO2 + CARS_surf_NO3

Table 16 lists the parameter estimates for the final model.

Table 16. Spawning blue grenadier parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	-233.716	33.399	0
MONTH7	0.355	0.07	0
MONTH8	-0.06	0.095	0.525
DAY_NIGHTM	-1.091	0.06	0
DAY_NIGHTN	-0.177	0.081	0.028
DAY_NIGHTU	-0.016	0.291	0.957
CARS_depth_sal	9.172	0.9	0
CARS_surf_sal	-2.388	0.233	0
CARS_surf_SiO2	-2.273	0.264	0
CARS_surf_NO3	0.486	0.092	0

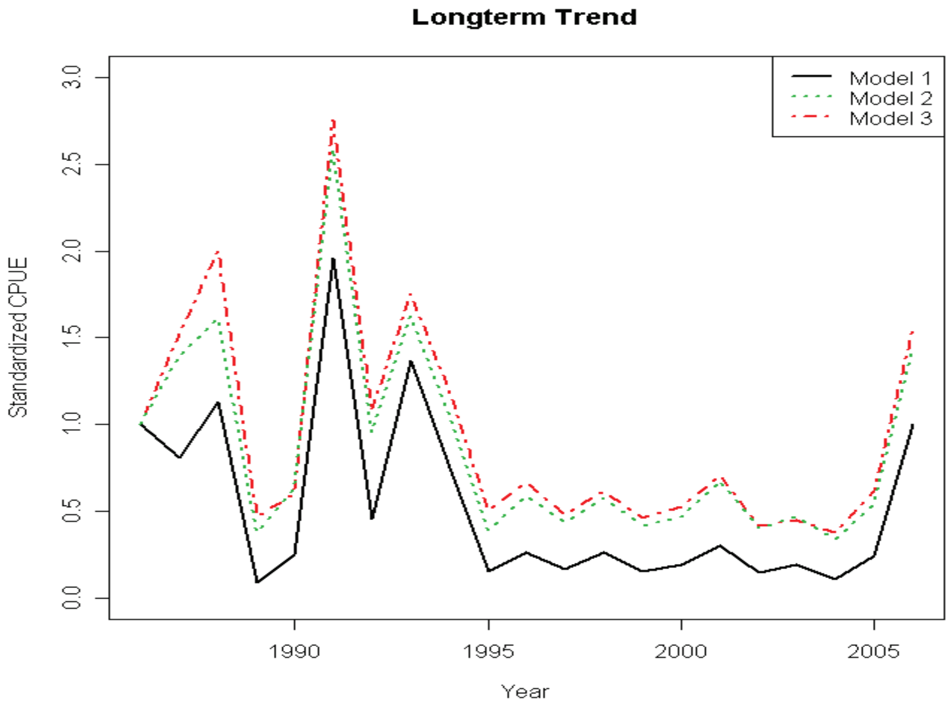


Figure 50. The standardised CPUE for blue grenadier during spawning season relative to catch rates in 1986, as represented by three models.

Figure 50 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 57.07% of the variation.

Model 3: the final model in Analysis I. This model explains 59.82% of the variation.

As seen in Figure 50, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

Analysis II – 1998 to 2006

A CPUE standardisation analysis was performed for 4,339 records collected from 1998 to 2006. Thirteen variables Altimetry, Magnetic_Anomaly, SST_frontal_density, CARS_surf_PO4, CARS_depth_SiO2, CARS_depth_DO, SeaWiFS_Chlo_A, SST_6day, CARS_depth_NO3, NewMoon, MLD_synTS, and SprMoon were excluded from the model in step 1 by BIC. Table 17 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 17. Spawning blue grenadier variance explained (1998 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + year	60.11%
+ MONTH	61.69%
+ DAY_NIGHT	62.88%
+ CARS_depth_sal	63.55%
+ Temp_depth	63.77%
+ CARS_depth_PO4	63.88%
+ SOI	63.97%
+ CARS_surf_NO3	64.03%
+ CARS_surf_SiO2	64.23%
+ CARS_surf_sal	64.51%
+ CARS_surf_DO	64.57%

The last variable chosen in step 2 is *CARS_surf_sal*.

Final model:

Trawl_depth + Vessel + Year + MONTH + DAY_NIGHT + Temp_depth + CARS_depth_sal + SOI + CARS_surf_SiO2 + CARS_surf_NO3 + CARS_depth_PO4 + CARS_surf_sal

Table 18 presents the parameter estimates of the final model.

Table 18. Spawning blue grenadier parameter estimates (1998 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	-432.313	53.584	0
MONTH7	0.454	0.105	0
MONTH8	0.375	0.147	0.002
DAY_NIGHTM	-0.936	0.079	0
DAY_NIGHTN	-0.316	0.104	0.002
DAY_NIGHTU	-0.535	0.887	0.547
Temp_depth	-0.275	0.071	0
CARS_depth_sal	14.592	1.425	0
SOI	0.022	0.007	0.003
CARS_surf_SiO2	-3.033	0.395	0
CARS_surf_NO3	0.619	0.134	0
CARS_depth_PO4	1.872	0.551	0.001
CARS_surf_sal	-2.116	0.347	0
	Smooth Terms	DF	
	ns(Trawl_depth)	2	0

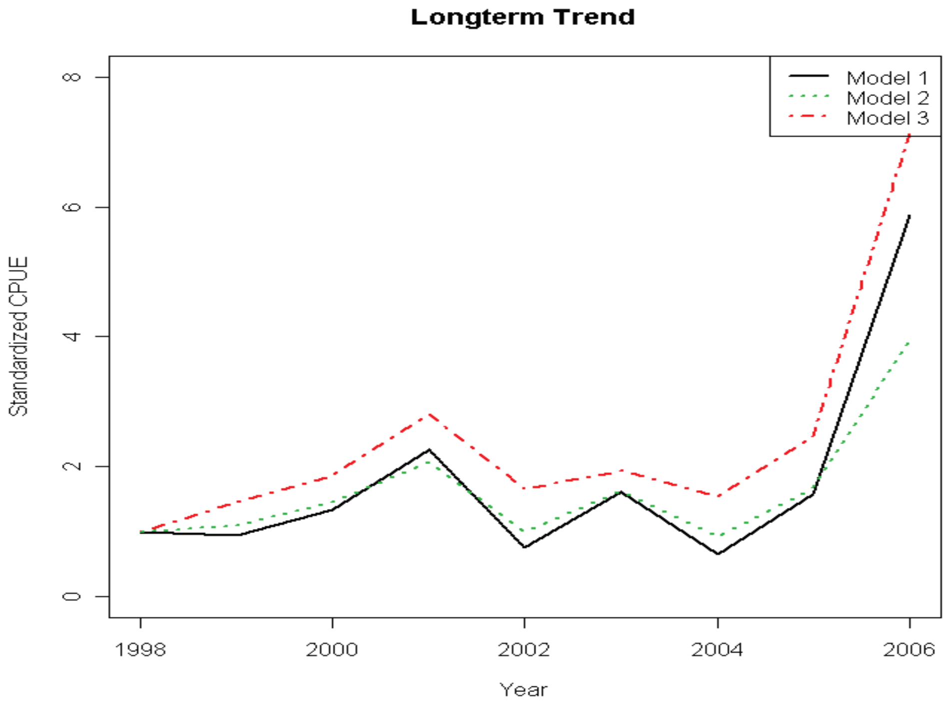


Figure 51. The standardised CPUE for blue grenadier during spawning season relative to catch rates in 1998, as represented by three models.

Figure 51 compares the long-term trend (standardized CPUE) of three different models.

Model 1: the standard model for standardized CPUE analysis for the SESSF. The model is

log(CPUE) = Year+Month+Trawl_depth+Zone+Vessel,

in which *vessel*, *year* and *month* are treated as categorical variables, and the relationship between *Trawl_depth* and *CPUE* was assumed to be linear.

Model 2: the smoothed version of Model 1. Periodic terms were used to replace the variable *Month*. Splines were used for *year* effect and *trawl_depth,* and *Vessels* were treated as a random-effect instead of a fix-effect in the model. This model explains 61.69% of the CPUE variation.

Model 3: the final model in Analysis II. This model explains 64.51% of the CPUE variation.

As seen in Figure 51, including the environmental variables (Model 3 compared to Model 2) makes a minor difference to the final model.

7.6.4.4 Non-spawning blue grenadier

This section presents the analysis of catches of blue grenadier by otter trawl in the non-spawning fishery, namely all catches from Zones 10, 20, 30, 50 and 60 all through the year, and Zone 40 for all months except June, July and August.

Analysis I – Jan 1986 to Dec 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 102,696 records collected over 21 years.

Five variables *Magnetic_Anomaly, CARS_depth_sal, SprMoon, SOI,* and *CARS_depth_PO4* were excluded in step 1 by the BIC criterion. Table 19 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 19. Non-spawning blue grenadier variance explained (1998 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + Year	29.38%
+ seasonal effect	31.74%
+ DAY_NIGHT	34.09%
+ Zone	35.23%
+ CARS_surf_Chlo	35.40%
+ CARS_depth_SiO2	35.51%
+ CARS_depth_temp	35.62%
+ CARS_surf_NO3	35.69%
+ CARS_surf_temp	35.75%
+ CARS_surf_DO	35.77%
+ CARS_depth_PO4	35.78%
+ NewMoon	35.81%
+ CARS_depth_DO	35.81%
+ CARS_surf_sal	35.83%
+ CARS_surf_SiO2	35.84%
+ CARS_depth_NO3	35.81%

The last variable chosen in step 2 was *CARS_depth_temp*.

Final model:

Trawl_depth + Vessel + YEAR + seasonal effect + DAY_NIGHT + Zone + CARS_surf_Chlo + CARS_depth_SiO2 + CARS_depth_temp

Table 20 lists the parameter estimates for the final model.

Table 20. Non-spawning blue grenadier parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	4.554	0.206	0
Zone20	0.361	0.033	0
Zone30	1.071	0.04	0
Zone40	0.329	0.042	0
Zone50	0.708	0.043	0
Zone60	0.958	0.131	0
DAY_NIGHTM	-0.465	0.011	0
DAY_NIGHTN	-1.049	0.02	0
DAY_NIGHTU	0.192	0.048	0
CARS_surf_Chlo	0.8	0.047	0
CARS_depth_SiO2	-0.103	0.006	0
CARS_depth_temp	-0.159	0.012	0

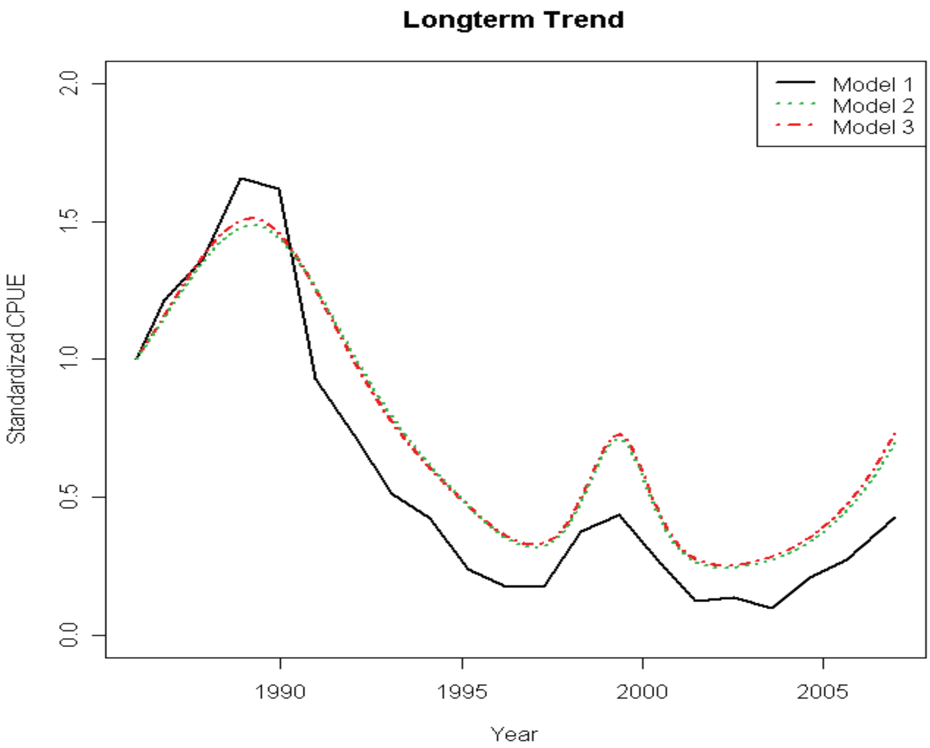


Figure 52. The standardised CPUE for blue grenadier (non-spawning) relative to catch rates in 1986, as represented by three models.

Figure 52 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 32.92% of the variation.

Model 3: the final model in Analysis I. This model explains 35.62% of the variation.

As seen in Figure 52, including the environmental variables (Model 3 compared to Model 2) makes almost no difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 52,663 records collected from Sep 1997 to 2006. The seven variables *SST_frontal_density, CARS_depth_DO, Magnetic_Anomaly, Altimetry, SOI, NewMoon,* and *SprMoon* were excluded from the model in step 1 by BIC. Table 21 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 21. Non-spawning blue grenadier variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	28.60%
+ DAY_NIGHT	31.31%
+ Seasonal trend	34.15%
+ Zone	35.47%
+ SST_6day	35.58%
+ CARS_depth_sal	35.65%
+ SeaWiFS_Chlo_A	35.71%
+ CARS_surf_PO4	35.76%
+ CARS_depth_NO3	35.79%
+ CARS_surf_sal	35.83%
+ CARS_depth_SiO2	35.86%
+ MLD_synTS	35.92%
+ Temp_depth	35.90%
+ CARS_surf_NO3	35.91%
+ CARS_surf_DO	35.91%
+ CARS_depth_PO4	35.91%
+ CARS_surf_SiO2	35.91%

The last variable chosen in step 2 was *SST_6day*.

Final model:

Trawl_depth + Vessel + YEAR + seasonal effect + DAY_NIGHT + Zone + SST_6day

Table 22 presents the parameter estimates of the final model.

Table 22. Non-spawning blue grenadier parameter estimates (1997 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	4.554	0.206	0
Zone20	0.312	0.058	0
Zone30	1.026	0.066	0
Zone40	0.393	0.071	0
Zone50	0.911	0.068	0
Zone60	1.052	0.209	0
DAY_NIGHTM	-0.507	0.015	0
DAY_NIGHTN	-1.211	0.027	0
DAY_NIGHTU	-0.012	0.153	0.935
SST_6day	-0.064	0.007	0

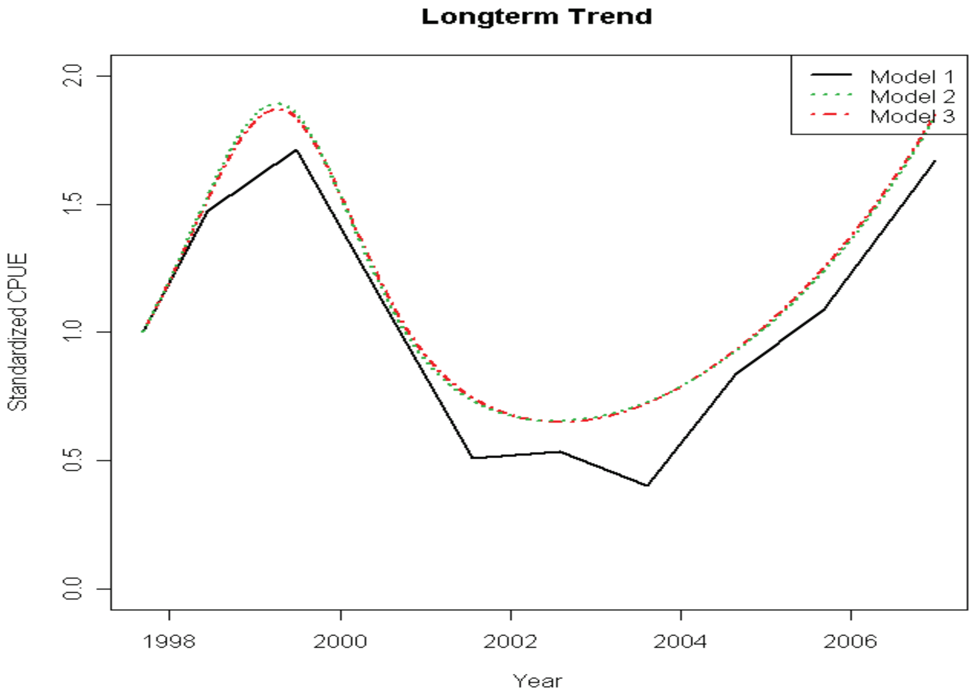


Figure 53. The standardised CPUE for blue grenadier (non-spawning) relative to catch rates in 1997, as represented by three models.

Figure 53 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 32.49% of the variation.

Model 3: the final model in Analysis II. This model explains 35.58% of the variation.

As seen in Figure 53, including the environmental variables (Model 3 compared to Model 2) makes almost no difference to the final model.

7.6.4.5 Pink ling – east

This section gives the results of the analysis of catches of pink ling restricted to the east, Zones 10, 20 and 30.

Analysis I – Jan 1986 to Dec 2006.

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 118,823 records collected over 21 years.

Four variables *SprMoon, CARS_surf_PO4, SOI,* and *CARS_surf_SiO2* were excluded in step 1 by the BIC criterion. Table 23 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 23. Pink ling – east variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	41.73%
+ seasonal effect	42.48%
+ DAY_NIGHT	42.76%
+ Magnetic_Anomaly	42.99%
+ CARS_depth_NO3	43.08%
+ CARS_depth_sal	43.23%
+ Zone	43.42%
+ NewMoon	43.47%
+ CARS_depth_PO4	43.51%
+ CARS_surf_sal	43.53%
+ CARS_surf_temp	43.55%
+ CARS_surf_DO	43.55%
+ CARS_depth_SiO2	43.56%
+ CARS_surf_NO3	43.57%
+ CARS_depth_DO	43.57%
+ CARS_depth_temp	43.57%
+ CARS_surf_Chlo	43.57%

The last variable chosen in step 2 was *Zone*.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + DAY_NIGHT + Magnetic_Anomaly + CARS_depth_NO3 + CARS_depth_sal + Zone

Table 24 lists the parameter estimates for the final model.

Table 24. Pink ling – east parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	-64.825	2.757	0
DAY_NIGHTM	-0.203	0.009	0
DAY_NIGHTN	-0.136	0.012	0
DAY_NIGHTU	0.206	0.029	0
Magnetic_Anomaly	0.001	0	0
CARS_depth_NO3	0.078	0.004	0
CARS_depth_sal	1.877	0.078	0
Zone20	0.15	0.013	0
Zone30	0.501	0.024	0

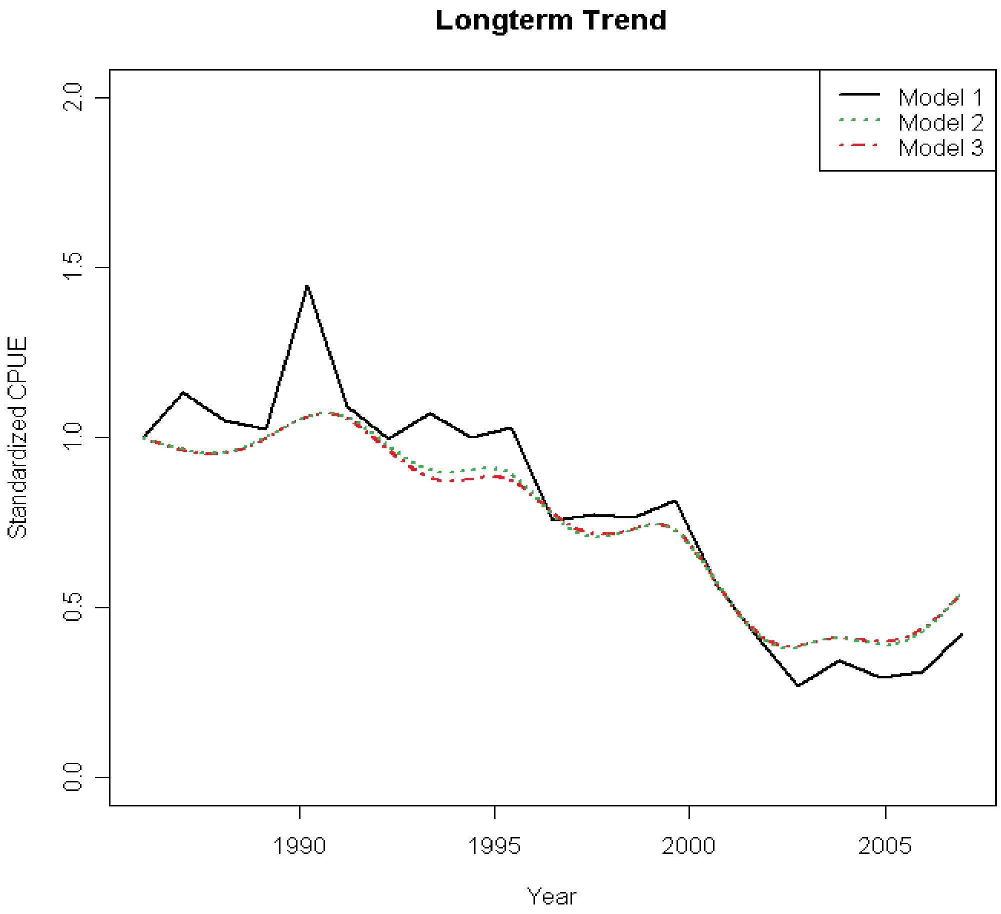


Figure 54. The standardised CPUE for pink ling (east) relative to catch rates in 1986, as represented by three models.

Figure 54 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 42.85% of the variation.

Model 3: the final model in Analysis I. This model explains 43.42% of the variation.

As seen in Figure 54, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

Analysis II – Sep 1997 to Dec 2006

The CPUE standardisation is performed on 57,483 records collected from Sep 1997 to 2006. The variables *CARS_depth_DO, CARS_surf_DO, CARS_depth_NO3, CARS_surf_PO4, SOI* and *SprMoon* were excluded from the model in step 1 by BIC. Table 25 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 25. Pink ling – east variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	45.63%
+ seasonal effect	46.60%
+ DAY_NIGHT	46.84%
+ Zone	46.97%
+ CARS_surf_sal	47.22%
+ Temp_depth	47.35%
+ NewMoon	47.41%
+ CARS_depth_SiO2	47.45%
+ Altimetry	47.51%
+ CARS_surf_SiO2	47.55%
+ SST_frontal_density	47.56%
+ CARS_surf_NO3	47.58%
+ Magnetic_Anomaly	47.62%
+ SST_6day	47.64%
+ SeaWiFS_Chlo_A	47.65%
+ CARS_depth_sal	47.65%
+ CARS_depth_PO4	47.67%
+ MLD_synTS	47.67%

The last variable chosen in step 2 is *Temp_depth*.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + DAY_NIGHT + Zone + CARS_surf_sal + Temp_depth

Table 26 presents the parameter estimates of the final model.

Table 26. Pink ling – east parameter estimates (1997 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	-59.177	4.009	0
DAY_NIGHTM	-0.194	0.013	0
DAY_NIGHTN	-0.106	0.018	0
DAY_NIGHTU	0.349	0.089	0
Zone20	0.282	0.023	0
Zone30	0.95	0.045	0
CARS_surf_sal	1.621	0.113	0
Temp_depth	0.084	0.007	0

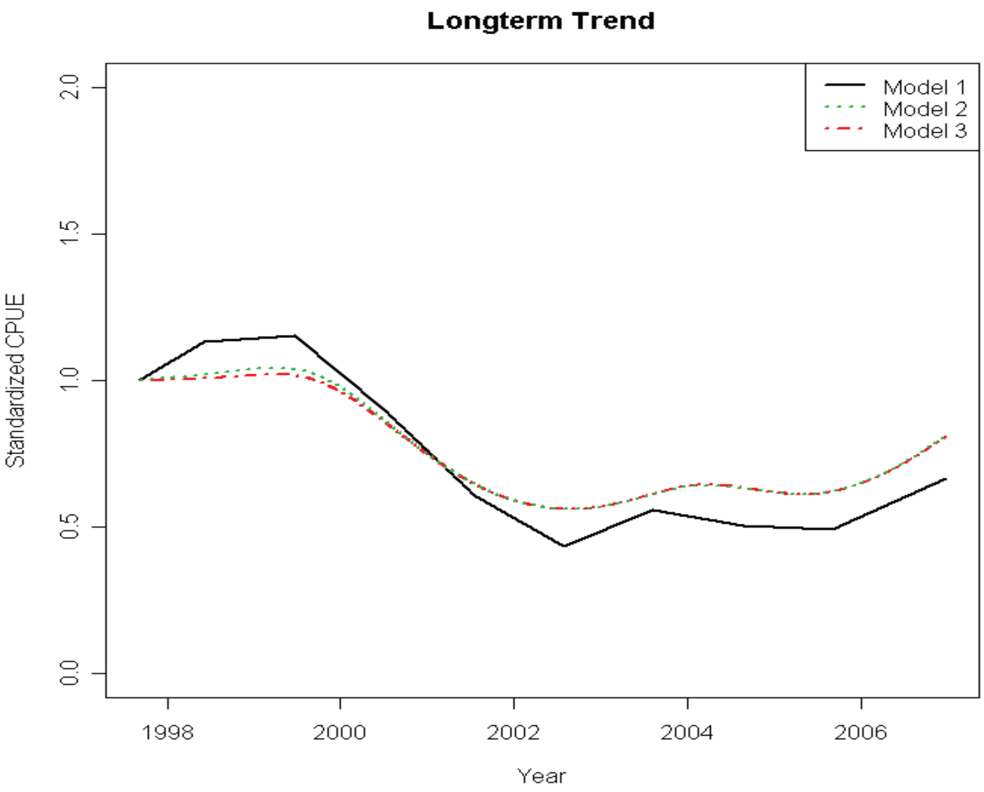


Figure 55. The standardised CPUE for pink ling (east) relative to catch rates in 1997, as represented by three models.

Figure 55 compares the long-term trend (standardized CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 46.59% of the variation.

Model 3: the final model in Analysis II. This model explains 47.35% of the variation.

As seen in Figure 55, including the environmental variables (Model 3 compared to Model 2) makes almost no difference to the final model.

7.6.4.6 Pink ling – west

This section presents the analysis of catches of pink ling restricted to the west, Zones 40 and 50.

Analysis I – Jan 1986 to Dec 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 59,085 records collected over 21 years.

Five variables *CARS_surf_NO3, CARS_depth_SiO2, CARS_surf_Chlo, NewMoon* and *SprMoon* were excluded in step 1 by the BIC criterion. Table 27 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 27. Pink ling – west variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	23.93%
+ seasonal effect	26.72%
+ CARS_surf_PO4	27.69%
+ CARS_surf_sal	28.22%
+ DAY_NIGHT	28.56%
+ CARS_depth_DO	28.70%
+ Magnetic_Anomaly	28.81%
+ CARS_depth_sal	28.89%
+ CARS_depth_NO3	29.15%
+ CARS_surf_SiO2	29.24%
+ Zone	29.34%
+ CARS_depth_PO4	29.38%
+ CARS_depth_temp	29.40%
+ SOI	29.41%
+ CARS_surf_temp	29.41%
+ CARS_surf_DO	29.41%

The last variable chosen in step 2 was *Zone*.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + CARS_surf_PO4 + CARS_surf_sal + DAY_NIGHT + CARS_depth_DO + Magnetic_Anomaly + CARS_depth_sal + CARS_depth_NO3 + CARS_surf_SiO2 + Zone

Table 28 lists the parameter estimates for the final model.

Table 28. Pink ling – west parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	82.006	3.869	0
CARS_surf_PO4	0.995	0.073	0
CARS_surf_sal	-0.489	0.036	0
DAY_NIGHTM	-0.072	0.009	0
DAY_NIGHTN	-0.288	0.018	0
DAY_NIGHTU	-0.015	0.055	0.791
CARS_depth_DO	0.332	0.056	0
Magnetic_Anomaly	0.001	0	0
CARS_depth_sal	-1.81	0.102	0
CARS_depth_NO3	-0.104	0.006	0
CARS_surf_SiO2	0.319	0.028	0
Zone50	0.173	0.02	0

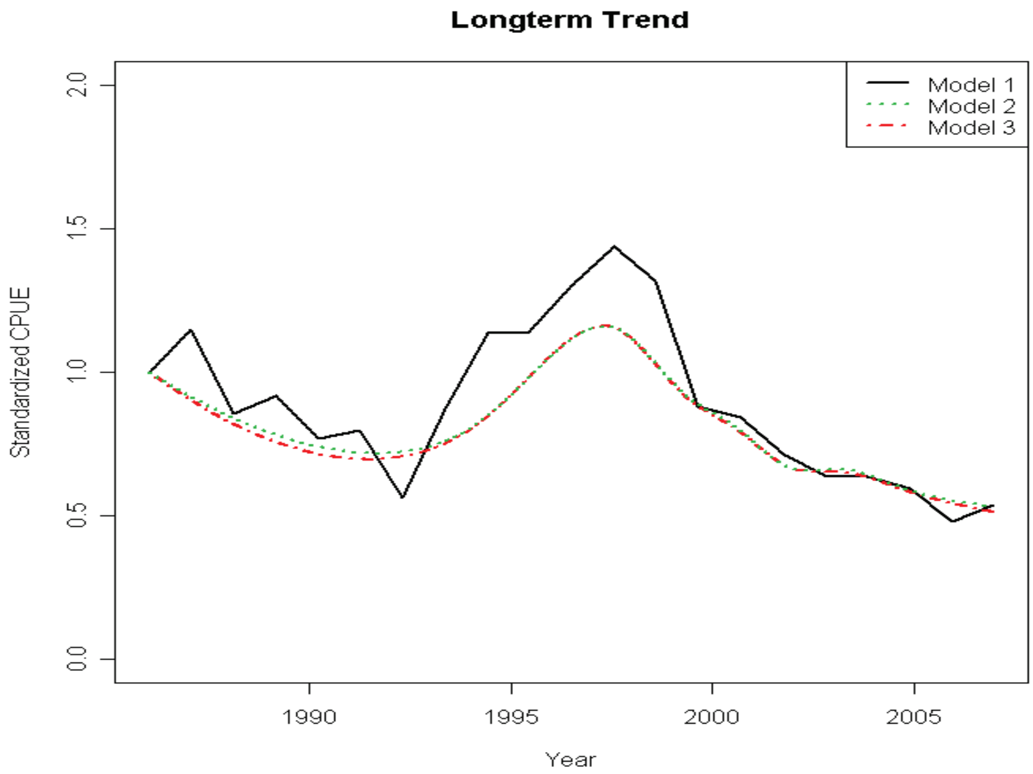


Figure 56. The standardised CPUE for pink ling (west) relative to catch rates in 1986, as represented by three models.

Figure 56 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 27.66% of the variation.

Model 3: the final model in Analysis I. This model explains 29.34% of the variation.

As seen in Figure 56, including the environmental variables (Model 3 compared to Model 2) makes almost no difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 31,811records collected from Sep 1997 to 2006. The variables MLD_synTS, CARS_depth_SiO2, SeaWiFS_Chlo_A, SOI, NewMoon, SprMoon, SST_frontal_density, SST_6day, Temp_depth, Altimetry and CARS_surf_DO were excluded from the model in step 1 by BIC. Table 29 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 29. Pink ling – west variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	25.48%
+ seasonal effect	28.22%
+ CARS_surf_PO4	29.25%
+ CARS_surf_sal	29.97%
+ DAY_NIGHT	30.40%
+ CARS_depth_DO	30.54%
+ Magnetic_Anomaly	30.61%
+ CARS_depth_PO4	30.66%
+ CARS_depth_sal	30.74%
+ CARS_surf_SiO2	30.83%
+ CARS_depth_NO3	30.90%
+ Zone	30.95%
+ CARS_surf_NO3	30.98%

The last variable chosen in step 2 is CARS_depth_DO.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + CARS_surf_PO4 + CARS_surf_sal + DAY_NIGHT + CARS_depth_DO

Table 30 lists the parameter estimates for the final model.

Table 30. Pink ling – west parameter estimates (1997 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	45.31	4.542	0
CARS_surf_PO4	1.269	0.09	0
CARS_surf_sal	-0.383	0.042	0
DAY_NIGHTM	-0.064	0.012	0
DAY_NIGHTN	-0.309	0.022	0
DAY_NIGHTU	-0.814	0.202	0
CARS_depth_DO	0.282	0.073	0

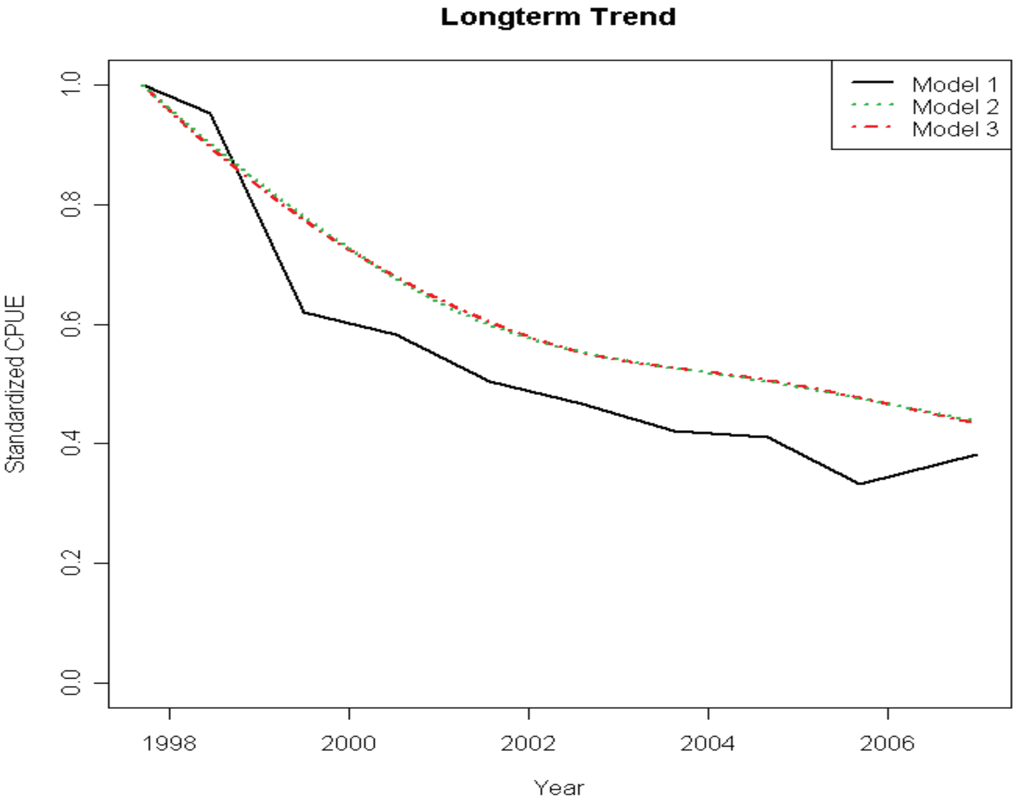


Figure 57. The standardised CPUE for pink ling (west) relative to catch rates in 1997, as represented by three models.

Figure 57 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 29.13% of the variation.

Model 3: the final model in Analysis II. This model explains 30.54% of the variation.

7.6.4.7 Redfish

This section gives the results of the analysis of catches of redfish by otter trawl in the south-east trawl region. Due to the low numbers of records available in Zones 30, 40, 50 and 60, these shots were merged into the shots from Zone 20.

Analysis I – Jan 1986 to Dec 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 73,658 records collected over 21 years.

Seven variables *SOI, SprMoon, NewMoon, CARS_depth_PO4, CARS_surf_SiO2, CARS_surf_PO4* and *CARS_depth_NO3* were excluded in step 1 by the BIC criterion. Table 31 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 31. Redfish variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	26.67%
+ Zone	27.77%
+ CARS_depth_sal	28.35%
+ CARS_depth_SiO2	28.71%
+ seasonal effect	29.01%
+ CARS_surf_temp	30.15%
+ DAY_NIGHT	30.32%
+ CARS_surf_NO3	30.42%
+ CARS_surf_sal	30.52%
+ CARS_surf_DO	30.66%
+ CARS_depth_DO	30.75%
+ CARS_depth_temp	30.76%
+ Magnetic_Anomaly	30.77%
+ CARS_surf_Chlo	30.77%

The last variable chosen in step 2 was *CARS_surf_DO*.

Final model:

Trawl_depth + Vessel + long-term trend + Zone + CARS_depth_sal + CARS_depth_SiO2 + seasonal effect + CARS_surf_temp + DAY_NIGHT + CARS_surf_NO3 + CARS_surf_sal + CARS_surf_DO

Table 32 presents the parameter estimates for the final model.

Table 32. Redfsih parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	68.397	11.284	0
Zone20	-0.102	0.022	0
CARS_depth_sal	2.199	0.223	0
CARS_depth_SiO2	0.112	0.021	0
CARS_surf_temp	0.408	0.019	0
DAY_NIGHTM	0.119	0.014	0
DAY_NIGHTN	0.241	0.019	0
DAY_NIGHTU	0.107	0.044	0.015
CARS_surf_NO3	-0.574	0.036	0
CARS_surf_sal	-3.976	0.29	0
CARS_surf_DO	-1.614	0.131	0

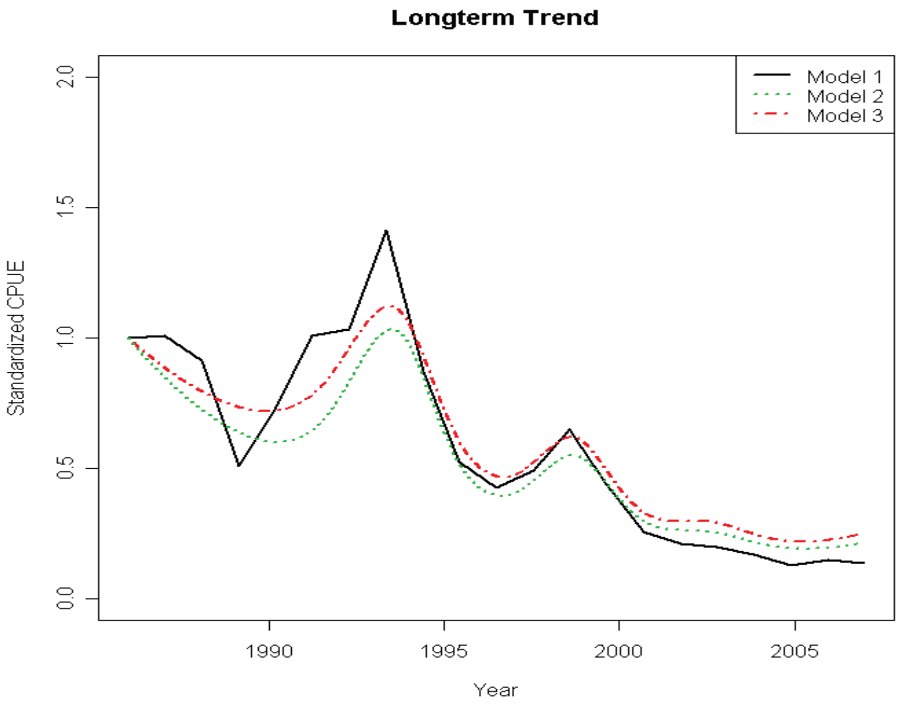


Figure 58. The standardised CPUE for redfish relative to catch rates in 1986, as represented by three models.

Figure 58 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 27.16% of the variation.

Model 3: the final model in Analysis I. This model explains 30.66% of the variation.

As seen in Figure 58, including the environmental variables (Model 3 compared to Model 2) makes a minor difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 26,351 records collected from Sep 1997 to 2006. Twelve variables SOI, SeaWiFS_Chlo_A, CARS_surf_SiO2, CARS_surf_sal, Zone, SprMoon, CARS_surf_PO4, CARS_depth_PO4, Magnetic_Anomaly, DAY_NIGHT, SST_frontal_density, and NewMoon were excluded from the model in step 1 by BIC. Table 33 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 33. Redfish variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	29.10%
+ Temp_depth	31.18%
+ Seasonal trend	31.77%
+ CARS_surf_DO	33.86%
+ CARS_depth_DO	34.23%
+ CARS_depth_NO3	34.79%
+ CARS_surf_NO3	34.93%
+ CARS_depth_sal	35.02%
+ CARS_depth_SiO2	35.21%
+ SST_6day	35.28%
+ Altimetry	35.40%
+ MLD_synTS	35.42%

The last variable chosen in step 2 is *Altimetry*.

Final model:

Trawl_depth + Vessel + long-term trend + Temp_depth + seasonal effect + CARS_surf_DO + CARS_depth_DO + CARS_depth_NO3 + CARS_surf_NO3 + CARS_depth_sal + CARS_depth_SiO2 + SST_6day + Altimetry

Table 34 lists the parameter estimates of the final model.

Table 34. Redfish parameter estimates (1986 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	-115.016	13.975	0
Temp_depth	0.103	0.018	0
CARS_depth_SiO2	0.375	0.043	0
CARS_surf_DO	-1.833	0.189	0
CARS_depth_DO	-1.846	0.128	0
CARS_depth_NO3	-0.152	0.016	0
CARS_surf_NO3	-0.42	0.049	0
CARS_depth_sal	3.814	0.383	0
SST_6day	0.046	0.011	0
Altimetry	0.951	0.212	0

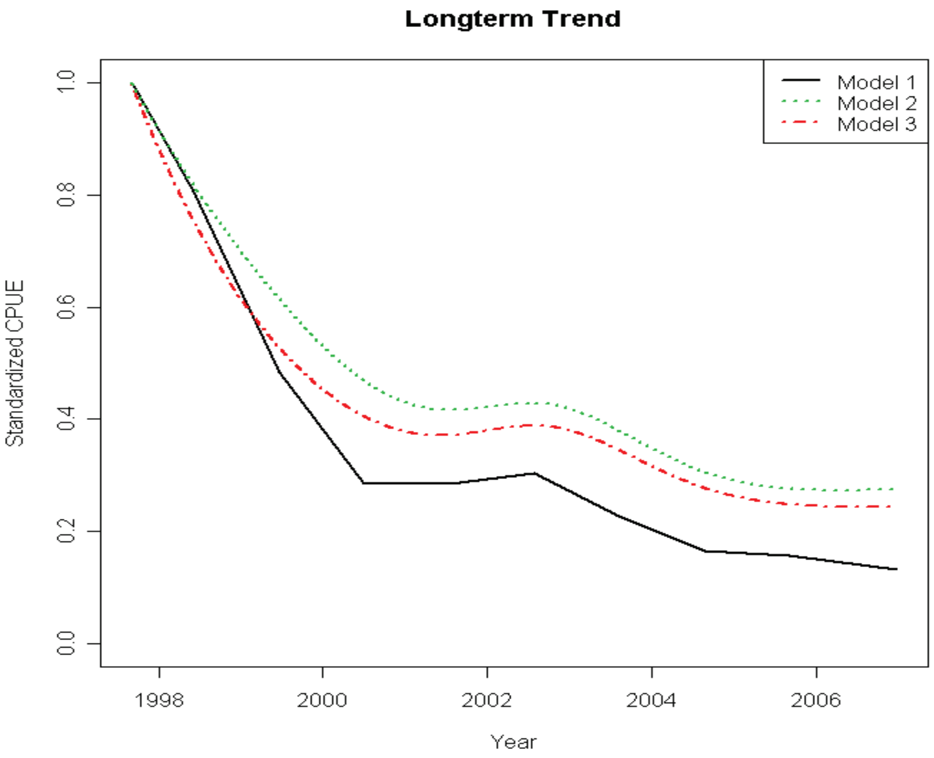


Figure 59. The standardised CPUE for redfish relative to catch rates in 1997, as represented by three models.

Figure 59 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 30.24% of the variation.

Model 3: the final model in Analysis II. This model explains 35.40% of the variation.

As seen in Figure 59, including the environmental variables (Model 3 compared to Model 2) makes only a minor difference to the final model.

7.6.4.8 Bight redfish

This section gives the results of the analysis of catches of Bight redfish by otter trawl in Zone 80.

Table 35. Total shots by year for Bight redfish

Year	Total shots	Year	Total shots
1986	249	1997	2090
1987	219	1998	1836
1988	316	1999	1721
1989	741	2000	1454
1990	1007	2001	1734
1991	1096	2002	1554
1992	895	2003	2818
1993	835	2004	3216
1994	869	2005	3832
1995	1352	2006	3785
1996	1610		

From 1986 to 1988, the number of shots recorded was relatively small (Table 35) so these three years were excluded from the analyses.

Analysis I – Jan 1989 to Dec 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 33,123 records collected over 18 years.

Seven variables *SprMoon, CARS_surf_NO3, CARS_depth_SiO2, CARS_surf_sal, CARS_depth_temp, CARS_surf_temp,* and *Magnetic_Anomaly* were excluded in step 1 by the BIC criterion. Table 36 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 36. Bight redfish variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	6.85%
+ DAY_NIGHT	15.33%
+ seasonal effect	23.42%
+ CARS_depth_NO3	26.44%
+ CARS_depth_sal	27.75%
+ NewMoon	28.47%
+ CARS_surf_SiO2	28.72%
+ SOI	28.83%
+ CARS_surf_DO	28.90%
+ CARS_depth_PO4	28.96%
+ CARS_depth_DO	28.97%
+ CARS_surf_PO4	28.98%

The last variable chosen in step 2 is *SOI.*

Final model:

Trawl_depth + Vessel + long-term trend + DAY_NIGHT + seasonal effect + CARS_depth_NO3 + CARS_depth_sal + NewMoon + CARS_surf_SiO2 + SOI

Table 37 lists the parameter estimates for the final model.

Table 37. Bight redfish parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	-159.464	6.74	0
DAY_NIGHTM	0.833	0.016	0
DAY_NIGHTN	1.162	0.019	0
DAY_NIGHTU	0.883	0.111	0
CARS_depth_NO3	0.534	0.024	0
CARS_depth_sal	4.519	0.187	0
NewMoon	-0.17	0.009	0
CARS_surf_SiO2	-0.589	0.054	0
SOI	0.005	0.001	0

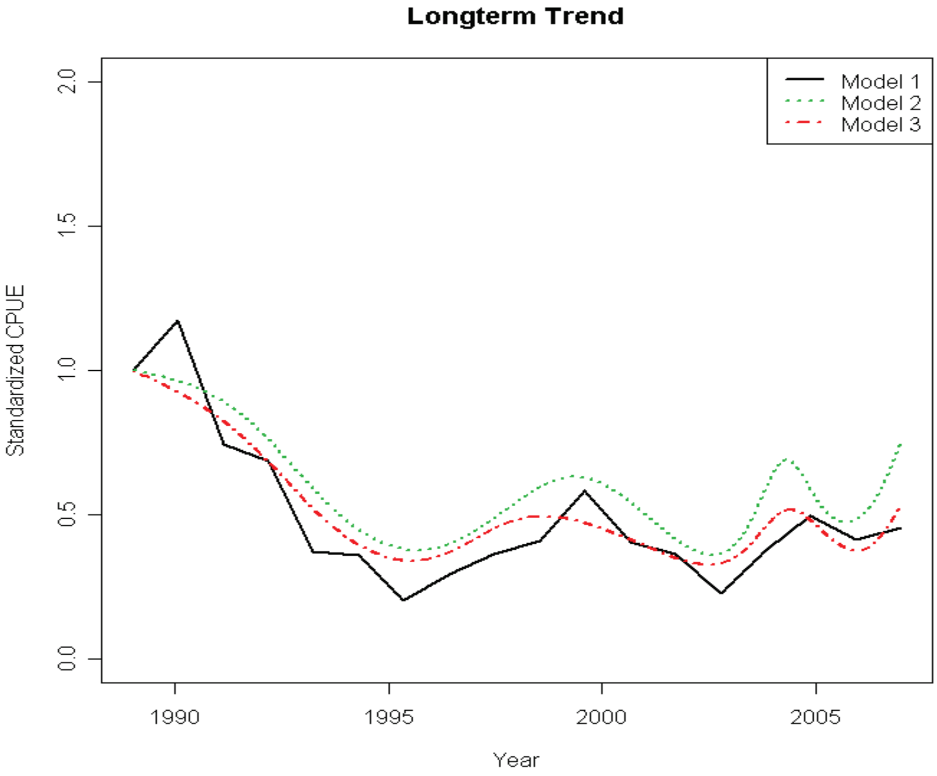


Figure 60. The standardised CPUE for Bight redfish relative to catch rates in 1989, as represented by three models.

Figure 60 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 23.42% of the variation.

Model 3: the final model in Analysis I. This model explains 28.83% of the variation.

As seen in Figure 60, including the environmental variables (Model 3 compared to Model 2) makes a difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 21,562 records collected from Sep 1997 to 2006. The variables *SprMoon, SeaWiFS_Chlo_A, CARS_surf_DO, SOI, CARS_surf_PO4, Temp_depth,* and *CARS_surf_sal* were excluded from the model in step 1 by BIC. Table 38 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 38. Bight redfish variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	5.13%
+ seasonal effect	16.25%
+ DAY_NIGHT	26.37%
+ CARS_depth_NO3	29.51%
+ CARS_depth_sal	30.41%
+ NewMoon	31.17%
+ CARS_surf_SiO2	31.37%
+ SST_6day	31.50%
+ MLD_synTS	31.59%
+ SST_frontal_density	31.66%
+ CARS_depth_PO4	31.71%
+ Magnetic_Anomaly	31.75%
+ CARS_surf_NO3	31.79%
+ CARS_depth_SiO2	31.85%
+ CARS_depth_DO	31.90%
+ Altimetry	31.94%

The last variable chosen in step 2 is *SST_6day*.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + DAY_NIGHT + CARS_depth_NO3 + CARS_depth_sal + NewMoon + CARS_surf_SiO2 + SST_6day

Table 39 lists the parameter estimates for the final model.

Table 39. Bight redfish parameter estimates (1986 – 2006) Analysis II.

Parametric Term	Estimate	SE	p-value
(Intercept)	-133.215	8.149	0
DAY_NIGHTM	0.911	0.02	0
DAY_NIGHTN	1.287	0.024	0
DAY_NIGHTU	0.416	0.281	0.139
CARS_depth_NO3	0.643	0.029	0
CARS_depth_sal	3.714	0.227	0
NewMoon	-0.177	0.011	0
CARS_surf_SiO2	-0.517	0.067	0
SST_6day	0.085	0.013	0

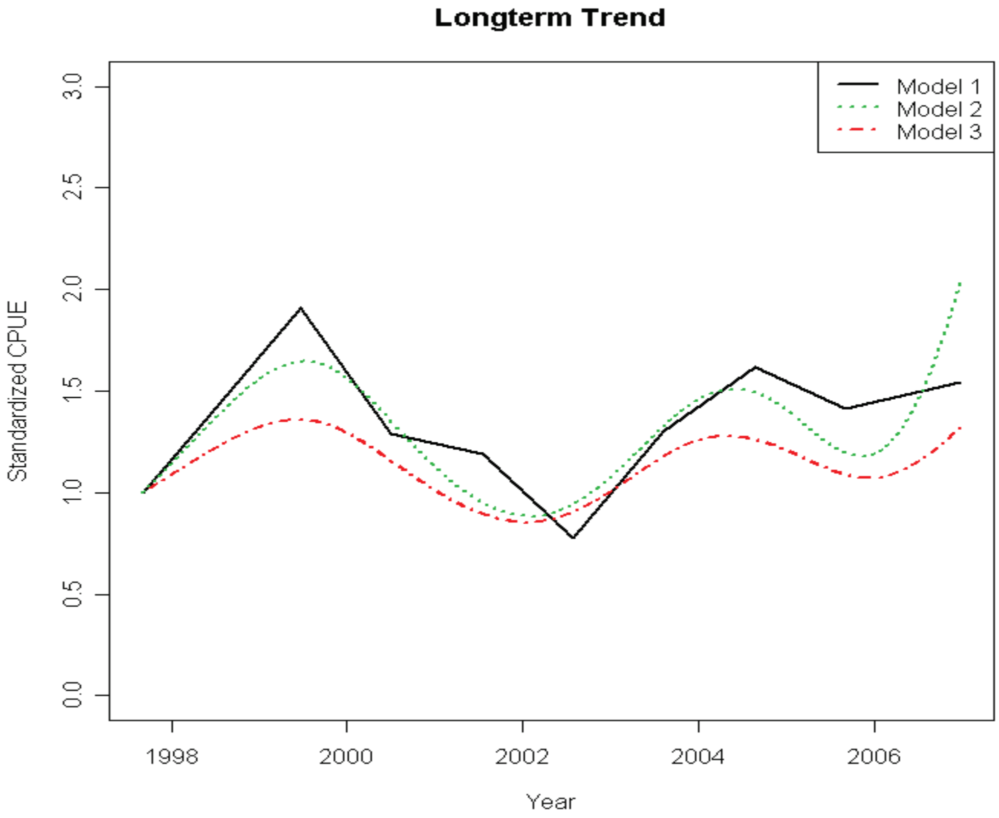


Figure 61. The standardised CPUE for Bight redfish relative to catch rates in 1997, as represented by three models.

Figure 61 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 26.38% of the variation.

Model 3: the final model in Analysis II. This model explains 31.50% of the variation.

As seen in Figure 61, including the environmental variables (Model 3 compared to Model 2) makes a difference to the final model.

7.6.4.9 Silver warehou

This section gives the results of the analysis of catches of silver warehou using otter trawl in the south-east trawl region.

Analysis I – Jan 1986 to Dec 2006

The standardised CPUE analysis using 21 explanatory variables in Category 1 was performed for 97,461 records collected over 21 years.

The variables *CARS_surf_PO4, CARS_surf_SiO2, CARS_depth_SiO2, SOI, SprMoon,* and *NewMoon* were excluded in step 1 by the BIC criterion. Table 40 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 40. Silver warehou variance explained (1986 – 2006) Analysis I.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	18.22%
+ seasonal effect	22.81%
+ Zone	24.04%
+ CARS_surf_sal	24.26%
+ DAY_NIGHT	24.38%
+ CARS_surf_temp	24.48%
+ CARS_depth_PO4	24.53%
+ Magnetic_Anomaly	24.57%
+ CARS_surf_DO	24.61%
+ CARS_surf_Chlo	24.66%
+ CARS_depth_sal	24.67%
+ CARS_depth_NO3	24.68%
+ CARS_depth_DO	24.69%
+ CARS_surf_NO3	24.69%
+ CARS_depth_temp	24.70%

The last variable chosen in step 2 is *CARS_surf_temp*.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + zone + CARS_surf_sal + DAY_NIGHT + CARS_surf_temp

Table 41 lists the parameter estimates for the final model.

Table 41. Silver warehou parameter estimates (1986 – 2006) Analysis I.

Parametric Term	Estimate	SE	p-value
(Intercept)	48.476	2.209	0
Zone20	0.502	0.028	0
Zone30	0.43	0.045	0
Zone40	1.232	0.048	0
Zone50	0.907	0.044	0
CARS_surf_sal	-1.324	0.065	0
DAY_NIGHTM	-0.123	0.013	0
DAY_NIGHTN	0.071	0.02	0
DAY_NIGHTU	0.285	0.055	0
CARS_surf_temp	0.118	0.011	0

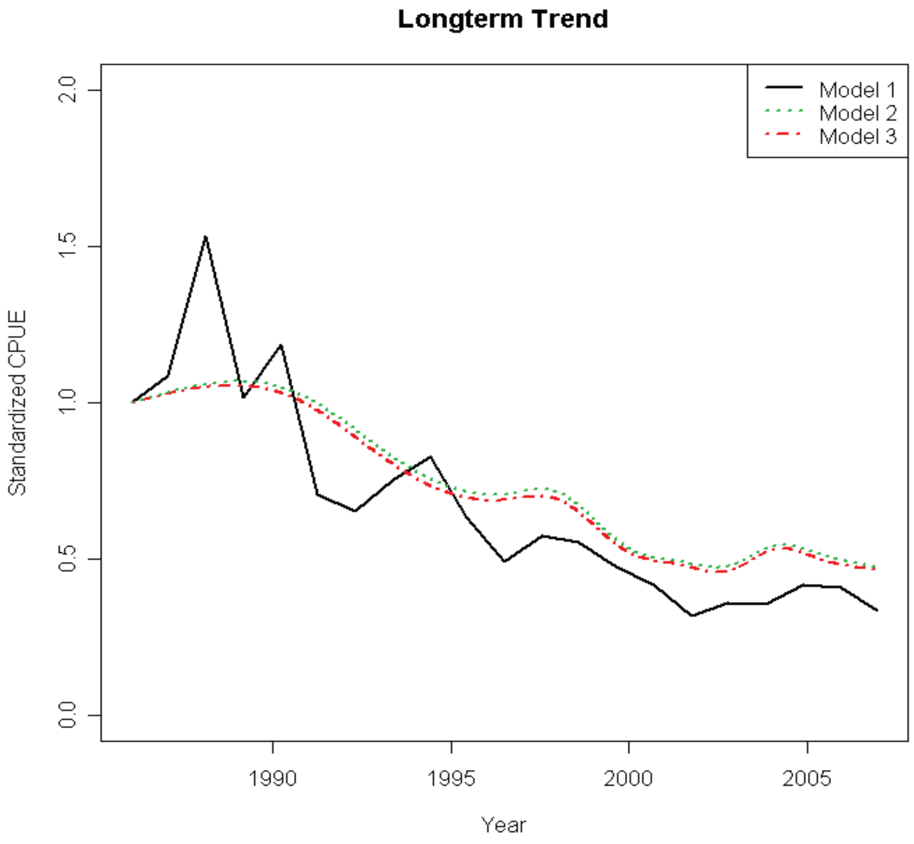


Figure 62. The standardised CPUE for silver warehou relative to catch rates in 1986, as represented by three models.

Figure 62 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 24.00% of the variation.

Model 3: the final model in Analysis I. This model explains 24.48% of the variation.

As seen in Figure 62, including the environmental variables (Model 3 compared to Model 2) makes very little difference to the final model.

Analysis II – Sep 1997 to Dec 2006

A CPUE standardisation analysis was performed for 54,283 records collected from Sep 1997 to 2006. The variables SeaWiFS_Chlo_A, SST_frontal_density, SOI, Altimetry, NewMoon, SprMoon, CARS_depth_sal, CARS_surf_NO3, MLD_synTS, CARS_depth_DO, and CARS_surf_PO4 were excluded from the model in step 1 by BIC. Table 42 lists the total variance explained by the model as variables were added sequentially in step 2.

Table 42. Silver warehou variance explained (1997 – 2006) Analysis II.

Models	Variance explained
Trawl_depth + Vessel + long-term trend	22.77%
+ seasonal effect	26.52%
+ Zone	27.73%
+ DAY_NIGHT	27.90%
+ CARS_surf_sal	28.03%
+ CARS_depth_PO4	28.20%
+ Temp_depth	28.25%
+ CARS_surf_SiO2	28.30%
+ SST_6day	28.34%
+ CARS_depth_SiO2	28.37%
+ Magnetic_Anomaly	28.40%
+ CARS_depth_NO3	28.42%
+ CARS_surf_DO	28.43%

The last variable chosen in step 2 is *CARS_depth_PO4*.

Final model:

Trawl_depth + Vessel + long-term trend + seasonal effect + Zone +DAY_NIGHT + CARS_surf_sal + CARS_depth_PO4

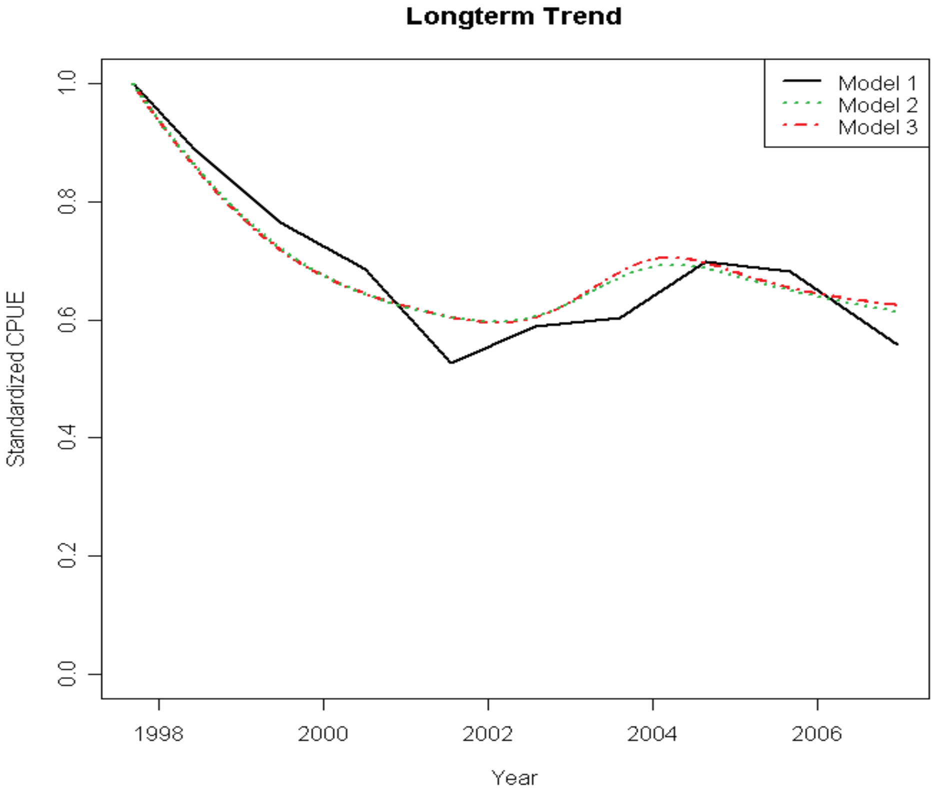


Figure 63. The standardised CPUE for silver warehou relative to catch rates in 1997, as represented by three models.

Figure 63 compares the long-term trend (standardised CPUE) of three different models.

Model 1: the standard discrete model.

Model 2: the smoothed version of Model 1. This model explains 27.90% of the variation.

Model 3: the final model in Analysis II. This model explains 28.20% of the variation.

7.6.5 Discussion

The analyses across all the species consistently shows that average trawl depth, fishing location (zone), seasonal effect and vessel are the most important variables relating to variation in CPUE. For most species, the effects of environmental variables on the CPUE standardisation are very small, with Bight redfish having the largest effect.

There are two issues to be addressed for appropriate investigation of the effects of environment variables.

1. Identify the appropriate set of environmental variables for each species.

We obtained the best available datasets and as much environmental information as possible which could be useful in explaining fluctuations in CPUE. However, it is possible that there are other environmental variables which are important but were not available for these analyses. One obvious candidate is prey availability, however these data would be hard to obtain.

2. Environmental variables should be measured at the appropriate scale.

Firstly, the measurement scale of the environmental data varied between datasets. Some of the variables, such as the CARS variables, represent average values across years (and hence have seasonal variation but no variation between years), some of them are measured on a monthly basis, some of them are on a daily basis, while some of them are derived products of other variables. If environmental variables are influencing catch rates, this influence may be on different temporal or spatial scales than those considered in this analysis. If the scale chosen is too broad, important small scale affects may be averaged over a larger scale effectively smearing or removing some of those effects. Secondly, the range for some environmental variables may be too limited. As an example, CARS_surf_PO4 has less than 7 distinct values ranging from 0 to 0.6. A finer scale or more accurate measurement may produce different results in this case.

The models in this report have been designed to explain the "log-normal" part of the "delta-models", leaving aside the binomial part of the "delta-models". The models can explain variation ranging from some 20% to 60% with most below 40%. Although this may not be surprising given the nature of the catch data, there is room for improvement. Some potential improvements to the methods are outlined below.

Zero shots (where a particular species was targeted but not caught) were not included in the analyses due to the computational and structural complexities involved in including zero shots. The SESSF is a multi-species fishery, and zero shots can be the results of either targeting and not catching or not targeting. Due to the difficulties in separating these two different types of zero shots, so that they can be weighted differently, we ignored zero shots from these analyses. To utilize the information contained in "zeros", more sophisticated methods are needed.

We also chose to exclude the interaction terms in the models due to computational and time limitations. Interactions, especially the ones with zones, could be very important in this analysis. The issue of how to treat interactions is not simple, due to the complex system of spatial and temporal interactions of environmental variables with CPUE. This may include issues such as interactions between species, possible time lags, and differences in behaviour across regions. A couple of simple interaction terms in the models could be misleading. A simple method of exploring the effect of zone would be to analyse the data by zone separately instead of using interaction terms.

To simplify this analysis, the spatial information was restricted to analysis by zone, rather than using longitude and latitude, but a more sophisticated method of dealing with spatial effects may be productive.

The splines family is used in our analysis. The disadvantage of using splines is that it is difficult to guess the most appropriate value to use for the degrees of freedom. Generalized additive mixed models (GAMMs) provide a method which use a penalized likelihood and automatically choose the value for the degrees of freedom by cross-validation. The mgcv package for R provides an implementation of GAMMs with all these features, but unfortunately, this dataset is too large and mgcv could not be used successfully.

7.7 EFFECTS OF INCLUDING ENVIRONMENTAL FACTORS INTO EXISTING CPUE FRAMEWORK

Malcolm Haddon and Jemery Day

7.7.1 Introduction and methods

Given the results of the previous section, an exploration of whether some of the standard variables used in the general linear model (GLM) analyses of CPUE standardisation were acting as proxies for "environmental" variables should be considered. In most cases, trawl depth and season were amongst the first variables included in CPUE standardisation and these two variables are highly correlated with two environmental variables: temperature-at-depth and sea surface temperature (SST) respectively. As such, environmental variables may already be indirectly included in the GLM through their strong correlations with other variables used in the standardisations. These other variables are not usually considered traditional environmental variables, but they may partially represent a range of environmental variables and because they are selected first in the GLM analysis this may then prevent the "pure" environmental variables from leading to significant improvements in the variability described when they are incorporated in the standardisation.

Further investigations were carried out for two species, tiger flathead trawl and ling (east) using a different GLM structure to that used previously. The GLM used were standardised according to the conventions of (Haddon, 2007), with depth treated as a categorical variable and year as a discrete variable. The only difference between this analysis and the standardisation used in SESSF assessments is the absence of any interaction terms. The available data were standardised following the Haddon conventions with the variables; year, vessel, trawl depth (categorical), zone, month, and daylight, with no interaction terms; thus

log(CPUE) ~ Year + Vessel + DepCat + Zone +Month + DayNight.

Alternative arrangements were explored so as to address the question of whether two of the standard "non-environmental" variables recorded in the logbook, trawl depth and month, could be replaced by purer environmental variables. The selected environmental variables were temperature-at-depth and SST, and these were highly correlated with trawl depth and with month respectively.

For each species, alternative GLM model structures were examined with the relative fit of competing models compared using Akaike's Information Criterion (AIC) and the percentage of deviance explained. The base model included the variables trawl depth and month, and excluded temperature-at-depth and SST. This base model was compared to models where the base model is modified by:

(a) SST replacing month,

(b) temperature-at-depth replacing trawl depth, and

(c) SST replacing month and temperature-at-depth replacing trawl depth.

For tiger flathead (trawl) five statistical models were compared (Table 43).

Table 43. The different statistical models examined. SST_6day is present twice, once alone and secondarily as a squared term. Such a quadratic representation, also used in Temp_depth, allows for non-linear responses of log (CPUE) to the variable concerned. DepCat were a series of 10 m depth categories. Zone included zones 10 to 60, DayNight included four categories; U – unknown, D – Day, N – Night, and M –mixed.

1	log(CPUE)~Year
2	log(CPUE)~Year+Vessel+DepCat+Zone+Month+DayNight
3	log(CPUE)~Year+Vessel+DepCat+Zone+SST_6day+I(SST_6day^{2})+DayNight
4	log(CPUE)~Year+Vessel+Zone+Temp_depth+I(Temp_depth^{2})+DayNight+Month
5	log(CPUE)~Year+Vessel+Zone+DayNight+SST_6day+I(SST_6day^{2})+Temp_depth+I(Temp_depth^{2})

7.7.2 Results and discussion

Relative to the Base Case (Model 2) for tiger flathead (trawl), the model fit is slightly worse, but comparable for Model 3, where SST replaces month only. For Models 4 and 5, where in both cases trawl depth is replaced by temperature-at-depth, the model fit is much worse (Table 44). In all cases, the trend in CPUE was not changed a great deal from the geometric mean catch rates and the difference between Models 2 and 3 is reflected in only minor changes to the predicted trend (Figure 64).

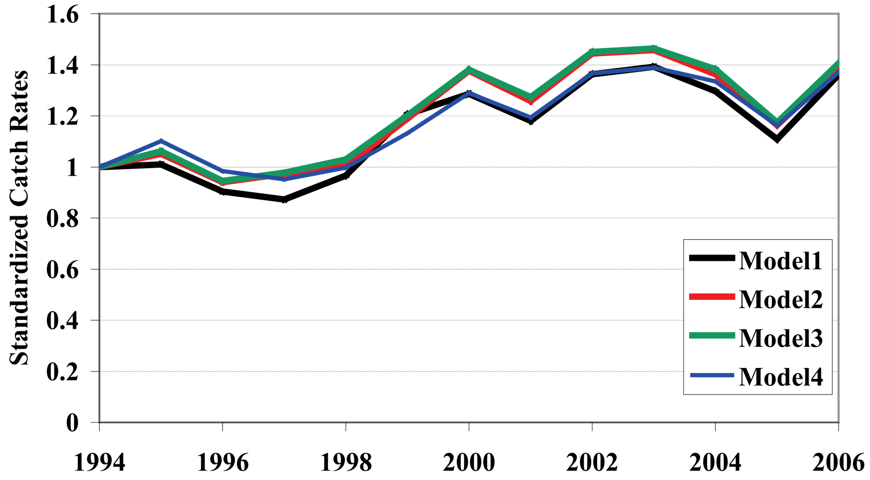


Figure 64. A comparison of the first four models for tiger flathead (trawl). Model 1 represents the geometric mean catch rate and all other models follow this trajectory approximately (c.f. Table 43, Table 44).

Table 44. Model selection criteria including the Akaike's Information Criterion, the residual sum of squares = Deviance, the Number of observations, the number of parameters fitted, the change in the sum of squares, the proportional change in the sum of squares, and the percentage change between respective lines (thus most of the difference between the geometric mean and the final model occurred by Model 2.

	Model1	Model2	Model3	Model4	Model5
AIC	46638	7453	7976	13676	13760
Deviance	213928	166978	167543	173721	173832
Nobs	159806	159804	159804	159804	159804
Npars	13	218	209	166	157
DDeviance		46950	-565	-6178	-110
%Change		21.947	-0.339	-3.688	-0.064
DChange		0.048	0.002	0.041	0.013

The same set of models was applied to pink ling (east) (Table 43). For pink ling (east), the model fit is actually improved slightly in Model 3, and improved further when both SST and month are used in the same model. As with tiger flathead, Models 4 and 5 produce a much worse fit (Table 45).

With pink ling (east) none of the standardizations change the trend in CPUE to any significant degree from the geometric mean catch rates (Figure 65, Table 45). The use of the alternative environmental variables in place of the more standard month and depth only has an influence in the first four years, after which the lines remain almost coincident with the geometric mean on the standardized trends.

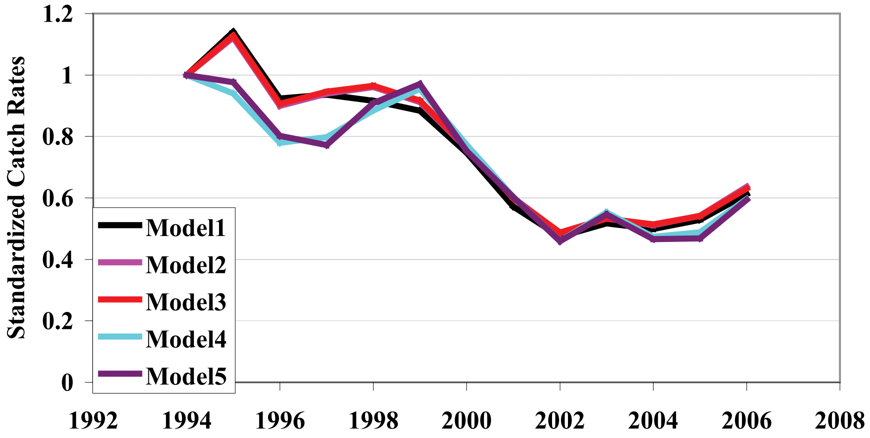


Figure 65. A comparison of the five models for pink ling (east). Model 1 represents the geometric mean catch rate and all other models follow this trajectory approximately. Model 2 is effectively obscured by Model 3 (c.f .Table 43, Table 45).

Table 45. Model selection criteria including the Akaike's Information Criterion, the residual sum of squares = Deviance, the Number of observations, the number of parameters fitted, the change in the sum of squares, the proportional change in sum of squares, and the percentage change between respective lines (thus most of the difference between the geometric mean and the final model occurred by Model 2), but the optimal model was Model 3.

	Model1	Model2	Model3	Model4	Model5
AIC	12490	12421	11882	44640	46041
Deviance	105331	105272	104636	149332	151641
Nobs	92465	92465	92465	92465	92465
Npars	222	213	224	159	150
DDeviance		59	637	-44696	-2309
%Change		0.0561	0.6048	-42.7164	-1.5459
DChange		0.0061	0.0002	0.0879	0.0043

This analysis suggests that temperature-at-depth is not a suitable replacement for trawl depth in the standardisations, but that SST could potentially replace month in the standardisation. In either case, the standardization produced gave approximately the same trend through time. So, given the difficulty in obtaining and analysing the environmental variables compared to the standard logbook variables, the advantages of including literal environmental data are minimal.

With this dataset, the "environmental variables", SST and temperature-at-depth, were not available for all shots, even where the log book recorded alternatives, month and trawl depth, were available. Hence the replacement of the variable Month with the more biologically meaningful variable SST could only be made for part of the available time series. To use these data would require either discarding some catch and effort data or creating two catch rate based abundance series.

The minor improvements in the fit to the model, in the case of pink ling (east), are unlikely to have made any practical difference to an assessment as the CPUE time series only changed marginally.

7.8 POST GLMM ANALYSES: EXPLORATION OF CORRELATION OF MEASURABLE ENVIRONMENTAL VARIABLES

Jemery Day

7.8.1 Introduction and methods

The GLMM analysis generally revealed limited additional variance explained through the inclusion of environmental variables. In light of this result, some simpler analyses were done, calculating the correlation coefficient of log scale CPUE with environmental parameters, to investigate whether individual environmental parameters may be influencing catch rates. A comprehensive list of these correlations is included in Appendix 8 for the Analysis I, looking at variables from 1985–2006. Given that many of these variables came from CARS and had only seasonal variability rather than annual variability, correlations were also calculated for the variables used in Analysis II from 1993–2006.

To determine which of the environmental variables could be most useful for predicting changes to CPUE as a result of changes in environmental variables, the correlations for all of the variables from Category 1–6, excluding the CARS variables were ranked according to absolute value of the mean correlation for all species/gear type combinations. The absolute value of the correlation was used because a large negative correlation is as important as a large positive correlation.

7.8.2 Results and discussion

Correlation coefficients were plotted (Figure 66) against trawl depth (TwD) (for information only, as this is not strictly an environmental variable) temperature-at-depth (TpD), sea surface temperature averaged over 6 and 3 day periods (SST6 and SST 3), Chlorophyll A from SeaWiFS data (SWCl), turbidity from SeaWiFS data (SWTu), Mixed layer Depth (MLD), Wind speed (W), and Wind speed in two components of wind direction (Wu and Wv), Magnetic Anomaly (MA), Frontal Density (FD), Altimetry (Alt), Southern Oscillation Index (SOI) and phase of moon including New moon (NM), and Spring moon (SM). The highest two values of mean absolute correlation were from temperature-at-depth and sea surface temperature (6 day), with the lowest correlates including SOI and phase of the moon. This suggests that for these fisheries, SOI and phase of moon has very little influence on catch rates.

Clearly, different environmental variables have the highest correlation with catch rates for different species/gear types. If only two environmental variables could be collected routinely, for this suite of species, this analysis suggests that temperature-at-depth and SST would be the most useful choices.

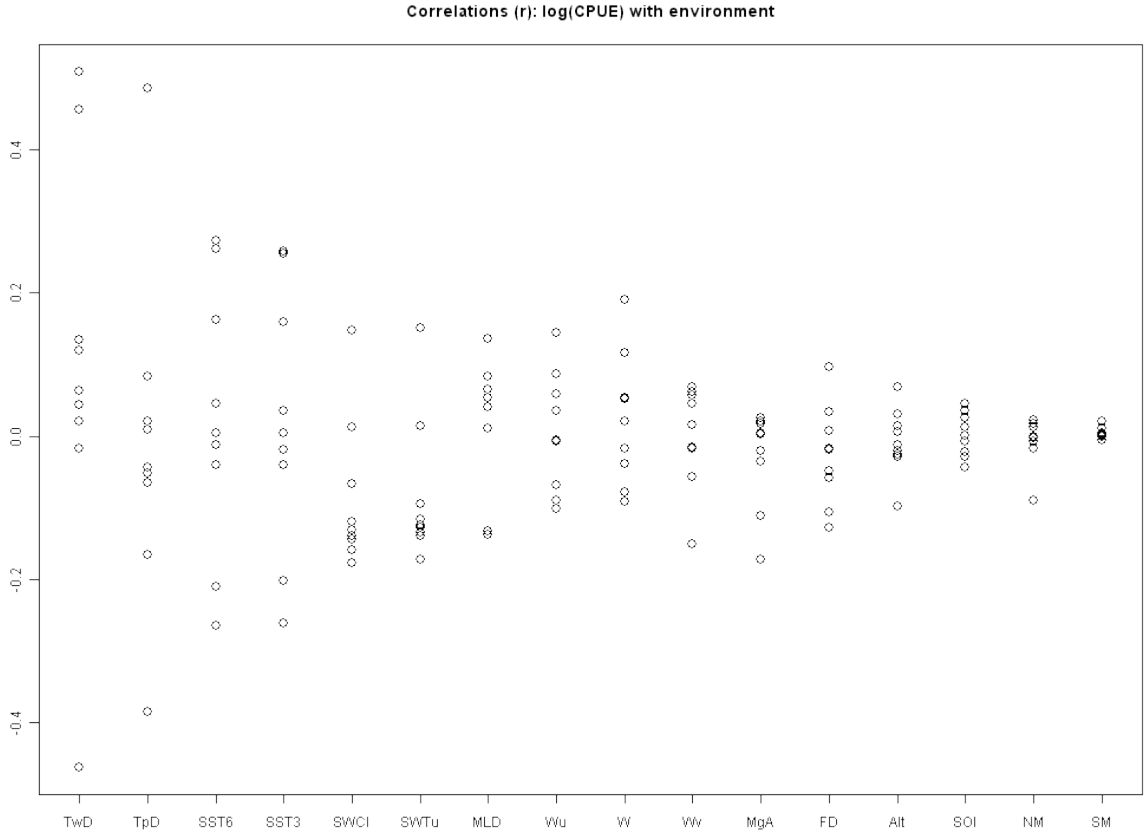


Figure 66. Correlation coefficients for catch rates and a list of environmental variables, with values plotted for each of the 9 species and gear type combinations

To enable individual species/gear types to be followed, the same data were plotted with a range of symbols (Figure 67). This allows easy comparisons of species, including comparisons of tiger flathead caught by Danish seine and otter trawls fleets (open and filled red squares), spawning and non-spawning blue grenadier fleets (open vs filled orange circles), and east and west pink ling (open and filled green triangles).

Examples of large changes of magnitude and sign of the correlation coefficient within a species include; spawning and non spawning stocks of blue grenadier correlated with temperature-at-depth, Danish seine or otter trawl caught tiger flathead correlated with SST, and east and west pink ling correlated with chlorophyll A. These changes suggest that some environmental effects on catch rates, for these species, are not consistent over the full range of the fishery, where "range" can include geographical range, gear type range or spawning versus non spawning sectors of the fishery.

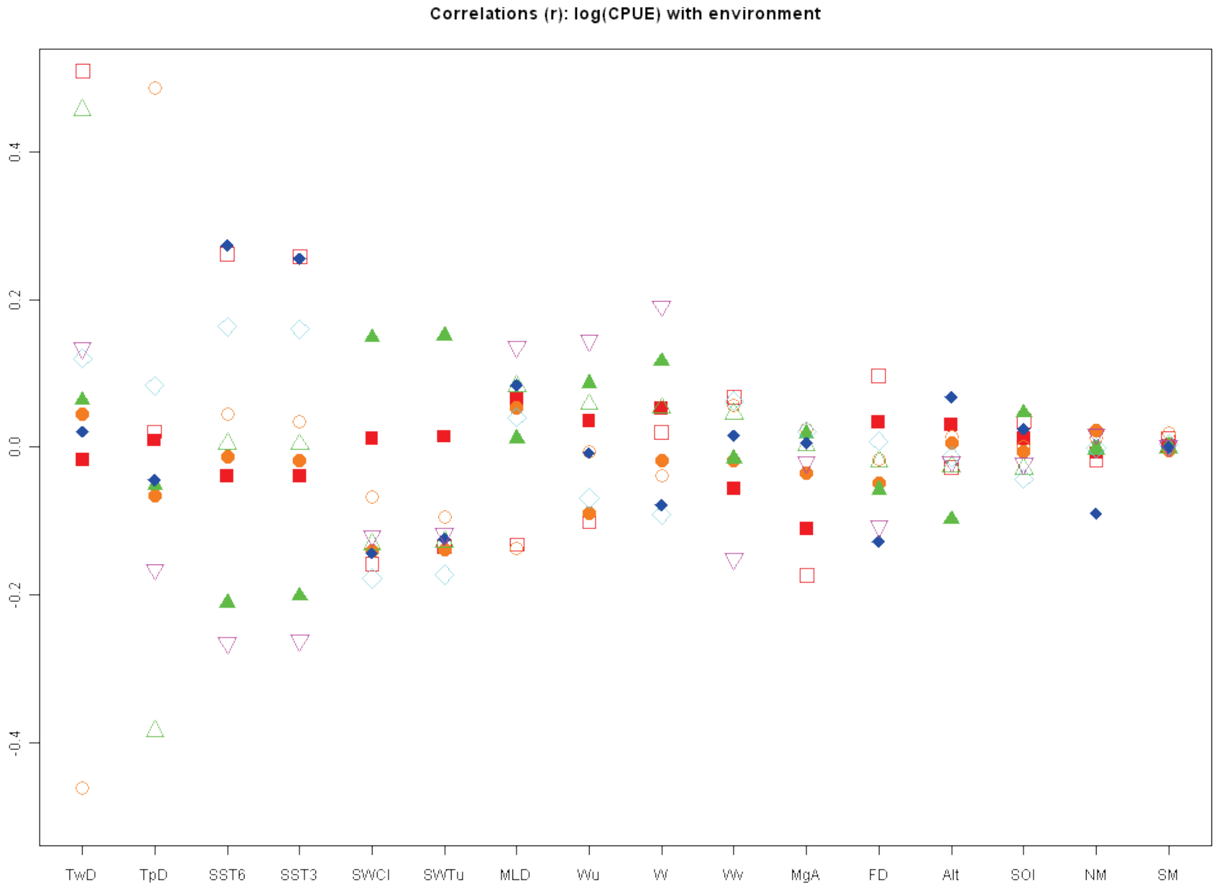


Figure 67. Correlation coefficients for catch rates and a list of environmental variables, with values plotted for each of the 9 species and gear type combinations. These are the same data as plotted in Figure 66, but with the correlation coefficients indentified for individual species and gear types as follows: tiger flathead Danish seine (open squares, red), tiger flathead otter trawl (filled squares, red), blue grenadier spawning (open circles, orange), blue grenadier spawning (filled circles, orange), pink ling east (open triangles, green), pink ling west (filled triangles, green), redfish (open diamonds, aqua), Bight redfish (closed diamonds, blue), and silver warehou (upside down triangles, magenta).

Figure 66 and Figure 67 also illustrate that there are no high correlation coefficients in this analysis. If trawl depth is excluded, there is only one correlation coefficient higher than 0.4, spawning blue grenadier and temperature-at-depth (r = 0.486), and in the non spawning fishery this correlation coefficient is negative and much smaller in magnitude (r = -0.065). Further, temperature-at-depth and SST are the only environmental variables where there is a correlation above 0.2.

These results suggest that there is no strong general relationship between environmental variables and catch rates, over the full range of the fisheries examined in this study. There may be effects on much smaller spatial regions, or there may not be any relationships present and the results presented here just show general noise.

7.9 ENVIRONMENT-AVAILABILITY RELATIONSHIPS

Jemery Day

7.9.1 Introduction and methods

This section provides data plots showing the raw data; displaying relations between catch rates and a range of environmental variables on a range of spatial and temporal scales. A more comprehensive list of data plots appears in Appendix 9.

All plots in this section include the raw data, plotted in grey dots, overlaid with a contour plot to indicate the areas of high and low density and a series of quantile regression lines for the 5%, 25%, 50%, 75%, and 95% quantiles. The quantile regression was done using the quantreg package (Koenker, 2009), for the software package R. This can be used to highlight differences in any relationship between high and low catch rates and the particular environmental variable.

7.9.2 Results and discussion

Tiger flathead (Danish seine)

The correlation of catch rates of tiger flathead caught by the Danish seine fleet with SST is 0.262. While this is one of the higher correlations between catch rates and environmental variables, the raw data plotted in Figure 68 indicate that the relationship is not very strong. For all quantile regression lines plotted, there appears to be an increase in catch rate associated with an increase in SST. The slightly steeper slope for the 5% and 25% quantile regression lines, suggests that any response to SST is greater when the catch rate is low. Further, there is considerable temporal variation in any relationship as is demonstrated by plotting this data by month (Figure 69). The increase in catch rate associated with an increase in SST appears to be stronger in winter months than in summer months. The ‘p’ shape of the distribution in the winter months suggests that when SST is below a threshold of around 14ºC, the full range of catch rates is possible, but for SST above 14ºC, the very low catch rates are rarely obtained. This is most clear in August (middle row, 4th column) when the highest catch rates have little relationship with SST (the 95% quantile regression lines is almost flat) and the lowest catch rates have a stronger relationship with SST (the 5% and 25% quantile regression lines are the steepest).

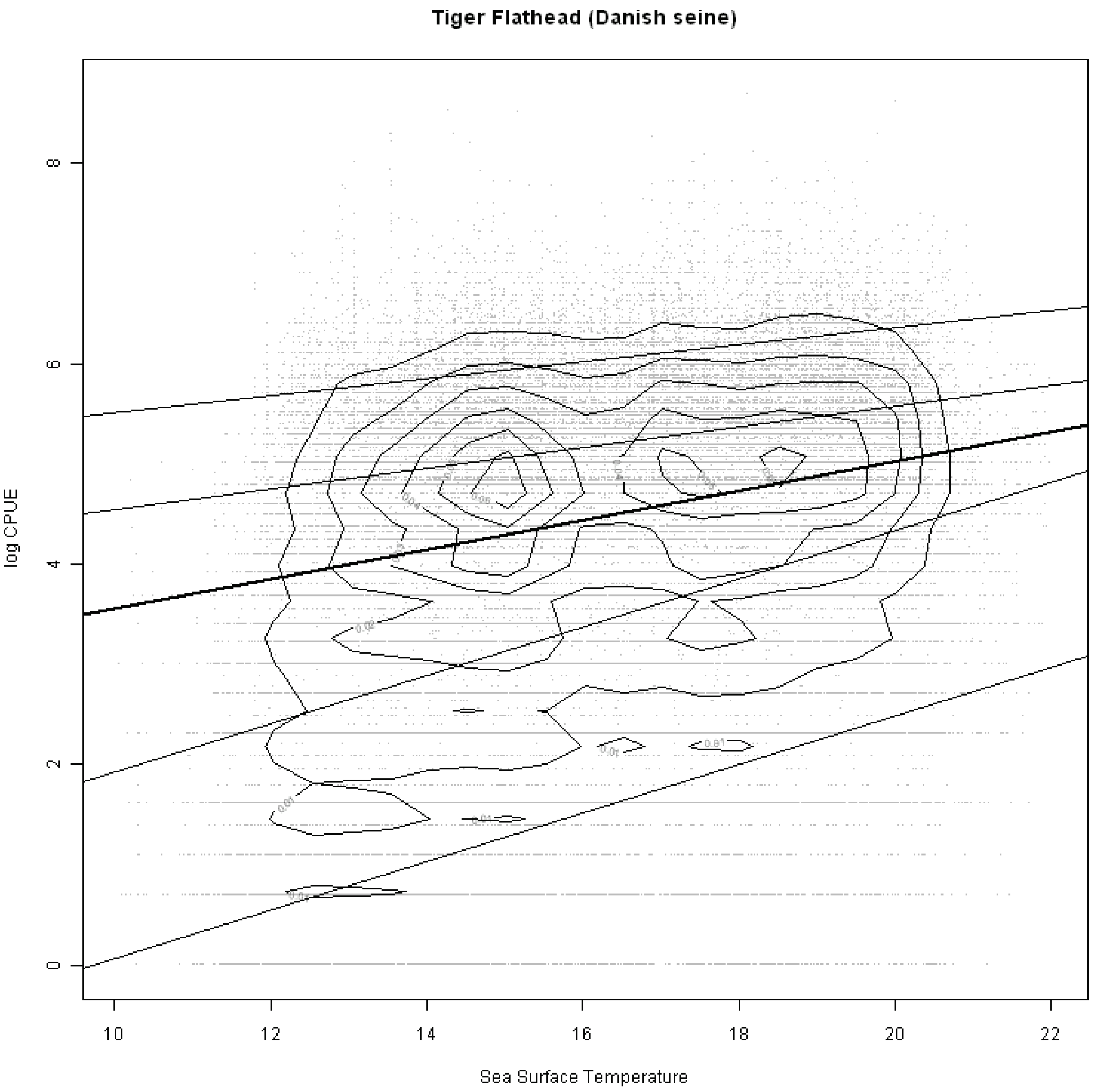


Figure 68. Log catch rate of tiger flathead (Danish seine) plotted against SST.

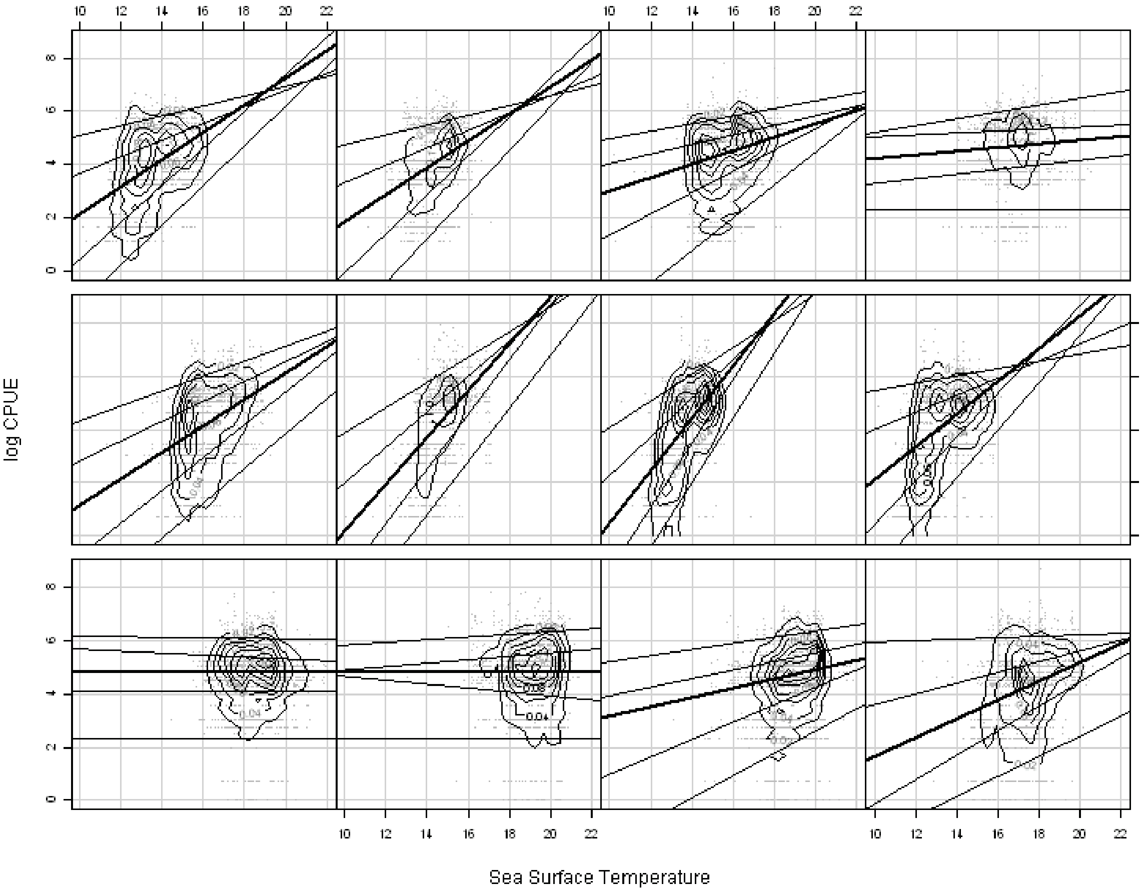


Figure 69. Log catch rate of tiger flathead (Danish seine) plotted against SST by month. The lower left corner corresponds to January, with February to the immediate right and then progressing left to right across each row successively and then up with the box on the top right corresponding to December.

Blue grenadier

The correlation of catch rates of spawning blue grenadier with temperature-at-depth is 0.486 (Figure 70). This is the largest correlation between catch rate and any environmental parameter for any of the cases examined here. Nevertheless, the bulk of the catches are caught where the temperature-at-depth is between 9 and 11 degrees.

In contrast to the spawning fishery, the relationship between catch rate and temperature-at-depth for non-spawning blue grenadier is much weaker with a correlation coefficient of -0.065 (Figure 71), suggesting no relationship between catch rate and temperature-at-depth.

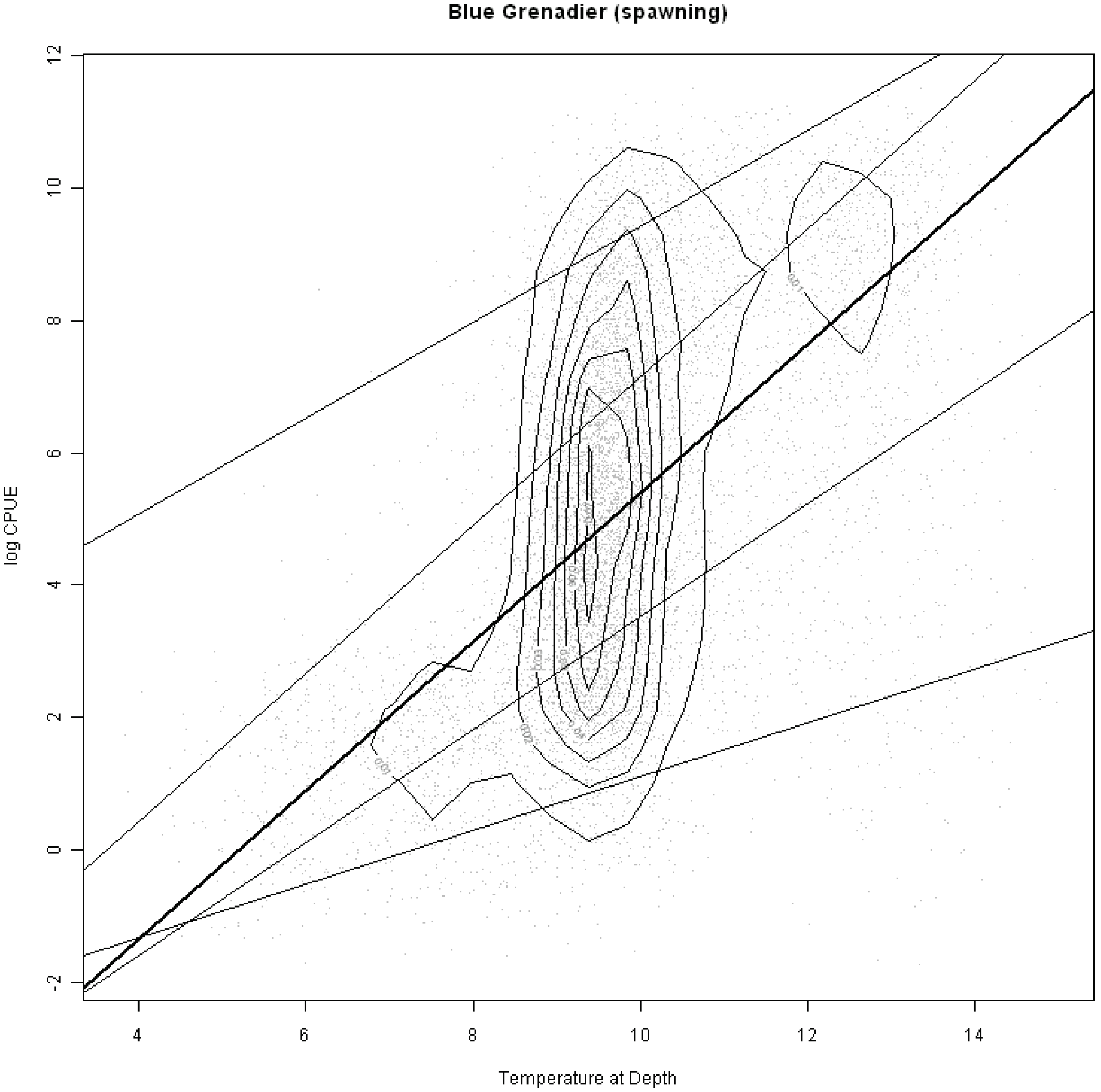


Figure 70. Log catch rate of spawning blue grenadier plotted against temperature-at-depth.

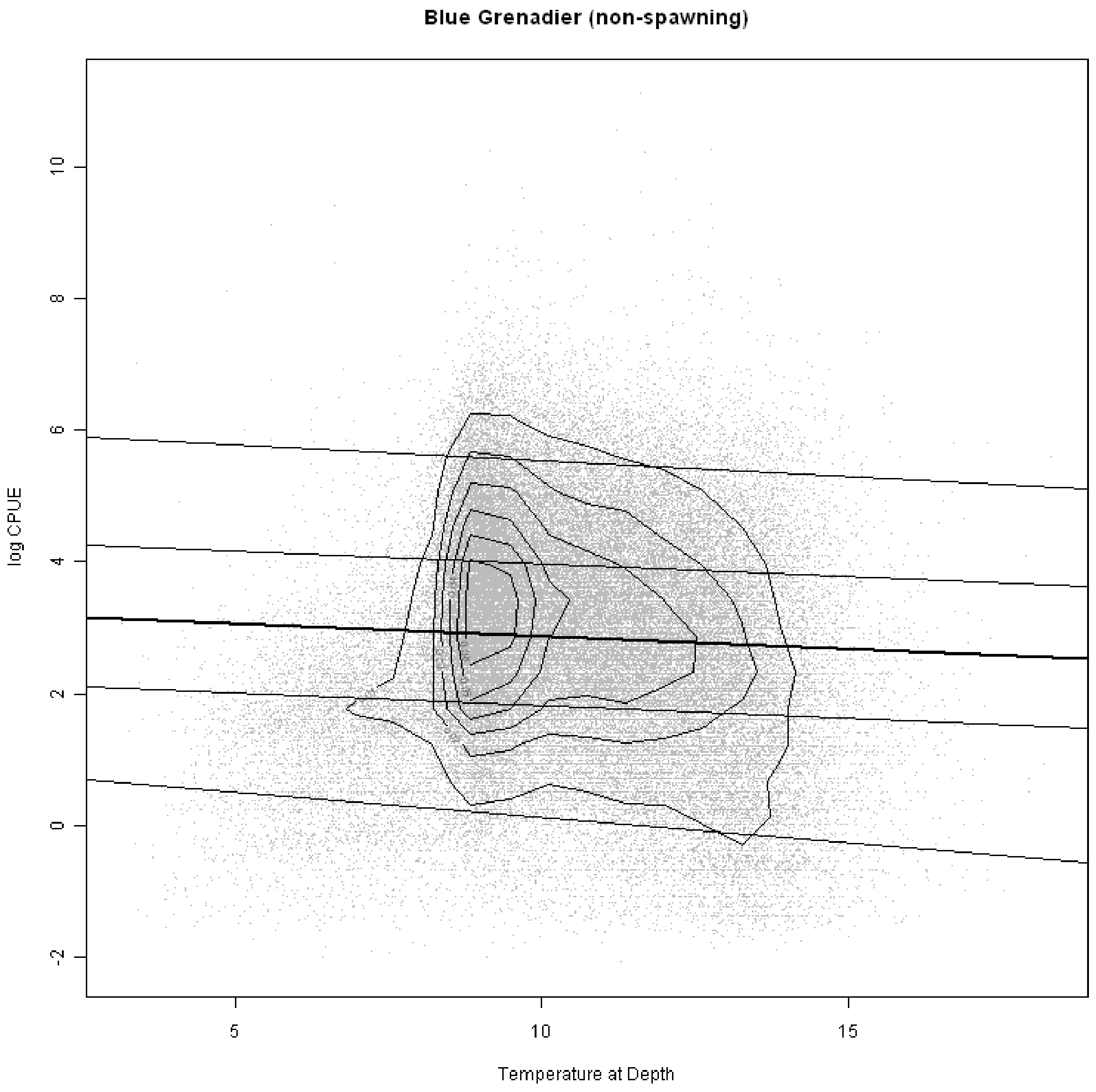


Figure 71. Log catch rate of non-spawning blue grenadier plotted against temperature-at-depth.

Silver warehou

The correlation of catch rates of silver warehou with SST is -0.265, suggesting a limited relationship between catch rate and SST (Figure 72).

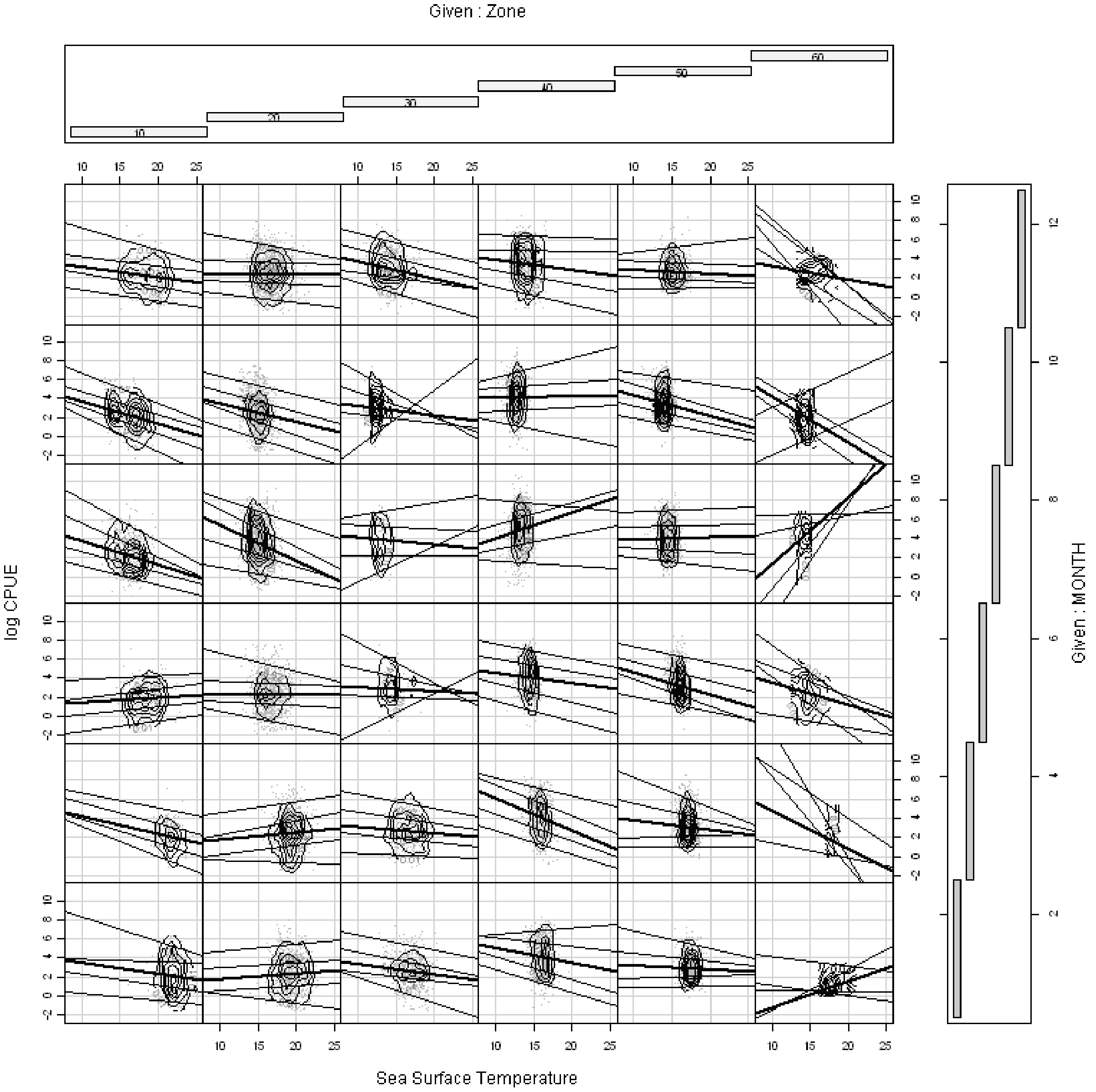


Figure 73 attempts to show spatial or temporal differences in the response of catch rate to SST. The number of records of catch rates of silver warehou varies greatly by zone. Zone 20 has almost 30,000 records; zone 50 has over 20,000; zone 40 has over 15,000; zones 10 and 20 have over 7,000; and zone 60 has less than 200 records. Inconsistent variation in trends between months and zones, suggests that there may be some interaction between zone and month in any relationship between catch rate and SST.

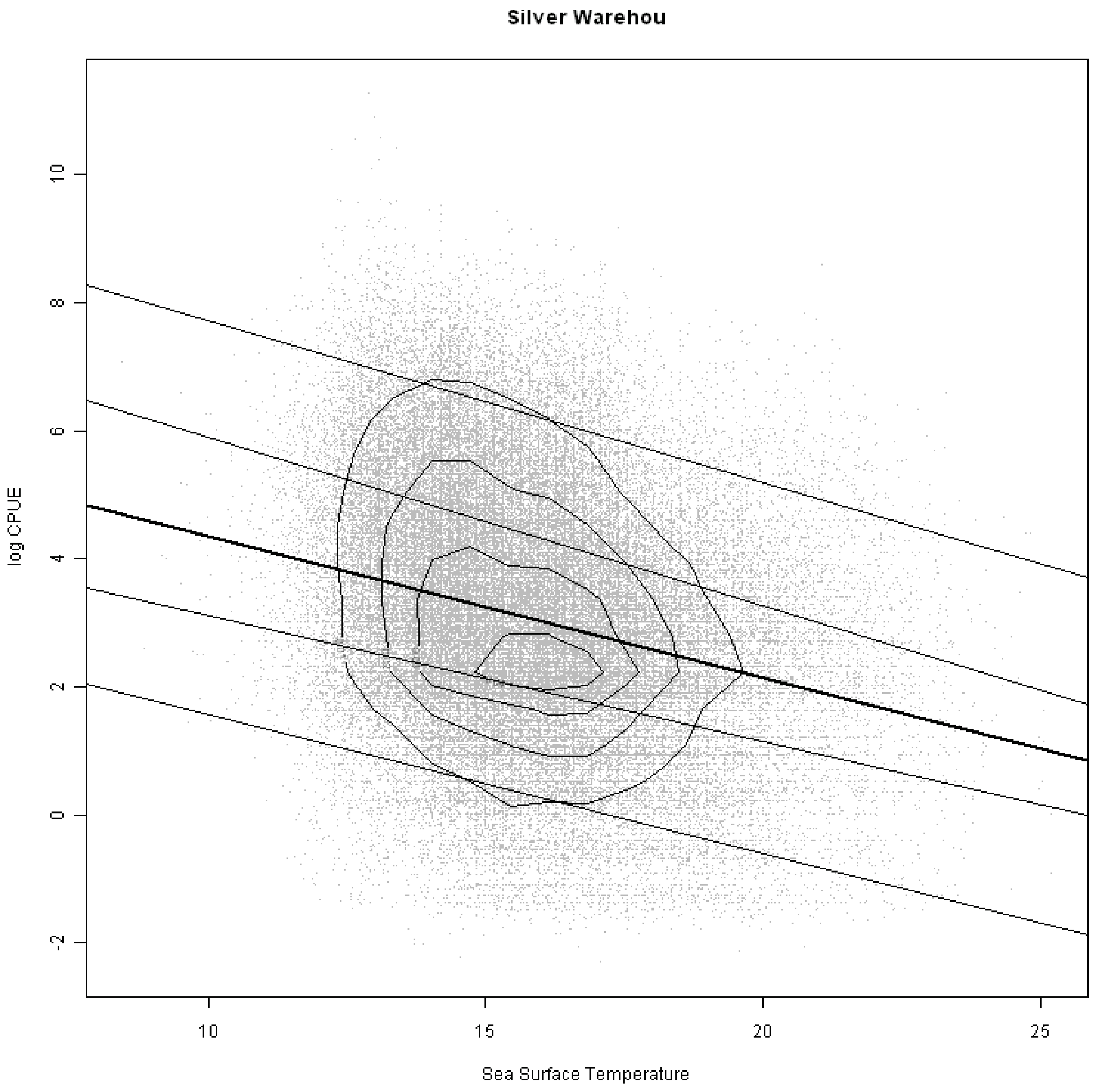


Figure 72. Log catch rate of silver warehou plotted against SST.

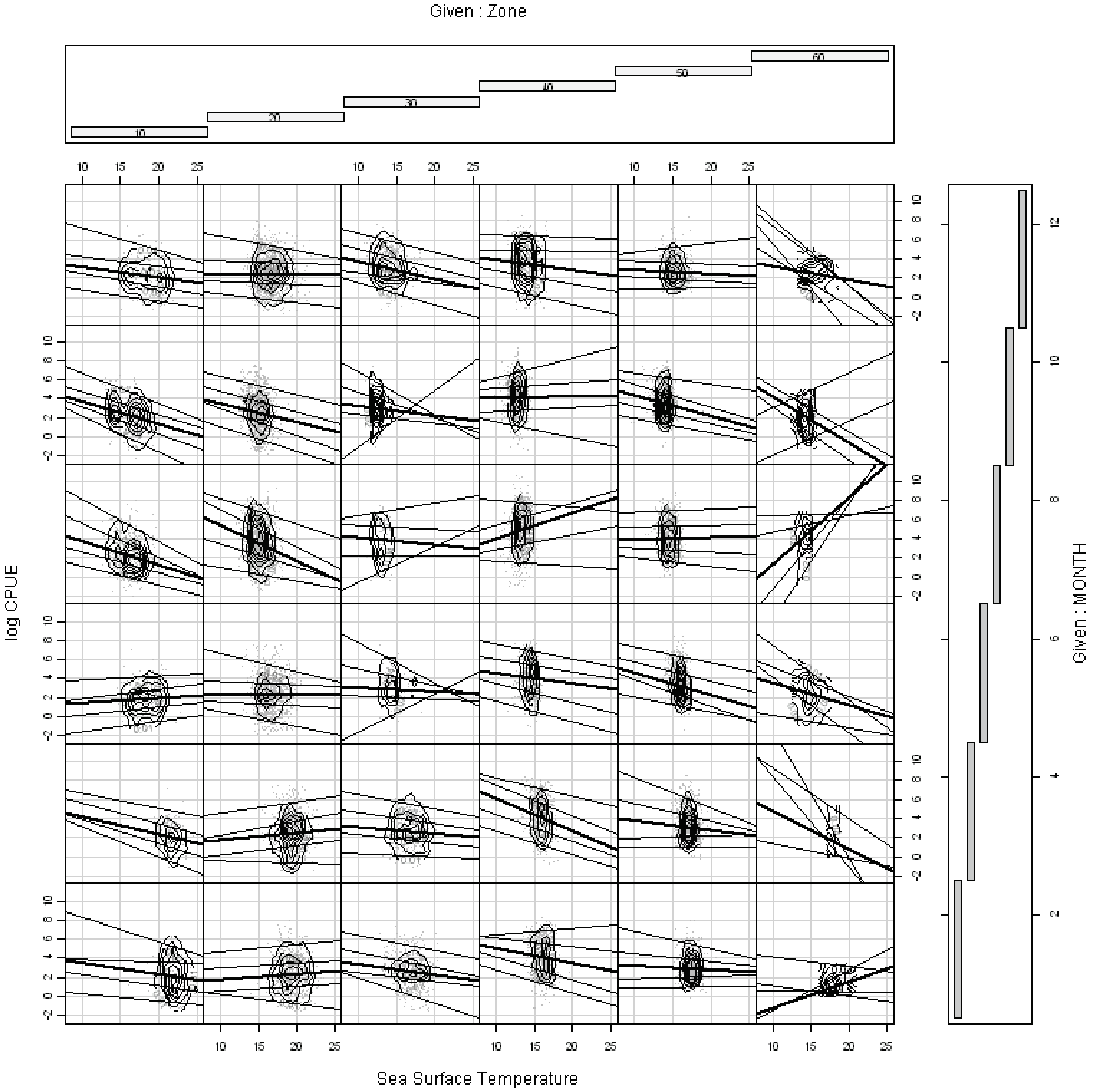


Figure 73. Log catch rate of silver warehou plotted against SST by month and zone. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

The temporal and spatial variation in any relationship between catch rates and environmental variables could indicate that there are important interactions between these terms or could indicate that any relationship is not strong enough to be consistent in different spatial and temporal portions of the fishery.

7.10 PRELIMINARY EXAMINATION OF RECRUITMENT CORRELATIONS FOR THE SESSF, 2009

Neil Klaer

7.10.1 Introduction and methods

Standardisation of stock assessment methods, primarily to Stock Synthesis 2 or 3 in recent years, has enabled the compilation of recruitment series from all of the assessed stocks in a common form. In all cases, the assessment assume an underlying Beverton and Holt stock-recruitment relationship with a given steepness value. Stock assessments report recruitment residuals fitted assuming a log-normal error distribution.

Log-recruitment residual values from 1980 to 2004 were standardised so that they sum to 0 and have a mean absolute value of 1. Pearson correlation coefficient values were calculated comparing each series to all others and tabulated (Table 46). The significance of the correlations was also calculated. A principal components analysis was carried out using annual log-recruitment residual values as factors in the analysis (Figure 74).

Species (and sub-stocks) included in the analysis were tiger flathead (AUFLT), deepwater flathead (AUFLD), Bight redfish (AUREB), eastern ling (AULIGE), western ling (AULIGW), eastern blue warehou (AUTRTE), western blue warehou (AUTRTW), blue grenadier (AUGRE), northern redfish (AUREDN), southern redfish (AUREDS), jackass morwong (AUMOW), Bass Strait gummy shark (AUGUMA), South Australian gummy shark (AUGUMB), and Tasmanian gummy shark (AUGUMC).

7.10.2 Results and discussion

There were 10 correlations among species or sub-stocks that were significant at the 90% or greater level (Table 46). Correlations occurring between geographically and/or biologically linked species include; tiger flathead with southern redfish, Bass Straight gummy shark with Tasmanian gummy shark, eastern ling with western ling, eastern ling with jackass morwong, eastern blue warehou with western blue warehou, and western blue warehou with South Australian gummy shark.

Groupings of common patterns from principle components analysis appear mostly to aggregate species from the same regions as expected, suggesting that general recruitment patterns are specific to regions across multiple species (Figure 74). Examples of groupings are; deepwater flathead and Bight redfish; tiger flathead, Bass Strait gummy shark and Tasmanian gummy shark; eastern blue warehou and eastern ling; blue grenadier, South Australian gummy shark and western blue warehou. Group placements of northern and southern redfish, western ling and morwong appear to be less intuitive.

Figures showing the recruitment residuals for each species in the separate component groups are shown in Figure 75 to Figure 78.

The groupings suggest the potential for concurrent processes driving recruitment for eastern deepwater species (blue warehou and ling) relative to shallower species (tiger flathead and gummy shark).

Further analysis should consider including more species or sub-stocks to improve the resolution of common patterns. Work has also commenced in finding environmental series that are correlated to major common trends among species. It is far more convincing to find common trends among recruitment residuals for a number of independently measured species or stocks than single species in isolation. It is then relatively easy to find environmental indices that correlate with these trends. The more difficult stage is to then find a biophysical mechanism that might explain the correlation of the environmental index with recruitment.

Table 46. Significance of Pearson correlation coefficients of recruitment from 1986 to 2004 among species in the upper right-hand matrix (>90% in bold italics) and r values in the lower left-hand matrix (>90% significant r values are shaded).

	AUFLT	AUFLD	AULIGE	AULIGW	AUTRTE	AUTRTW	AUGRE	AUREDN	AUREDS	AUMOW	AUGUMA	AUGUMB	AUGUMC
AUFLT	1.0000	0.9647	0.6619	0.3287	0.8819	0.7447	0.1942	0.1368	***0.0204***	0.6076	***0.0224***	0.3733	0.1703
AUFLD	0.0109	1.0000	0.4728	0.5213	0.7765	0.8982	0.6834	0.1396	0.1809	***0.0334***	0.2318	0.3496	0.8331
AULIGE	-0.1073	0.1753	1.0000	***0.0022***	0.2494	0.9268	0.4607	0.3720	0.3492	***0.0142***	0.4022	0.3082	0.3297
AULIGW	-0.2369	-0.1569	0.6582	1.0000	***0.0298***	0.2143	0.9473	0.2035	0.1692	0.1464	0.2410	0.1860	0.5586
AUTRTE	-0.0366	-0.0698	0.2779	0.4987	1.0000	***0.0940***	0.7203	0.5188	0.5969	0.7820	0.4196	0.9372	0.7828
AUTRTW	0.0800	-0.0315	0.0226	0.2986	0.3952	1.0000	0.8785	0.2536	0.2858	0.2279	0.7564	***0.0349***	0.7246
AUGRE	-0.3115	0.1001	0.1801	0.0163	0.0880	0.0376	1.0000	0.2733	0.1113	0.1473	0.8071	0.2426	0.5198
AUREDN	-0.3542	0.3519	0.2171	0.3054	-0.1578	0.2755	0.2648	1.0000	0.1015	0.4488	0.8747	0.4304	0.2204
AUREDS	0.5269	-0.3205	0.2274	0.3289	0.1296	-0.2582	-0.3773	-0.3871	1.0000	0.4090	0.9291	***0.0002***	0.7883
AUMOW	0.1259	-0.4896	-0.5525	-0.3463	-0.0680	0.2903	0.3455	-0.1848	-0.2011	1.0000	0.5905	0.1303	0.8102
AUGUMA	0.5204	0.2880	-0.2040	-0.2826	-0.1967	0.0762	-0.0600	0.0388	0.0219	-0.1319	1.0000	0.8835	***0.0410***
AUGUMB	-0.2165	0.2272	-0.2469	-0.3170	0.0194	0.4860	0.2817	0.1922	-0.7572	0.3598	0.0360	1.0000	0.8813
AUGUMC	0.3281	0.0518	-0.2365	-0.1432	0.0678	-0.0866	-0.1574	-0.2949	0.0660	-0.0591	0.4726	0.0367	1.0000

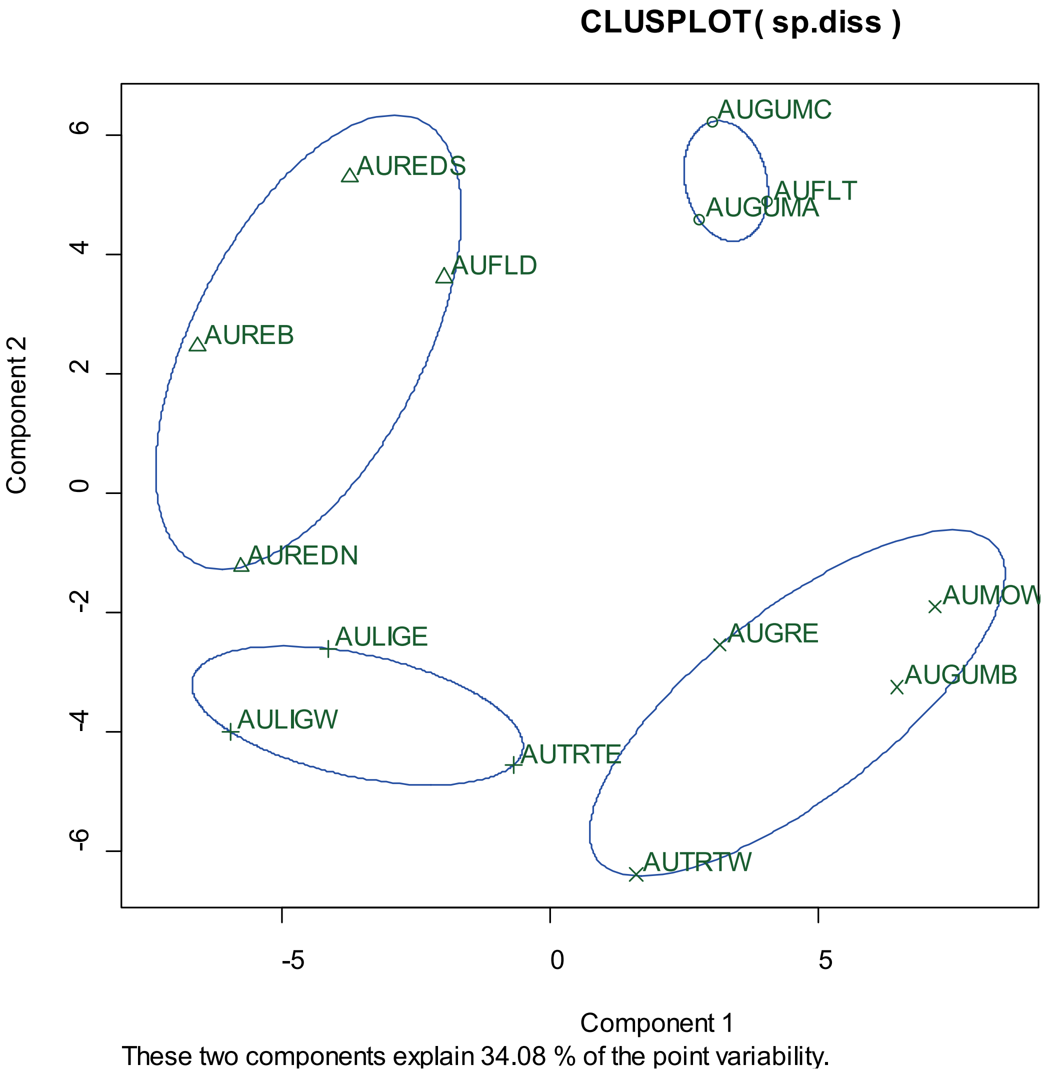


Figure 74. Principal components analysis using annual recruitment residuals in all years highlighting species that show similar patterns.

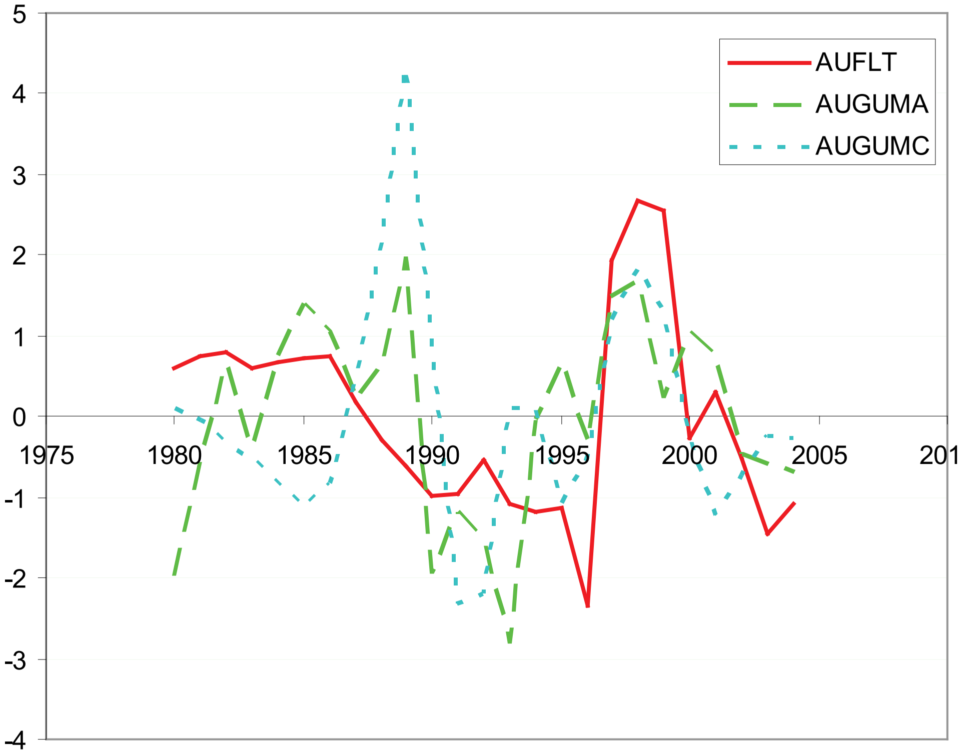


Figure 75. Recruitment residuals of the component group consisting of tiger flathead (AUFLT), Bass Strait gummy shark (AUGUMA) and Tasmanian gummy shark (AUGUMC).

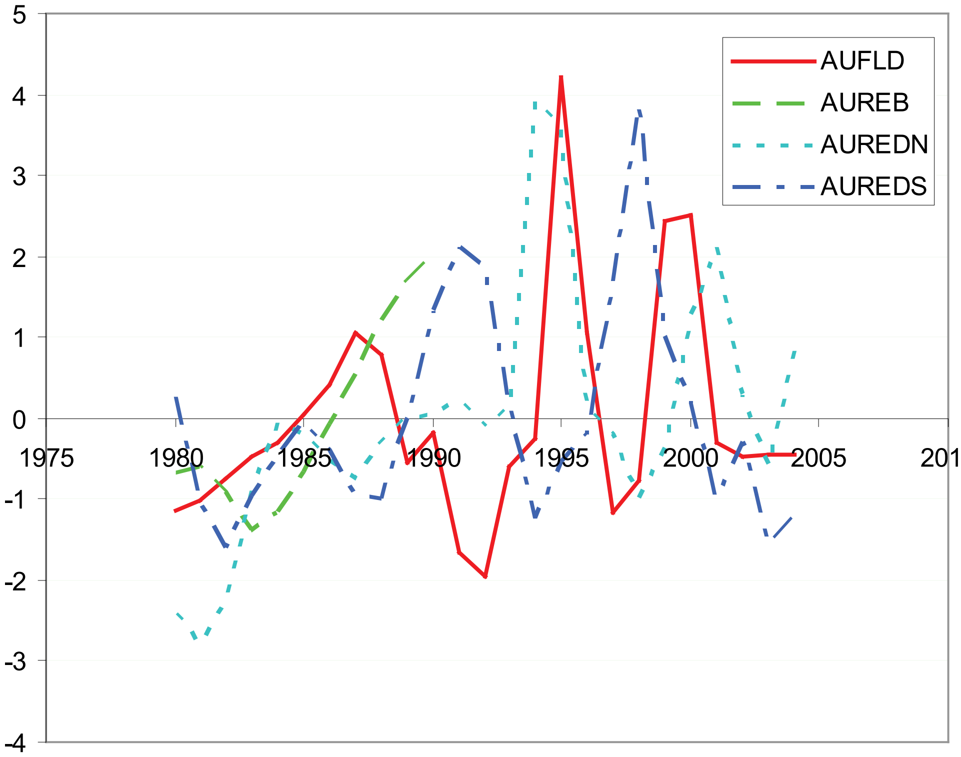


Figure 76. Recruitment residuals of the component group consisting of deepwater flathead (AUFLD), Bight redfish ((AUREB), northern redfish (AUREDN) and southern redfish (AUREDS).

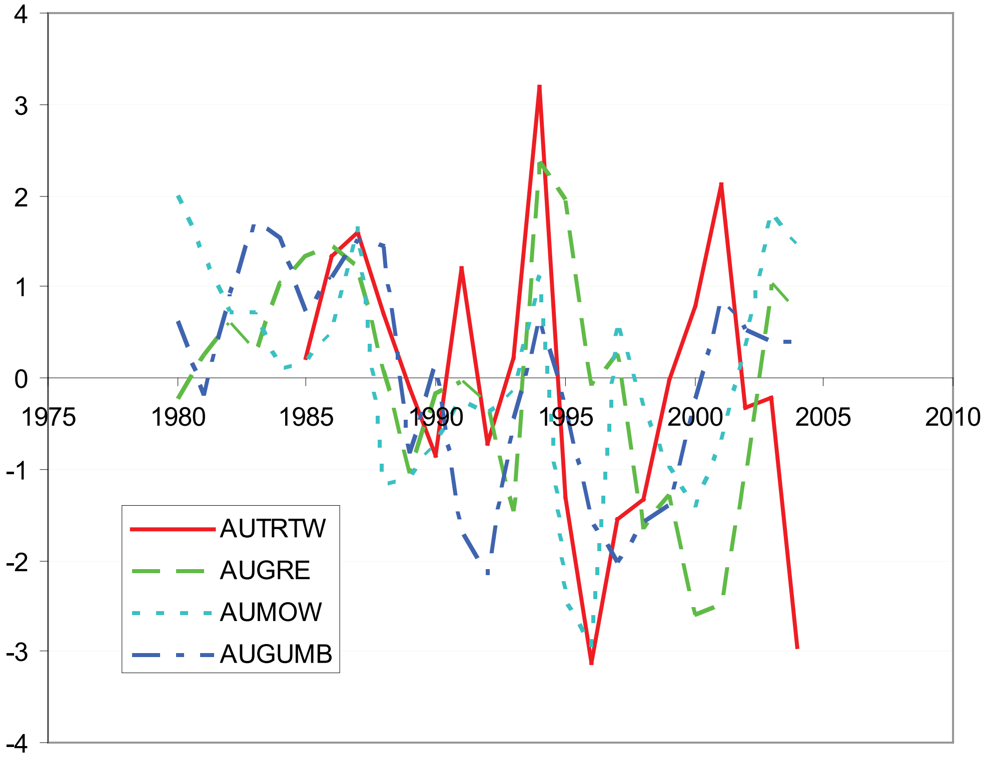


Figure 77. Recruitment residuals of the component group consisting of western blue warehou (AUTRTW), blue grenadier (AUGRE), jackass morwong (AUMOW) and south Australian gummy shark (AUGUMB).

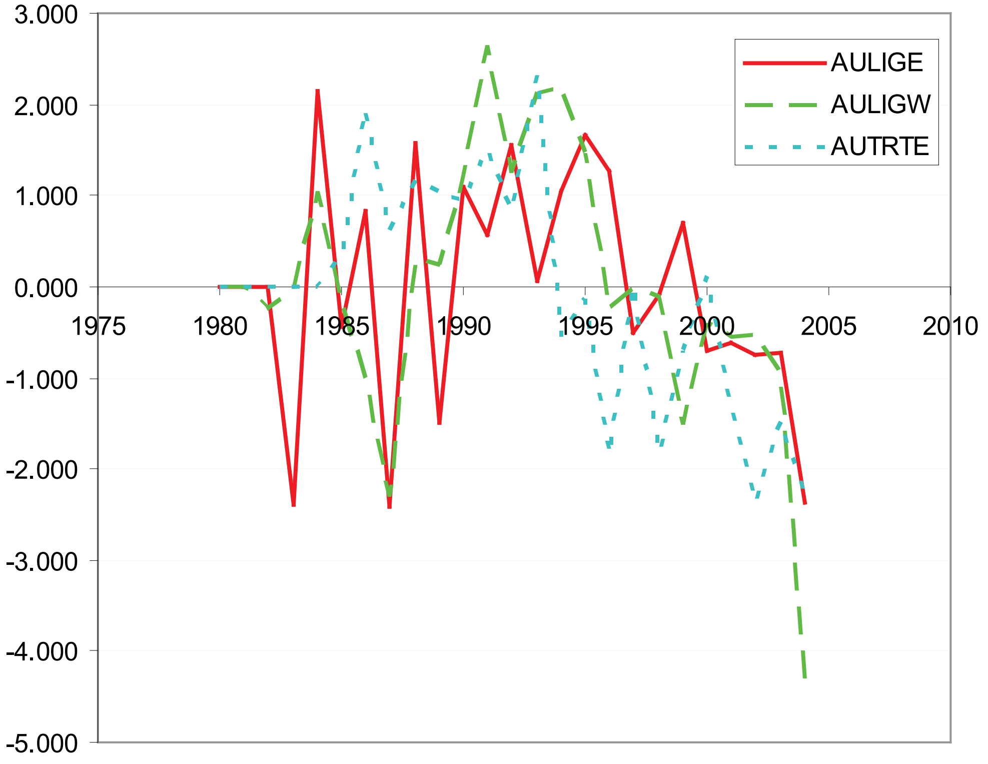


Figure 78. Recruitment residuals of the component group consisting of eastern ling (AULIGE), western ling (AULIGW) and eastern blue warehou (AUTRTE).

7.11 INDUSTRY DATA COLLECTION

Matt Koopman

7.11.1 Introduction

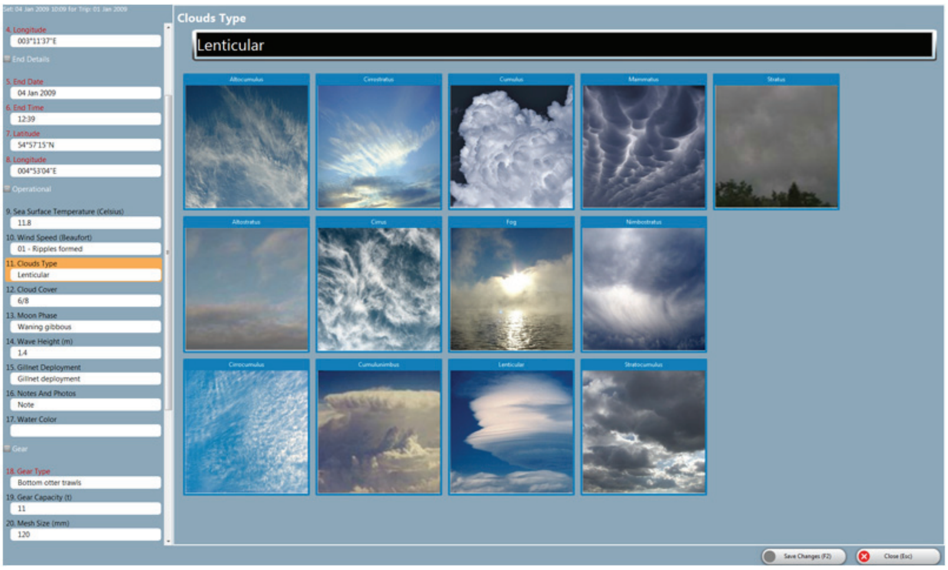
Much of the environmental data used in previous chapters was remotely collected or modelled, which means there is a level of uncertainty in its accuracy, particularly at the fine spatial and temporal scales of relevance to fishing shots. Collection of more accurate fisheries-independent data collected over such a large area at a fine spatial scale has the potential to be time consuming and expensive. With the burden of increasing costs of fishery monitoring, data collection and analysis, the fishing industry is looking towards cost effective alternatives to collect information relevant to stock assessments. Industry vessels are an ideal platform from which to collect low cost, real-time environmental data (for example see Bucklin *et al.,* 2001), because they are present on the fishing grounds of interest and operating their gears at the depth of interest. As part of this project, we investigated the efficacy of collecting environmental data from selected fishing vessels working across the SESSF. To be of value, there was a need for this to be a coordinated process, which could empower the industry to bring valuable, quantitative data, interpretations and analysis into the stock assessment process. In this section we describe the empowerment of selected SESSF skippers to collect environmental data during normal commercial fishing operations.

7.11.2 Methods

Operators that were chosen to participate in data collections spanned the different fishing methods and encompass the wide geographical area of the SESSF (Table 47). Environmental data logsheets were developed to collect relevant information from each fishing event (See Appendix 4). Environmental variables included in logsheets were selected to match data fields in the electronic logbook software Olfish DDL (Figure 79) and designed to enable data to be easily merged with catch and catch rates for logbooks. Logsheets were bound into pads and provided to participants.

Participants were also given a Lotek LAT 1400 time, temperature and depth tags to mount on their fishing gear (Figure 80). LAT 1400 tags were chosen because of their small size, relatively low cost, accuracy and custom programmable capacity. Specifications of the LAT 1400 are shown in Appendix 5. Tags were placed in stainless steel tubes (housings) for protection (Figure 80). Housings were 110 mm in length with an external diameter of 16 mm and could easily be mounted on trawl or long-line gear with little inconvenience. Housings have ports positioned in line with the tag's sensors, to aid water exchange and enable *in situ* downloading of data. The method of attachment varied from vessel to vessel, but most operators used stainless steel cable ties to attach the tag to the headline or net monitor, lashed on with net twine as an added precaution (Figure 81). Tags were set to record date, time, pressure (depth) and temperature at 600 second (10 minute) sampling intervals (Figure 82). Using these settings, the tags can store more than 45,000 records over a duration of 313 days, before the data needed to be downloaded. Data was downloaded via a USB connector and saved as text files. Catch data from those participating vessels was obtained from AFMA and matched to environmental data.

Despite this data collection being a small time burden for skippers, generally they were keen to participate and several skippers/owners approached us to become participants in the data collection.



Set: 04 Jan 2009 10:09 for Trip: 01 Jan 2009

4. Longitude: 003°11'37"E

End Details

5. End Date: 04 Jan 2009
6. End Time: 12:39
7. Latitude: 54°57'15"N
8. Longitude: 004°53'04"E

Operational

9. Sea Surface Temperature (Celsius): 11.8
10. Wind Speed (Beaufort): 01 - Ripples formed
11. Clouds Type: Lenticular
12. Cloud Cover: 6/8
13. Moon Phase: Waning gibbous
14. Wave Height (m): 1.4
15. Gillnet Deployment: Gillnet deployment
16. Notes And Photos: Note
17. Water Color:

Gear

18. Gear Type: Bottom otter trawls
19. Gear Capacity (t): 11
20. Mesh Size (mm): 120

Clouds Type: Lenticular

Figure 79. Screen shot of Olfish DDL environmental observation input form.

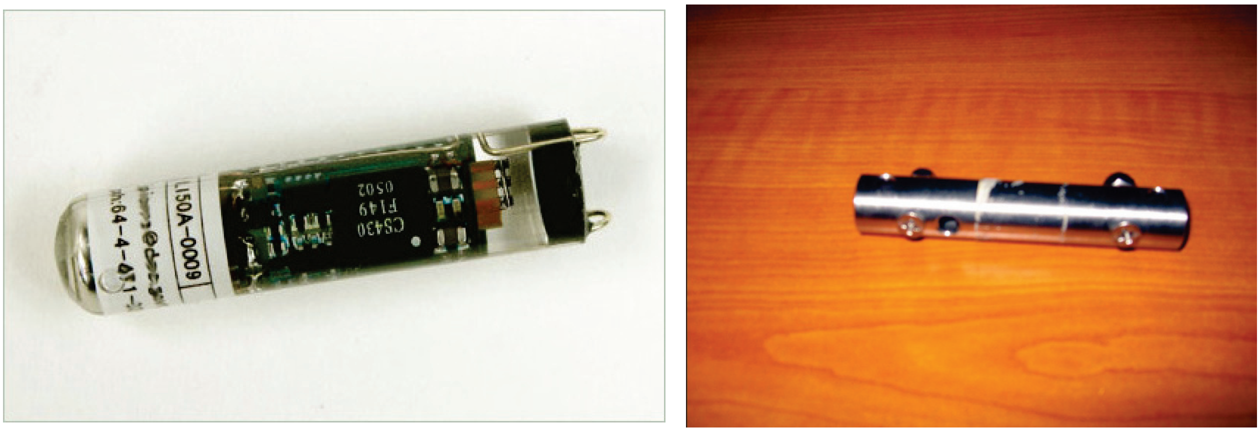


Figure 80. The Lotek LAT 1400 tag and stainless steel housing.

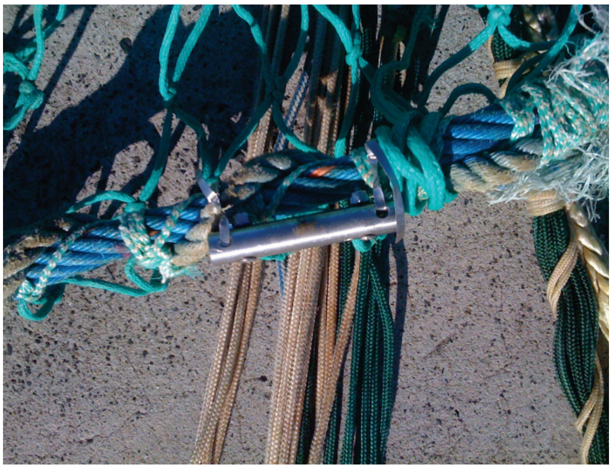
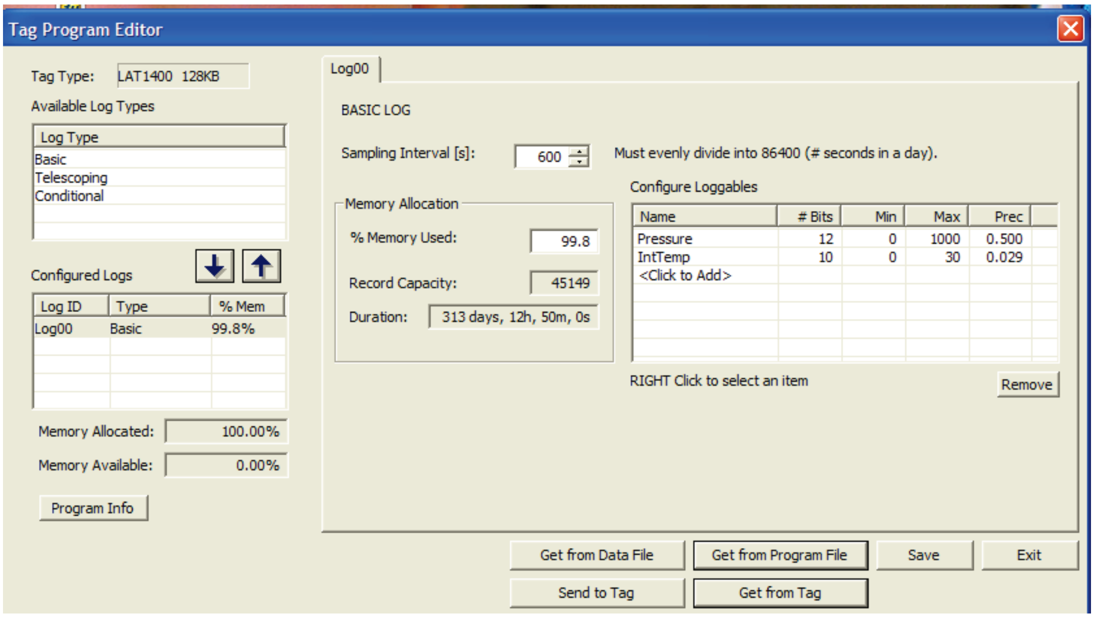


Figure 81. The tag and stainless steel housing attached to the headline of a trawl net. These were further lashed with net twine for security, and the loose ends taped to reduce the chance of entanglement in the net.



Tag Type: LAT1400 128KB

Log Type
Basic
Telescoping
Conditional

Log ID	Type	% Mem
Log00	Basic	99.8%

Memory Allocated: 100.00%

Memory Available: 0.00%

Sampling Interval [s]: 600

Must evenly divide into 86400 (# seconds in a day).

% Memory Used: 99.8

Record Capacity: 45149

Duration: 313 days, 12h, 50m, 0s

Name	# Bits	Min	Max	Prec
Pressure	12	0	1000	0.500
IntTemp	10	0	30	0.029
<Click to Add>				

Figure 82. Setting selected for each LAT 1400 tag.

Table 47. Vessels participating in environmental data collection.

Port	Vessel	Gear type	Owner
Portland	Zeehaan	Otter Trawl	Bert Tober
	Moira Elizabeth	Otter Trawl	Tom Bibby
Lakes Entrance	Western Alliance	Otter Trawl	David Guillot
	Lady Miriam	Otter Trawl	Tony Gurnaccia
	Tullaberga	Otter Trawl	Rod Casement
	Kendean	Danish seine	Peter Clarke
	Nungurner	Danish seine	Wayne Cheers
	Sarda	Auto Longline	Chris Curry
Port Lincoln	Explorer S	Otter Trawl	Semi Skoljarev
Sydney	Francesca	Otter Trawl	Tony and Vince Bagnato
Hobart	Dianna	Auto Longline	Will Mure
Devonport	Petuna Endeavour	Auto Longline	Peter and Una Rockliff
Melbourne	Empress Pearl	Otter/Midwater Trawl	David Guillot

7.11.3 Results and discussion

7.11.3.1 Preliminary data collected

Data collection proceeded well, with most participants regularly filling out environmental logbooks and maintaining tags on their fishing gears. Downloading of temperature and depth data was simple and the data was easily matched to both environmental and fishing logbook data. Examples of the data collected are shown in this section.

Temperature and depth profiles of two typical Danish seine and otter trawl shots are shown in Figure 83. The profiles from Danish seine gear during summer show that temperature decreased with depth where it remained very stable between 55–60 m, and then increased as the gear was retrieved. Once on the surface, the temperature was initially higher than ambient air temperature, presumably the tag was still in the warm surface water just prior to retrieval. During winter shots, temperature initially increased by nearly 3^{o}C to immersion in the relatively warm surface water, and dropped as the gear reached the sea floor. Again, temperature remained stable for the duration of the shot, increased above ambient air temperature during retrieval, before falling when the gear came on deck. The sea bottom temperature in these two plots was surprisingly similar (13.9°C during winter and 14°C during summer). Profiles from deep shots conducted using otter trawls showed more within-shot depth and temperature variation than observed during Danish seine shots, because they covered a greater distance. Spikes in sea surface temperature were observed in both summer and winter profiles where the tag happened to take a record while the net was near or on the surface. Bottom temperature during summer in 400–500 m depth was 8.5–9.5°C, while in 450–500 m depth during winter was 10–11°C.

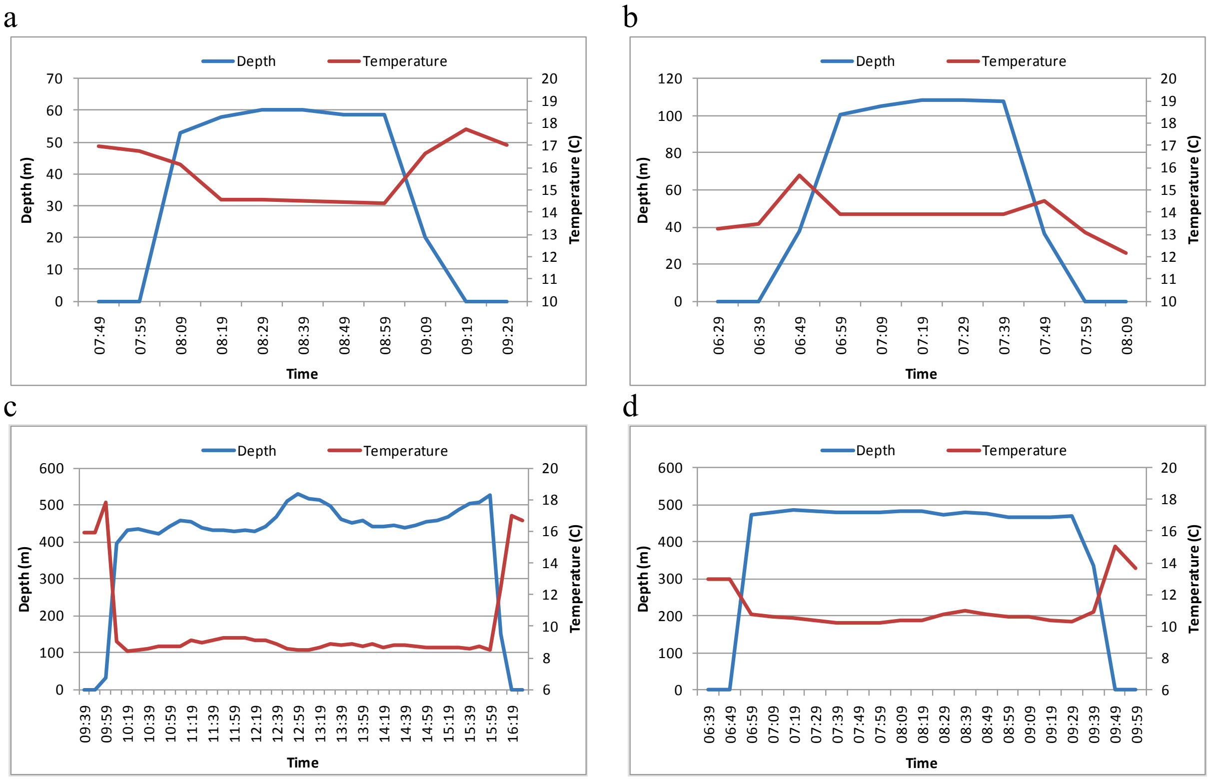


Figure 83. Example of temperature and depth profile shots undertaken with a) Danish seine gear during summer, b) Danish seine gear during winter, c) otter trawl during summer, and d) otter trawl during winter.

There may be some interest in short-term trends in environmental variables and catch rates, however a long time series are required to test hypotheses regarding their influence on catches and catch rates. As such, we have only provided here a basic output from the merged fisheries and environment databases. This was done to evaluate the appropriateness of the data collection in relation to merging it with fisheries data.

Catch and effort data was obtained for participating vessels and merged based on vessel names, shot dates, start times, logbook serial numbers, logbook page numbers and shot numbers. Merging was made easy due to the fisherman filling in the operational details of the environmental logbook at the same time as the fishing logbook, so the start times matched almost exactly with temperature logger data. Merging data from the loggers to the fisheries was done using date and time. Because the logger records a data point every 10 minutes, decisions need to be made as to what data should be used as a representative data point for each shot (i.e. maximum, average, modal or minimum depth and temperature). In producing these figures, minimum temperature was used to characterise each shot.

Bottom temperature generally decreased with depth, particularly for data collected from otter trawl gear (Figure 84). This relationship was less obvious for Danish seine gear, which fished in depths ranging 20–170 m. Variability was greatest at depths less than 100 m, ranging 13–

18.5°C. At depths greater than 100 m, bottom temperatures were generally between 12.5–16°C, but were as high as 17.4°C. Data from otter trawl gear shows no trend of temperature and depth shallower than 175 m, but a clear trend at greater depths. Temperatures at 500 m depth ranged 7.5–9.3°C.

Both sea surface and bottom temperature were seasonal. Temperatures recorded from both Danish seine and otter trawl gears were greatest during autumn (Figure 85). Sea surface and bottom temperature decreased over winter before showing signs of an increase during November–December. Given the relationship between depth and bottom temperate, depth should be considered when interpreting these data.

There appeared to be some relationship between depth and CPUE, however, looking for relationships between CPUE and bottom temperature at this scale is problematic, because of the confounding effects of latitude, longitude, shot time and depth fished (Figure 86).

Most of the Danish seine and otter trawl shots took place over flat, sand/gravel or soft bottom (Figure 87 and Figure 88). Otter trawling also occurred over hard ground and bottom reliefs that were described as rough or ridges. Highest CPUE using Danish seine gear were recorded during south-south-east and west-north-west currents, while CPUE was highest using otter trawls during currents coming from the north to the east (Figure 89).

CPUE, barometric pressure and bottom temperature were plotted for the 10 months of data collection, for both Danish seine (Figure 90) and otter trawl gear (Figure 91). Now, obvious trends are apparent, however, other factors would need to be considered to reduce confounding effect of, for example, shot location. A longer time series would also be required to establish substantial relationships between environmental variables and CPUE.

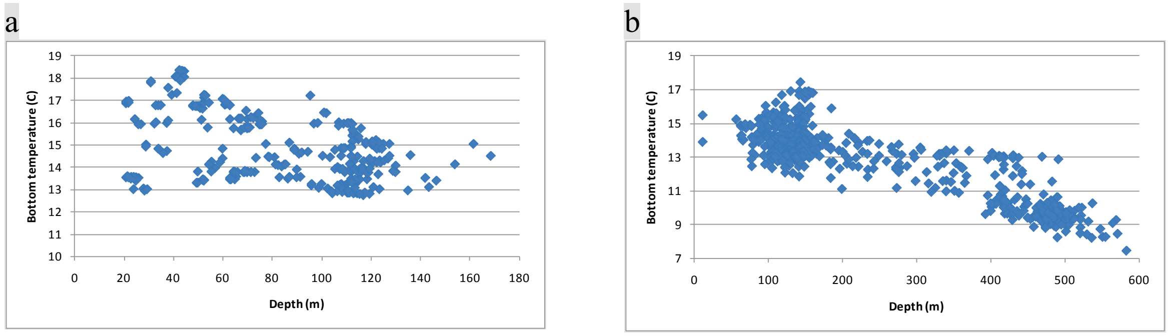


Figure 84. Bottom temperature versus depth fished by a) Danish seine gear, and b) otter trawl gear.

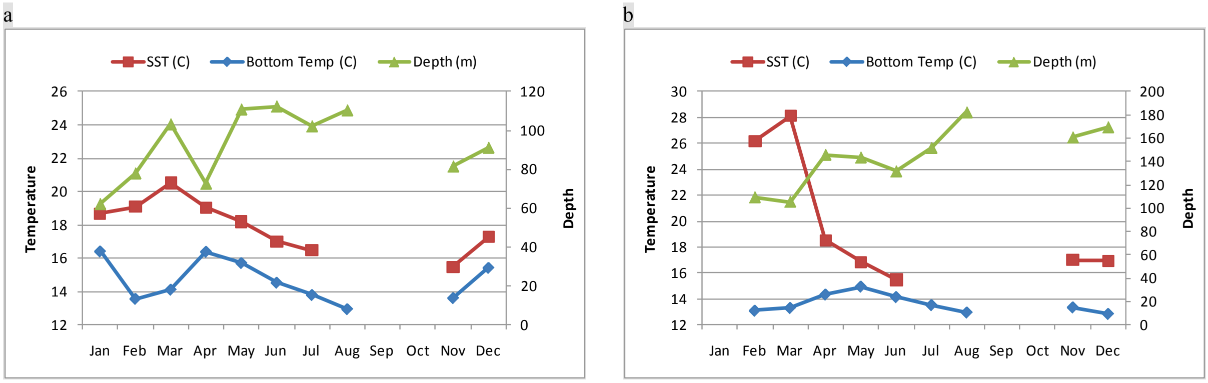


Figure 85. Average bottom temperature (°C), sea surface temperature (°C) and depth fished (m) by a) Danish seine gear and b) otter trawl gear.

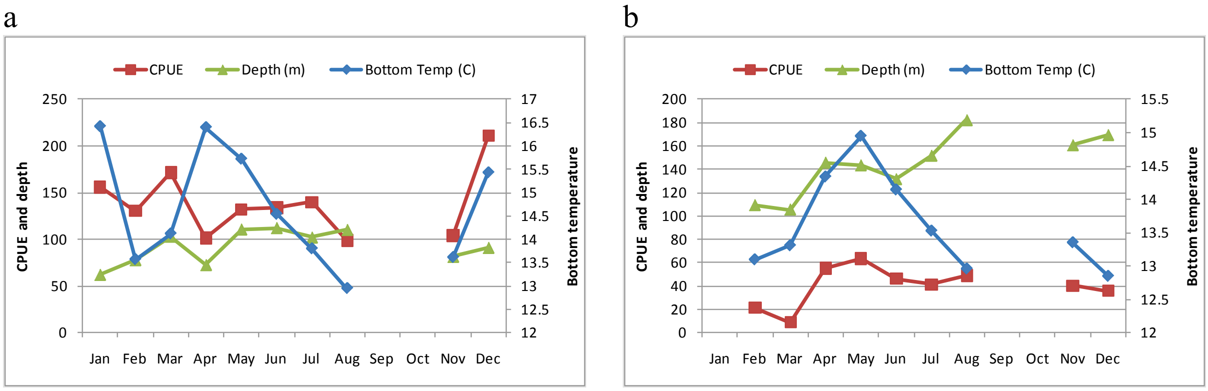


Figure 86. Average bottom temperature (°C), depth fished (m) and CPUE by a) Danish seine gear and b) otter trawl gear.

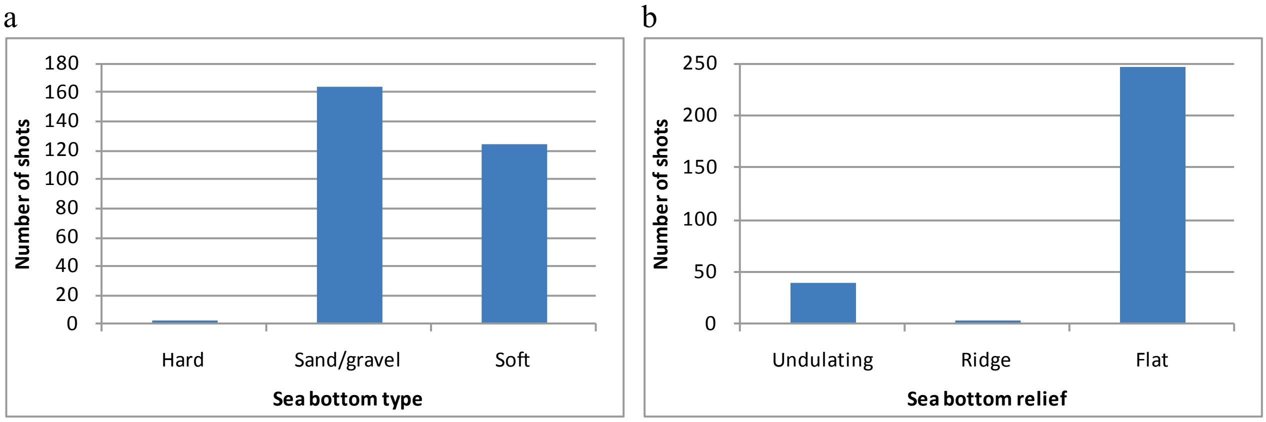


Figure 87. Number of shots observed over each sea bottom type and sea bottom relief by Danish seine gear.

a

b

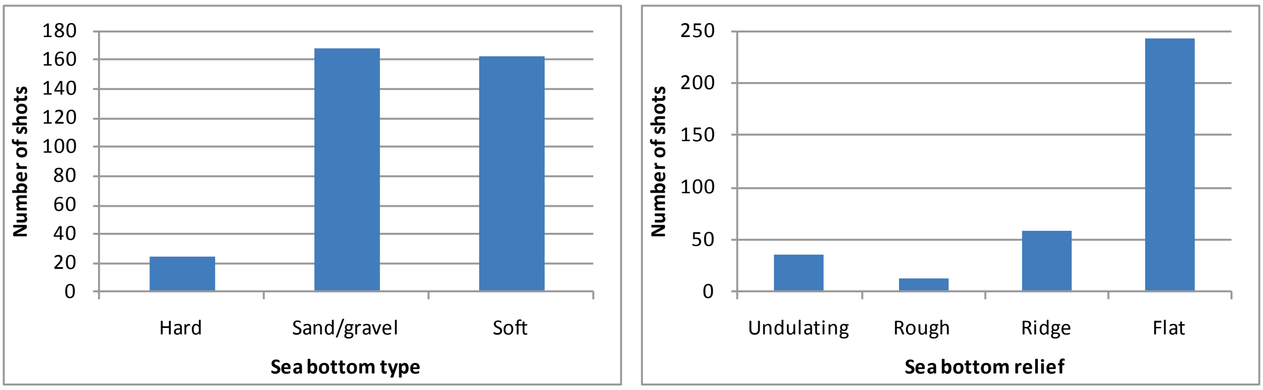


Figure 88. Number of shots observed over each sea bottom type and sea bottom relief by otter trawl gear.

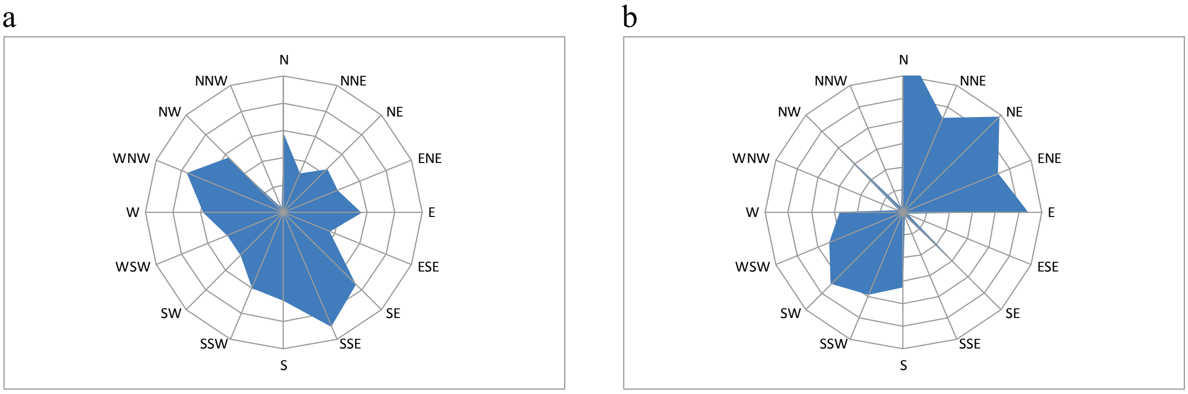


Figure 89. Radar plots showing average CPUE recorded against the current direction observed for a) Danish seine gear and b) otter trawl gear.

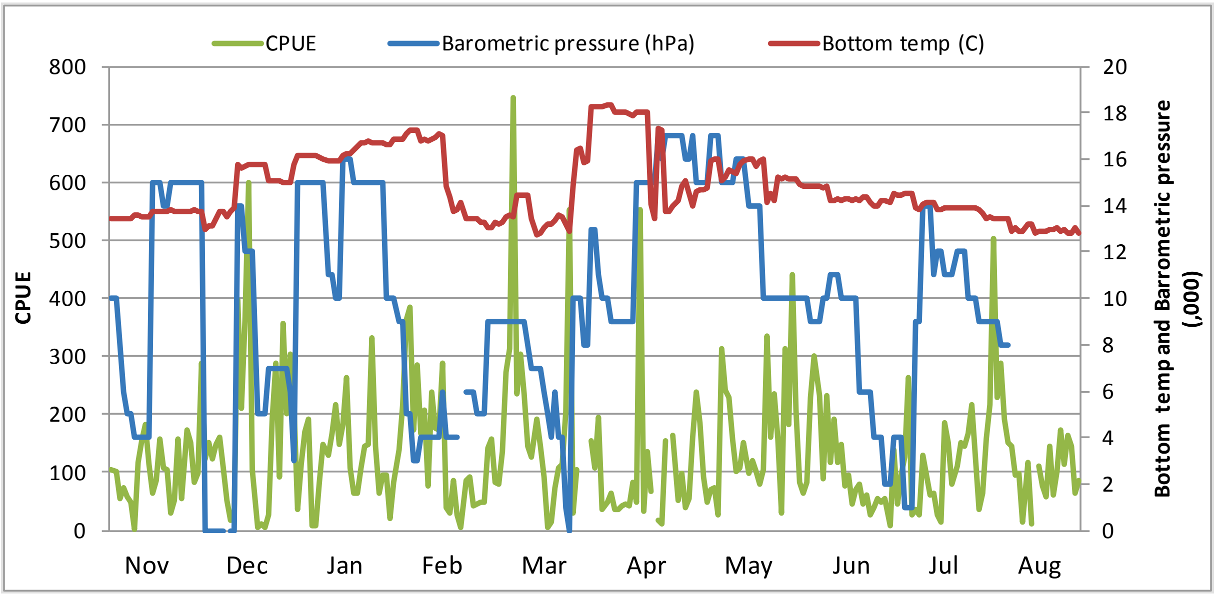


Figure 90. Bottom temperature (^{o}C), CPUE and barometric pressure (hPa) for each Danish seine shot recorded.

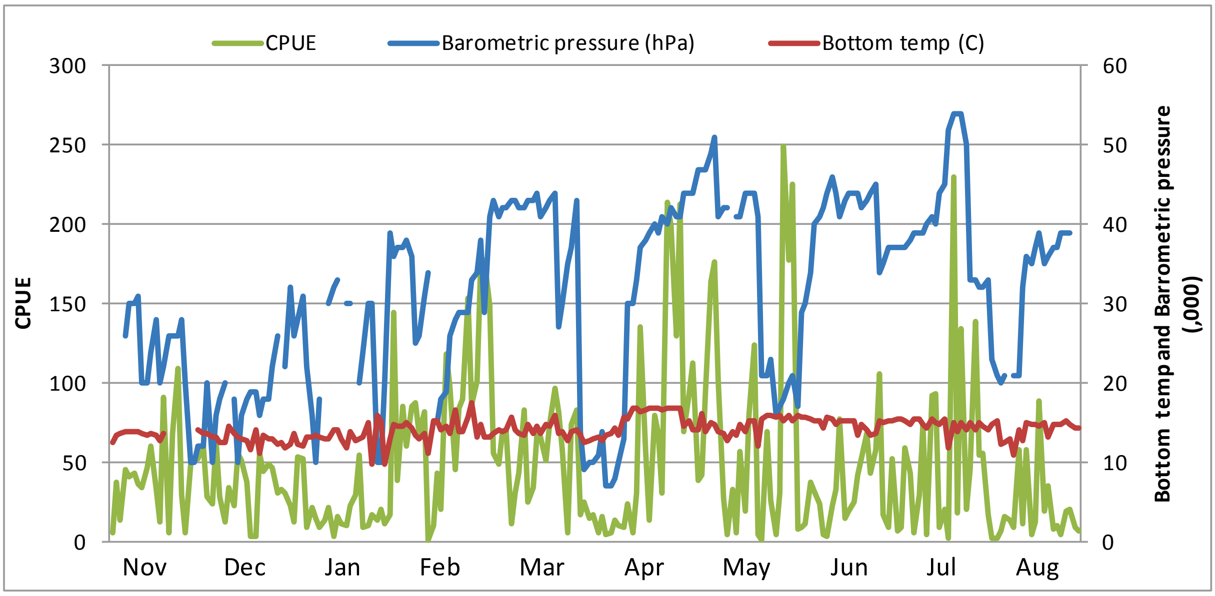


Figure 91. Bottom temperature (^{o}C), CPUE and barometric pressure (hPa) for each otter trawl shot recorded.

7.11.3.2 Evaluation of Industry data collection

Once operators had agreed to collect environmental data and begun the collection process, they reliably recorded useful data that appears to be accurate. Some vessels initially committed to the collection but failed to begin. On the other hand, some operators volunteered to participate without being approached. There have been issues with vessels stopping data collection during prolonged maintenance and not recommencing once back on the water. Constant communication reduces this risk, however, we believe that incentives would be required if this sort of data collection was to continue long-term. A big incentive will be to get the results of the recordings back to the skipper in a reasonable timeframe.

Of the 24 fields that were on the environmental data observation logbook, several were regularly not completed: tide height, tide phase, salinity and precipitation. These, possibly along with several other factors, could be removed to reduce the apparent time burden of filling out the logbooks.

The Danish seine fleet are well suited to this type of monitoring. They are a relatively small fleet, mostly operating out of the same port (Lakes Entrance), and often work similar areas over a small depth range. For these reasons, data collected from a small number of vessels could be used to characterise most of the fleet. The two main target species of the Danish seine fleet are tiger flathead and eastern school whiting, which are fished using different nets. Initially, the Danish seine fishers participating in this project mounted the tags on their flathead net, and because of the robust and secure method of attachment, it was impractical and time consuming to move the tags between nets. This resulted in gaps in the data when they targeted eastern school whiting. Later, one of the fishers began moving loggers between nets, the resulting attachment method being less reliable than a permanently fixed logger. Subsequently, the logger was lost when ropes from the net tangled and ripped the logger off the headline. There are two ways to overcome the issue of using 2 different nets, provide each vessel with at least two loggers, or redesign the housing to accommodate easy change over between nets. A prototype of a housing that could easily be changed from net to net was designed and built by Tony Gurnaccia (Lake Entrance trawl operator). It consists of a stainless steel tube with lockable stainless steel quick release clips welded at each end. These are slightly bulkier than the original design, but can be quickly and easily changed between nets. Provision of two loggers would be the preferred option, as there is a chance that fishers would forget to move tags between nets when the gear is changed.

In comparison to the Danish seine fleet, the SESSF bottom trawl and auto longline fleets target a much wider range of species, meaning they operate over a much wider range of areas and depths. More intensive sampling would be required to adequately monitor environmental conditions in this sector. As with Danish seine fishing, bottom trawlers often use multiple nets per trip, and would require either two loggers or a housing that can easily be changed between nets.

The major issue with sampling on auto longline vessels was gear loss, which could result in a loss of tags and data. This occurred several times during this project, and a solution to the problem has not been found. In a long-term data collection program, the loss of loggers on longline would need to be budgeted for. Regular data downloads from longline vessels is needed to reduce the loss of data and we would recommend that each longline vessel be equipped with a tag reader and software. Downloading of these units could be done at the end of each trip by the crew, after minimal training. So far we have lost three loggers that were attached to the longline gear. Two were lost together with the fishing gear, the other was lost after the stainless steel cable ties attaching it to the fishing gear came away from a tangle in the ropes.

When matching tag data up to catches and catch rates, a decision would need to be made as to what temperature and depth should be used to characterise the shot. The tags record a temperature and depth every 10 minutes, so over a four hour shot, 24 observations are recorded. In this report we used minimum temperature and maximum depth to display data, however, mean or median values may have been more appropriate.

The housings built to protect the tags appear to have been appropriate. Only one tag has been damaged during this trial and has been returned to the manufacturer for examination. The pressure sensor malfunctioned, and with no obvious external damage on the tag, it appears it was a firmware/hardware problem. Placement of the loggers on fishing gears has not caused inconvenience to the fishing operations. They are easily attached to the fishing gear and the data easily downloaded. The ports in the housing appear to have not affected the flow of water to the tags as is evidenced by the temperature variations closely matching changes in depth in Figure 83.

7.11.3.3 Ongoing Industry data collection

If ongoing collection of environmental data is to continue, several changes would need to be made to the procedures:

- At least two different tags in housings should be given to participating operators to allow fitting to different nets, this would reduce the number of gaps in the data without increasing the time burden to fishers.
- The number of fields in the environmental logbook should be decreased to retain only those considered potentially important. While it takes less than two minutes to complete the environmental observations each shot, the list of 24 different fields, appears to the recorder as time consuming.
- If data collection was to continue on auto longline vessels, the skipper should be equipped with a USB connector and software to enable regular downloading. This would reduce the amount of data lost, if the gear/tag was lost. Downloading is a simple procedure requiring only minimal training. Olfish DDL software incorporates environmental data collected during this project. In-built queries allow interrogation of all data collected, enabling simple examination of the effects of changes to environmental parameters on CPUE by Industry members.

8 BENEFITS AND ADOPTION

The main benefit of this project was for all stakeholders to better understand the influence of environmental factors on SESSF species and the fishery. This has been achieved, with examples provided for a variety of species and will help people understand not just the dynamics of SESSF fish stocks, but also the dynamics of the fishing fleets that target them.

At the outset of the project, it was expected that adoption of results would be reflected in further environmental parameters being included in the CPUE standardisations used in stock assessments. A surprising outcome was that, apart from a few exceptions, the addition of extra environmental variables made very little difference to the standardised CPUE time series. The project was able to demonstrate that two of the most influential parameters in the SESSF CPUE standardisations – month and depth – effectively acted as proxies for the two most influential "environmental variables" – SST and temperature-at-depth. As such, there appears to be little value at this stage in adding further environmental variables into the CPUE standardisations used in most SESSF stock assessments. One exception, however, may be Bight redfish, for which the Resource Assessment Group may wish to consider adding some extra environmental parameters such as moon phase or NO_3 and salinity-at-depth.

The fact that few CPUE standardisations used in assessments will need to be altered to include environmental variables does not imply little adoption of results from this project. The knowledge that a number of the parameters used in current CPUE standardisations can explain much of the variability associated with environmental variables will go some way to allay concerns that the assessments do not incorporate any information on environmental influences. This may lead to improved acceptance of assessment outcomes and more focussed and productive discussion during RAG meetings.

In contrast to the fine-scale, shot-by-shot catch and effort data, the environmental data available for hypothesis testing were generally either of a broad spatial and/or temporal scale, or modelled from other measured data. As a result, it was difficult to establish statistically defensible correlations between environmental variables and fishing data.

Collection of environmental data from industry vessels was successfully trialled, and if maintained in the long term, may yield options for standardised CPUE indices for individual vessels using data collected by that vessel. If continuing industry collection of environmental data is considered worthwhile, the tools and procedures are in place to enable cost effective autonomous data collection. Methods developed for industry data collection will be used during Fisheries Independent Surveys to provide accurate temperature and depth profiles of survey shots.

9 FURTHER DEVELOPMENTS

Given the results of this project, it is unlikely that there will be another intensive exploration of the influences of environmental variables on SESSF species for some time. This is probably appropriate while there remains a large difference in the broad spatial and/or temporal scale of the environmental data available compared to the fine scale of the fishery catch and effort data. However, collection of a time series of environmental data from industry vessels throughout the fishery across a number of years could potentially change this situation, by providing measured environmental information at the same spatial and temporal scale as fishery catch and effort data. When this is available it would be well worth revisiting exploration of the relationships between environmental variables and catch rates. To facilitate this, we would recommend that a select group of vessels continue to collect temperature and depth information from data-loggers placed on the fishing gear. Those vessels involved should be supplied with two loggers in housings to mount on multiple nets. If data collection was to continue on auto longline vessels, it is recommended that they be supplied with a USB connector and software to enable regular downloading to reduce the potential for data loss.

10 PLANNED OUTCOMES

This project planned to develop: (1) a set of models to enable the incorporation/investigation of the influence of environmental and oceanographic variables on fisheries in south-east Australia; and (2) a method of incorporating these models into species stock assessments. Models were developed that investigated the influence of environmental and oceanographic factors on fisheries in south-east Australia. SST and temperature-at-depth showed some potential for inclusion in CPUE standardisations; however, regular, *in situ* measurements of these parameters were not available. The effect of incorporating observed environmental/CPUE relationships into the existing CPUE frameworks (and hence, into species stock assessments) was examined using GLMs. Minor improvements in the fit of the model for pink ling were observed, however, it was concluded that explicitly including environmental variables was unlikely to make any practical difference to an assessment. The current practice of using month and depth as proxies for these environmental factors appears to be appropriate in most cases, however under future climate change scenarios, these proxies may be inadequate, and SST and temperature-at-depth may be necessary for the standardisations. For some species, such as Bight redfish, where improved model fits can be obtained by the use of additional environmental variables, the data and models are available for the Resources Assessment Groups to consider and incorporate into assessments as appropriate.

The project also planned to assist industry members in setting up and maintaining a database that combines catch and effort information with extensive fine-scale data on environmental and oceanographic variables. At the end of the project, the fishing industry will have developed the capabilities for the ongoing collection of extensive fishery-related data by their own means. Industry collection of environmental data was successfully trialled on otter trawl and Danish seine vessels in the SESSF. The methods were developed in line with the Olfish DDL database, into which, environmental data are recorded and combined with catch and effort data. This system enables easy interrogation of data collected, including the effect of environmental data on catch rate. Such a system is being installed on numerous SESSF vessels from the various sectors.

11 CONCLUSION

At the initial workshop, Industry members revealed a wealth of information on their understanding of the influence of environmental factors on their fisheries and targeting of particular species. Water temperature and currents were the most common factors discussed, and in turn, these were related to season, which was also identified as being important in influencing catches of SESSF species. Other related, but difficult to quantify factors included the depth of the feed layer, and the depth of the thermocline, together with information on what target fish were eating and what other (often invertebrate) species were present. Results of the workshop suggest that factors affecting catch rates or availability of target species are complex, often inter-related, and may act on different spatial and temporal scales. This information was valuable when determining what environmental factors might be useful in helping to understand the dynamics of the fishery.

Unfortunately, despite the extensive array of environmental data available to this project, we were not necessarily able to match or represent the environmental/biological parameters and/or the fine spatial/temporal scales that fishers considered important in influencing their catches. Feed layers and thermoclines were best represented by gross parameters such as chlorophyll A and SST frontal density respectively, both of which are either modelled or measured at the scales of tens of kilometres, many days or a number of degrees, whereas the good fishers target their best catches with tolerances of hundreds of metres, a few hours or half a degree in temperature.

Similarly, examining trends in catch rates across broad areas of the fishery may be ineffectual when fishers target species within known fishing grounds that might only extend a dozen miles.

Nevertheless, despite the above differences in parameter scale, examination of temporal variation and the geographical distribution of effort shows clear patterns in targeting and catch of some species. These patterns suggest seasonal movement of those species, presumably in response to environmental and oceanographic stimuli to which they show particular preference. Whether this movement is of a stock from one fishing ground to another, or from fishing moving from outside into the fishing ground, is likely to be species dependent. We are a long way off from establishing robust relationships, much less understanding any causal mechanism.

Despite earlier rudimentary examinations with promising correlations between catches or raw catch rates and SST and SOI, when examined on a finer scale against standardised shot-by-shot CPUE, the relationships appeared much weaker. The 2000–2001 analyses of flathead for example, were conducted using basic correlations between a large number of "point-measure" environmental variables and fisheries catch data at a number of spatial and temporal scales. Such exploratory methods have a high chance of returning significant relationships simply because of chance or circumstance. Further, early analyses used environmental measures that might not have been appropriate for the scale of the fishery. For example, physico-chemical data from a Port Hacking research station were used as an indicator for conditions throughout Zone 10. The validity of this was never examined. In comparison, the current study used a number of techniques that significantly improved analyses, and increased confidence in results. Sophisticated analyses using mixed-effect models were used that compare many parameters at once (as opposed to pair-wise comparisons). Data from individual shots for each vessel were analysed with vessels treated as random effects. Environmental data were matched (where possible) to the location that shots were conducted and careful data filtering was carried out to ensure data quality. The time series of data available for this project was also much longer than that used during 2000–2001. Using these techniques, if the trends that were detected in the earlier study were real, long-term relationships, they would have been detected by the analyses used in this project.

This is not to say that environmental and oceanographic conditions do not influence fisheries in south-east Australia on a broad scale – they obviously do – otherwise you would not witness the recurrent seasonal patterns in targeting and fleet dynamics apparent throughout the SESSF. But, there have been significant changes in the use of catch and effort data as an index of abundance over the last decade. Whereas previously raw or geometric mean catch rates were used with little or no considerations of external factors, now standardised catch rates are used in the assessments to reduce the effects of factors such as vessel, location, depth and time that fishing occurred, what gear was used, and whether fishing occurred during the day or night (Haddon 2007). As we have demonstrated, some of these standardisation factors effectively act as proxies for environmental variables and are already being incorporated into CPUE standardisations. Because of this, further inclusion of environmental variables in current standardisations results in little, if any, improvement to the standardised CPUE series and therefore only minor changes to stock assessment results.

The two environmental parameters with the most potential for inclusion in CPUE standardisations for a broad range of species are SST and temperature-at-depth. However, in situ measurements of these environmental parameters have not been made routinely in the past 20 years, in contrast with the measurements of month and trawl depth which are routinely collected in the logbook data. To incorporate these environmental parameters would either require use of remotely sensed data or modelled data, or a combination of the two along with the associated error in these values. Alternatively, starting a new time series and measuring these values directly could be a more useful approach, especially if the response of changes in catch rates to changes to environmental conditions were important. Ultimately, the ease of using month and trawl depth in standardised CPUE analysis, and the fact that they appear to capture a large part of the variability associated with SST and temperature at depth leads to the conclusion that there is little need to change current methods.

It is also important to note that any localised conditions that may result in good catch rates for individual fishing boats may vary from region to region, season to season, or from year to year, or may only operate in restricted spatial and temporal scales. If this is the case, a fishery wide analysis is not going to be useful. Many of these optimal localised conditions are very hard to identify from the environmental data that are available. For example, the modelled mixed layer depth estimates are not reliable or accurate enough to be able to tell if a particular shot is taking advantage of the thermocline hitting the shelf, and the resulting increased availability of fish.

The recruitment patterns of several species inhabiting geographically similar distributions were significantly correlated, suggesting common external influences affecting recruitment. The nature, extent and potential causes of such correlations are likely to be complicated and, given the various life history stages between spawning and recruitment to the fishery upon which they may act, very difficult to establish.

The collection of environmental data by industry members was successful. A simple methodology was developed and employed that was only a small time burden on skippers, yet has the potential to provide very useful information on the same scale as the catch and effort data recorded in the logbooks. The success of this trial was aided by the natural interest of fishers to learn more about the environment in which they fish. The archival tags chosen proved reliable and easy to use, with the only major problem being the loss of several tags on auto longline gear.

While the use of large scale environmental data may not yield significant improvements in stock assessments for most of the SESSF species, fine-scale data collected from selected vessels using methods developed during this project may, in the longer term, be useful for incorporation into CPUE standardisations in the future.

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APPENDIX 1 INTELLECTUAL PROPERTY

No intellectual property resulted from this project.

APPENDIX 2 STAFF LIST

The following persons were involved with this project

Ian Knuckey	Fishwell Consulting - Principal Investigator
Ken Ridgway	CSIRO
Jemery Day	CSIRO
Neil Klaer	CSIRO
Min Zhu	CSIRO
Beth Fulton	CSIRO
Geoff Tuck	CSIRO
Malcolm Haddon	TAFI / CSIRO
Matt Koopman	Fishwell Consulting

APPENDIX 3 OCEANOGRAPHY AND DATASETS

Oceanographic Datasets

CSIRO Atlas of Regional Seas (CARS)

CARS is a digital atlas of seasonal ocean water properties, covering the seas around Australia (90° 180°E; 60°S – 10°N). The six water properties mapped are temperature, salinity, oxygen, nitrate, silicate, phosphate. The gridded fields may be accessed using a range of simple Matlab routines.

Full details of CARS are found at

http://www.marine.csiro.au/~dunn/eez_data/atlas.html

CSIRO Mixed-layer Depth Atlas

An atlas of mean and seasonal mixed-layer depth, covering the Australian region on the same 1/2 degree grid as CARS. Mixed-layer depths were calculated from observed level hydrographic data in the NODC World Ocean Atlas 94 and the CSIRO Marine Laboratories archives. Four methods were used to estimate mixed-layer depth:

1. depth at which a temperature difference of 0.5^{o}C with respect to the surface is first encountered,
2. same as above, except using a temperature difference of 1.0^{o}C
3. depth at which first encountered a gradient of temperature with depth of -0.015^{o}C/m
4. depth at which first encountered a gradient of density with depth of 0.004^{o}kg/m^4

Further details at

http://www.marine.csiro.au/eez_data/doc/mld.html

CSIRO Ocean Archive

The in situ data profiles which form the basis for CARS may be accessed using a simple Matlab routine. Details are found at

http://www.marine.csiro.au/eez_data/doc/hydro.html

Satellite Altimetry

Daily gridded fields of sea level anomaly (SLA) obtained from all available satellite altimetry observations are produced routinely. Both a hindcast product (1993–2004) product generated from the highest quality delayed-mode data and a near real-time product (~3 day lag) are available. Full surface sea level fields (mean surface height from CARS), and surface geostrophic currents are also available.

http://www.marine.csiro.au/remotesensing/oceancurrents

Satellite SST

Sea Surface Temperature (SST) obtained from the NOAA AVHRR satellites has been composited over varying periods (3, 6, 10, 15 days). Data from individual passes have been merged to provide more complete data coverage. As the ‘averaging’ period increases the number of gaps in the coverage decreases but smaller scale features such as eddies and fronts also tend to be smeared out.

Matlab routines to access the altimeter and SST datasets are described in http://www.marine.csiro.au/eez_data/doc/gridded_access.html/

The data are available via a LAS server at the following address

http://www.marine.csiro.au/remotesensing/oceancurrents/DIY.htm/

http://www.marine.csiro.au/las/servlets/dataset/

SynTS

This is an observational analysis system for Australian waters. SLA and SST from satellite are used to infer subsurface temperature and salinity down to 2000 m. As for SLA and SST there is both a hindcast (1993-2004) and near real-time product available.

Details of the system are at

http://www.marine.csiro.au/OMAS/analysis/description.html

To gain access to these datasets go to

http://www.marine.csiro.au/remotesensing/oceancurrents/access.htm

BLUElink Reanalysis (BRAN)

BLUElink is a partnership between CSIRO, Bureau of Meteorology and the Royal Australian Navy. A global hydrodynamic ocean model with ~10km resolution around Australia has been developed. The model estimates are combined with observations to produce more realistic hindcast and forecast fields. A hindcast model run (1993–2004) has been generated and a full suite of ocean variables have been archived.

To gain access to these datasets go to:

http://www.marine.csiro.au/remotesensing/oceancurrents/access.htm/

Meteorological Reanalysis Data

A range of atmospheric variables derived from a model reanalysis are available. The NCEP-DOE Reanalysis 2 project is using a state-of-the-art analysis/forecast system to perform data assimilation using past atmospheric observations from 1979 through 2001. The data in its original 4 times daily format is provided via DODS from the TPAC server.

http://www.tpac.org.au/datasets/ncep_reanal2.htm

Ocean Color

Data from the MODIS ocean color mission is available at

http://www.marine.csiro.au/dods/nph-dods/dods-data/modis

Other useful references for locating datasets are found at

http://www.marine.csiro.au/eez_data/doc/index.html

http://www.marine.csiro.au/%7Emansbrid/dods/climatology.html

http://www.tpac.org.au/datasets/diglib.htm

SeaWiFS chlorophyll A and turbidity

SeaWiFS data compiled by Thomas Moore and CMR Remote Sensing, courtesy of the NASA SeaWiFS Project and Orbimage. Information on SeaWiFS is available at:

http://oceancolor.gsfc.nasa.gov/SeaWiFS/BACKGROUND/SEAWIFS_BACKGROUND.html

Magnetic Anomaly

These data represent the January 2002 edition of the Magnetic Anomaly Grid of the Australian Region. This version is the first integrated onshore/offshore magnetic anomaly grid for the complete Australian margin extending across 8S - 52S, 106E - 172E. The grid cell size is 0.01 degree (approx. 1 km). Earlier releases were restricted to portions of NW and SW Australia.

Magnetic anomaly unit is nanoTesla (nT). Appropriate IGRFs have been removed. Horizontal datum is GDA94 (which is equivalent to WGS84).

The marine data were leveled independently of the onshore data in three sectors (see below). The NNW and SSW sectors were released as grids previously. The eastern sector was leveled in 2000 in collaboration with Intrepid Geophysics (Melbourne, Australia). The three leveled sectors, together with the unleveled sectors were combined with the onshore grid to give the present grid. Altogether, 3,022,656 data points are in the database from which the marine grid was created.

Unleveled sectors: (-8 -25 160 172), (-39 -52 156 172), (-46 -52 106 140)

Leveled sectors: (-37 -52 140 156), (-25 -39 143 172), (-8 -25 143 160), (-24 -46 106 140), (-8 -24 106 143)

There are several places at the join between onshore and offshore grids where the two grids do not match. The problem exists because the onshore grid was developed earlier, and there was poor control on the grid merging process at the margins. Future work will attempt to address this issue and improve the continuity between the onshore and offshore grids.

http://www.ga.gov.au/meta/ANZCW0703004321.html

Wind speed

NCEP Reanalysis data provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at

http://www.cdc.noaa.gov/

SDODE

Many of the oceanographic products used here are available using SDODE (Hobday et al, 2006), a series of Matlab routines that can be used to extract data at the appropriate scale.

APPENDIX 4 ENVIRONMENTAL LOGBOOK

FISHERIES AND ENVIRONMENT PROJECT

FISHERIES AND ENVIRONMENT PROJECT

ENVIRONMENTAL OBSERVATION DATASHEETS

Contact: Matt Koopman Mobile: 0408 582422

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FISHERIES AND ENVIRONMENT PROJECT

Vessel and Technology Details

Vessel name:	Distinguishing mark:	Vessel length (m):	Vessel tonnage (t):
Home port:	Fishing method:	Engine power (hp):	Company name:

Contact Details

Please indicate preferred contact for economic survey

Vessels name	
Owners name	
Owners phone numbers	
Owners postal address	
Owners email address	
Vessel managers name	
Vessel managers phone numbers	
Vessel managers postal address	
Vessel managers email address	
Skippers name	
Skippers phone numbers	
Skippers postal address	
Skippers email address	

Technology

Please record the model of each of the following equipment you use on your vessel

Sonar	
Sounder	
Net sonde	
GPS	
Others…..	

Contact: Matt Koopman Mobile: 0408 582422

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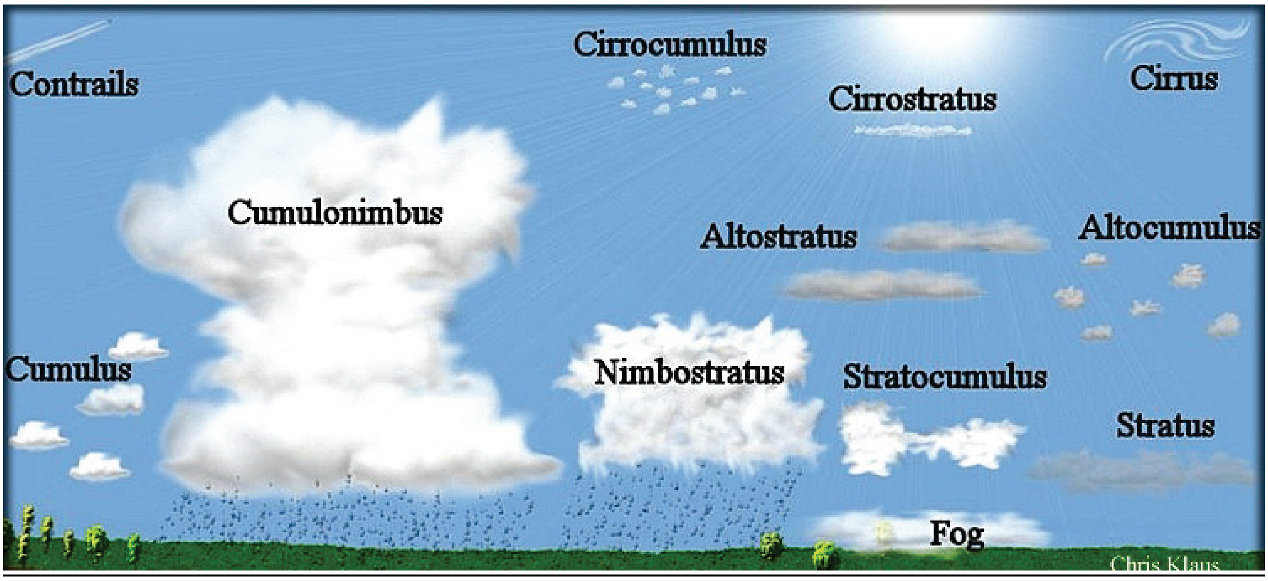
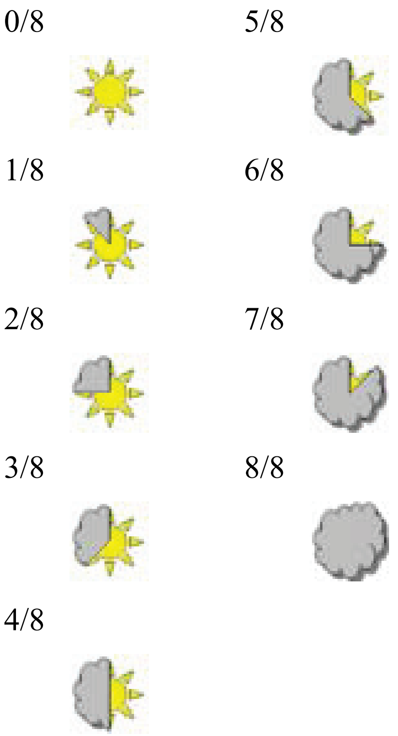
FISHERIES AND ENVIRONMENT PROJECT

Cloud and Moon Phase Key

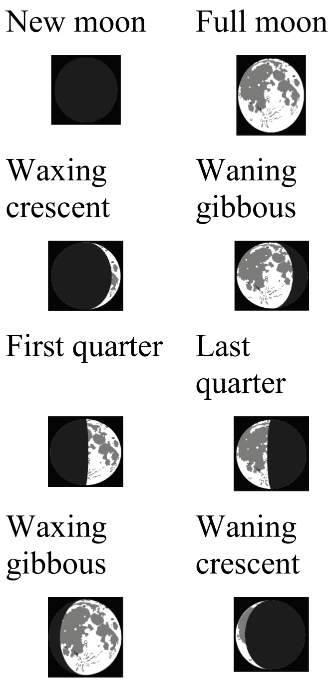
Cloud types



Cloud cover



Moon phases



Contact: Matt Koopman Mobile: 0408 582422

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FISHERIES AND ENVIRONMENT PROJECT

Confidential Shot Log

Vessel name:	Date:	Log No:	Page No:

SHOT 1 Time:

Sea conditions

Current strength at surface (knots)	
Current direction at surface (e.g. SW)	
Tide height (m)	
Tide phase	high/low/flood/ebb
Sea bottom depth (fth)	
Current strength at gear (knots)	
Current direction at gear (e.g. SW)	
Swell height (m)	
Wave height (m)	

Sea bottom type

Hard (rock/coral) ☐ Soft (mud) ☐
Sand/gravel ☐ ☐

Sea bottom relief

Undulating ☐ Flat ☐
Rough ☐ Pinnacle ☐
Ridge ☐ Other ☐

Sea water properties

Sea temperature at gear (^{0}C)	
Sea surface temperature (^{0}C)	
Water color	black/blue/brown/milky/sand
Salinity (parts per thousand)	
Water visibility (m)	

Weather

Air temperature (^{0}C)	
Barometric pressure (hPa)	
Wind strength (knots)	
Wind direction (e.g. SW)	
Precipitation:	rain/hail/snow

Sky conditions

Cloud type

Cirrus ☐ Cirrocumulus ☐
Cirrostratus ☐ Altocumulus ☐
Altostratus ☐ Nimbostratus ☐
Stratocumulus ☐ Stratus ☐
Cumulus ☐ Cumulonimbus ☐

Moon phase

New moon ☐ Full moon ☐
Waxing crescent ☐ Waning gibbous ☐
First quarter ☐ Last quarter ☐
Waxing gibbous ☐ Waning crescent ☐

Cloud cover

0/8 ☐ 3/8 ☐ 6/8 ☐
1/8 ☐ 4/8 ☐ 7/8 ☐
2/8 ☐ 5/8 ☐ 8/8 ☐

SHOT 2 Time:

Sea conditions

Current strength at surface (knots)	
Current direction at surface (e.g. SW)	
Tide height (m)	
Tide phase	high/low/flood/ebb
Sea bottom depth (fth)	
Current strength at gear (knots)	
Current direction at gear (e.g. SW)	
Swell height (m)	
Wave height (m)	

Sea bottom type

Hard (rock/coral) ☐ Soft (mud) ☐
Sand/gravel ☐ ☐

Sea bottom relief

Undulating ☐ Flat ☐
Rough ☐ Pinnacle ☐
Ridge ☐ Other ☐

Sea water properties

Sea temperature at gear (^{0}C)	
Sea surface temperature (^{0}C)	
Water color	black/blue/brown/milky/sand
Salinity (parts per thousand)	
Water visibility (m)	

Weather

Air temperature (^{0}C)	
Barometric pressure (hPa)	
Wind strength (knots)	
Wind direction (e.g. SW)	
Precipitation:	rain/hail/snow

Sky conditions

Cloud type

Cirrus ☐ Cirrocumulus ☐
Cirrostratus ☐ Altocumulus ☐
Altostratus ☐ Nimbostratus ☐
Stratocumulus ☐ Stratus ☐
Cumulus ☐ Cumulonimbus ☐

Moon phase

New moon ☐ Full moon ☐
Waxing crescent ☐ Waning gibbous ☐
First quarter ☐ Last quarter ☐
Waxing gibbous ☐ Waning crescent ☐

Cloud cover

0/8 ☐ 3/8 ☐ 6/8 ☐
1/8 ☐ 4/8 ☐ 7/8 ☐
2/8 ☐ 5/8 ☐ 8/8 ☐

SHOT 3 Time:

Sea conditions

Current strength at surface (knots)	
Current direction at surface (e.g. SW)	
Tide height (m)	
Tide phase	high/low/flood/ebb
Sea bottom depth (fth)	
Current strength at gear (knots)	
Current direction at gear (e.g. SW)	
Swell height (m)	
Wave height (m)	

Sea bottom type

Hard (rock/coral) ☐ Soft (mud) ☐
Sand/gravel ☐ ☐

Sea bottom relief

Undulating ☐ Flat ☐
Rough ☐ Pinnacle ☐
Ridge ☐ Other ☐

Sea water properties

Sea temperature at gear (^{0}C)	
Sea surface temperature (^{0}C)	
Water color	black/blue/brown/milky/sand
Salinity (parts per thousand)	
Water visibility (m)	

Weather

Air temperature (^{0}C)	
Barometric pressure (hPa)	
Wind strength (knots)	
Wind direction (e.g. SW)	
Precipitation:	rain/hail/snow

Sky conditions

Cloud type

Cirrus ☐ Cirrocumulus ☐
Cirrostratus ☐ Altocumulus ☐
Altostratus ☐ Nimbostratus ☐
Stratocumulus ☐ Stratus ☐
Cumulus ☐ Cumulonimbus ☐

Moon phase

New moon ☐ Full moon ☐
Waxing crescent ☐ Waning gibbous ☐
First quarter ☐ Last quarter ☐
Waxing gibbous ☐ Waning crescent ☐

Cloud cover

0/8 ☐ 3/8 ☐ 6/8 ☐
1/8 ☐ 4/8 ☐ 7/8 ☐
2/8 ☐ 5/8 ☐ 8/8 ☐

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National Research
FLAGSHIPS
Wealth from Oceans

CSIRO

APPENDIX 5 SPECIFICATIONS OF LOTEK LAT1400 TEMPERATURE AND DEPTH TAGS

Feature	LAT1400
Dimensions	11mm X 35mm
Weight in air	5.5 g
Weight in Fresh Water	~ 1.5 g
Memory	64K, 128K
Memory Management	Custom Programming
Survival Depth	2000 meters
Max Operation Temperature	35° C
Min Operation Temperature	-5° C
Number of samples	Variable based upon data storage options selected
Sample rate setting	≥1s in 1 sec. increments
Data Download	Gold electrical contacts, 57.6 kbauds
Sea water switch	No
Standard Depth Range	50m, 500m, 1000 m, 2000m
Data Resolution	Up to 8 bit (64k version) or up to 12 bits (128k version)
Processing scale and offset	No
Sensors	Internal Temperature, and Pressure
Temperature Sensor Stalk	No
Light sensor stalk	No
Pressure Accuracy	+/-1%
Pressure Resolution	0.05%
Temperature Measurement	-5° to 35° C
Temperature Accuracy	Better than 0.2° C
Temperature Resolution	0.05° C or better
User Setup	Miscellaneous ways to log data (see Key Features)
Number of log structures allowed	1 (64k version), 3 (128k version)
Typical Life	>2 years

APPENDIX 6 WORKSHOP AGENDA

Australian Government
Fisheries Research and Development Corporation

Environmental effects on fish stocks

WORKSHOP PROGRAM

4-5th December 2006
Oaks on Collins, 480 Collins St Melbourne (03) 8610 6444

DAY 1		**Speakers**
1. Welcome & project introduction	1000	Ian Knuckey
2. Oceanography of the south-east region	1030	Ken Ridgway
3. Fisheries logbook data - What's in it and what can we do with it	1100	Jemery Day
4. Westerly winds and long term climate trends – how will it affect fishing off south-east Australia	1130	Ron Thresher
5. Some examples from other fisheries	1200	Jemery Day, Neil Klaer
6. Lunch	1230	
7. Influences effecting the east coast NSW/E VIC/E TAS - General discussion by fishers on what factors they think most influence good fishing, catch rates, abundance, availability of different fish stocks - All fishers welcome to provide input	1330	Mark Bell, Rod Casement Peter Clarke, Leigh Claydon Chris Currie, Brian Daff Fritz Drenkhahn, Kevin Grey Tony Gurnaccia, John Jarvis Will Mure, Neil Stump
8. Afternoon Tea	1530	
9. Summary of east coast - What scientists heard when fishers spoke - How do we turn this information into data for an assessment	1600	Jeff Moore General Discussion
10. Workshop day close	1800	
11. Workshop Dinner	1930	TBA

Environmental effects on fish stocks

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DAY 2			**Speakers**
12.	Introduction to Day 2	0900	Ian Knuckey
13.	Patterns of recruitment in different fish stocks	0915	Neil Klaer
14.	Atlantis – modelling lots of things……	0945	Beth Fulton
15.	Feedback and summary of Day 1	1015	Jeff Moore
16.	Morning Tea	1030	
17. - -	Influences effecting the west coast W TAS/W VIC/GAB General discussion by fishers on what factors they think most influence good fishing, catch rates, abundance, availability of different fish stocks All fishers welcome to provide input	1100	Tom Bibby, Leigh Claydon Chris Currie, Louis Hatzimihalis Peter Kenny, Will Mure Tim Parsons, Stuart Richey, Peter Risely, Semi Skoljarev,
18.	Lunch	1230	
19.	Summary of west coast/GAB - What scientists heard when fishers spoke - How do we turn this information into data for an assessment	1330	Jeff Moore General Discussion
20.	Collection of environmental data by fishers	1430	Ian Knuckey
21.	Next steps	1500	Ian Knuckey
22.	Wrap up Workshop Close	1530	Ian Knuckey

APPENDIX 7 WORKSHOP SUMMARY

Environmental effects on fish stocks

WHAT ARE THE INFLUENCES IN SOUTH-EAST AUSTRALIA?

Workshop outcomes (Notes from Jeff Moore, Beth Fulton and Jemery Day)

Workshop held at Oaks on Collins, 480 Collins Street, Melbourne VIC, 4-5 December 2006.

Participants list at Appendix 1.

Workshop Program at Appendix 2.

Welcome and introduction

Dr Ian Knuckey welcomed participants to the meeting and all introduced themselves (see Appendix 1). Dr Knuckey explained that the FRDC funded project "The influence of environmental factors on recruitment and availability of fish stocks in south-east Australia" has been highly anticipated. This is probably more achievable now due to the extent of fishery and environmental and oceanographic information available.

Main objectives of the project:

1. to develop hypotheses to model;
2. review and identify available data to support hypotheses;
3. demonstrate some of the environmental influences quantitatively at RAGs/MACs;
4. integrate systems within fisheries to collect robust environmental information for future additional work.

Main concerns expressed/points raised by Industry in the introduction:

- Environmental influences not typically taken into account in a quantitative manner in existing stock assessment process despite the importance of being informally recognised
- Need to have dedicated consideration of environment, depth, season and skipper in assessments during standardisation of catch rates
    - To date only logbook recorded information included, need to bring in extra environmental information
- Main pressures on fish = growth + recruitment + immigration - deaths - catch – emigration
    - What wins out in a year determines whether high or low biomass
    - Availability and catchability also confound the actual catch seen vs the biomass present
    - Industry want flexibility built in by introducing management measures such as long term TACs, but this has been rejected in the past – this project could provide the basis for justifying such measures
- Problem = lag in TAC cycle (18 months behind what's on water at present)
    - Good years = recruitment and/or availability increasing
    - Multi-year TAC, flexible harvest strategies etc make it possible to make the most of good years (otherwise quota too limiting)
    - Also have problem in off years with carry over of expectation and TACs being too high given poor conditions
- a predictive capacity would be ideal, as currently the stock assessment and TAC setting process lags what is happening on the water by 12-18 months
- SARDI working on similar study for inshore SA species

Ken Ridgway talk – oceanographic features and influences of the south-east region

Industry noted:

- the availability of temperature, salinity, productivity and other information from both the east coast EAC and south/west Leuwin/Zeehan currents
- the topography and the way it seems to influence currents and the formation of eddies, which were possibly linked to fishing hotspots
- the long term increasing trend in temp and confirmed some species seem to have "moved south"

Industry expressed interest in reviewing:

- catch/effort data with productivity trends
- whether nutrient rich vs nutrient poor areas/waters and the associated transition zones could be predicted
- catch/effort data for a range of species with water temperature data
- catch/effort data for a range of species with water salinity data
- what links if any exist between Australia and New Zealand re productivity

Other topics covered:

- Tasmania = intersection site as on boundary between Pacific and Indian oceans
- Seamounts, south Tasman rise etc have strong influence on oceanography of the area
- Data collected over last 100 years, more in last 50 and majority in last 30 years
- East coast of south-east = one of six places in the world with such a high level of eddy production and variability
- Eddies are very deep (significant impact to about 1000m, but lingering effects all the way to the bottom, though more other water properties at depth as little temperature differential in/out of eddy at bottom)
- Penetration of warm water in summer further south sees less production to northern tip of Tassie (pushed further south), but in winter its cooler and nutrients mixed in as mixed layer deep
    - End result = strong spring bloom
- Few upwelling regions in Australia, but do have a few (localised and small features)
    - NSW coast, Bonnie, Maria
- Leeuwin/Zeehan brings nutrient poor warm waters from NWS and then extra pulse of warm salty water at head of Bight/off shelf (where produced by summer evaporation) as Zeehan flows past towards Tassie
    - Leeuwin/Zeehan is wind driven current
    - Get upwelling flow in reverse direction along Kangaroo Island and Bonnie area of South Australia and that end of the Bight (doesn't always reach surface but is there)
- Possibility to match logbook catches with environmental conditions (from data timeseries) to see how they relate (what is driving hotspots?)
- Subsurface structure is much more continuous and smooth structure (300m+)
    - This will effect species seen there
- Can see El Nino signal in current strength and temperatures in west but not east of Tassie
- Range of evidence for long term climate change in south-east Australia
    - Change in species distributions (e.g. southern penetration of sea urchins)
    - Maria time series has run from mid 1940s
        - Strong seasonal temperature pattern
        - EAC influence on salinity

  - Without seasonal signal see decadal oscillation (when low get region of cold water centred on Tassie, when high get regional warm water pools around Tassie and tip of WA) plus overall increasing trend
  - Inter-decadal has something to do with strength of the EAC
  - Trend = strongest in global ocean, due to changes in winds and resulting gyre strength in entire southern Pacific
- Anomalies remove overall average and seasonal patterns, left with the "phenomena" of interests such as eddies and upwellings

Jemery Day talk – Catch/effort and other fishery information available at a range of spatial and temporal scales and benefits of SDODE for ease access to oceanographic information

The benefits of the scientists having access to this information in an easily useable system were noted. Data that is available in SDODE includes:

- Logbooks
- SST
- Front locations (identified via step changes in SST
- SDODE

Ron Thresher talk – westerly winds and long-term climate trends, how will it effect fishing off south-east Australia

Participants noted with interest:

- the cyclical (10yr) trend evident in zonal wind persistence, particularly the days of westerly wind vs catch trends for a range of species
- the example of eastern gemfish "collapse" and the recruitment failure which caused it (reason not clear, but environmental conditions may have assisted)
- the correlation of rainfall and wind with sunspot cycles
- the water temperature warming trend across the southern portion of Australia, apparently causing fish assemblage changes in southern waters e.g., certain species off Tasmania
- very strong trends of increased growth rates of some species with warming water

- Gemfish
  - Why crashed = recruitment failure due to… (all went to NZ; all fished; enviro changed)
  - Seems to be correlation between gemfish recruitment and zonal winds
  - Strong wind cycle of 10–11 year period in the zonal west winds south of Tassie (part of circumpolar fronts) as = bit between high over southern Australia and low in Antarctic circumpolar front
  - Wasn't considered in the assessments of the time
- This signal in other fish too?
  - Tasmanian trumpeter, Eden flathead, scallops, abalone, rock lobster, whiting, squid etc seem to follow similar oscillatory pattern (imposed on overall fishery up/down trend)
  - Recruitment follows (with suitable lag)
  - Penguin hatchings, whale stranding, lake depth, trout recruitment etc also coincide with this cycle
  - Some suggestion even roughy even seem to follow this
- Persistent 10–11 cycle seen across many components (though based on data of varying quality)
- 7 year cycle for toothfish and grenadier
- Environmental oscillation of matching decadal length = Sydney-Hobart difference in pressure in winter

  - Very long and strong decadal oscillation
  - perfect match with strength of zonal surface winds
- Related to sunspots (11 yr cycle)?
  - Well correlation is strong, but means of causation not well understood
  - Related to levels of rainfall in south-east Australia too
    - Mainland and Tasmania
    - In Tasmania high winds = lots of rain in SW Tasmania, with rain shadow in NE Tasmania
    - Due to fact its large scale circulation variability
  - Contentious science, some say yes, some say no (too weak for sun to effect atmospheric pressure)
    - Probably part of the story at least
    - Strongest correlation between atmospheric pressure at sea surface and solar flux/sunspots (and their effect on the upper atmosphere) = at 40 deg L (especially 40 deg S – right on Tassie!); also wanders a bit up and down, which matches the interdecadal oscillation Ken showed
- Mechanisms connecting oceanography to population dynamics is speculative at present
  - May be different on species-by-species basis
- Warming trend already evident here (probably because area most sensitive to it on the planet)
  - Plays out as new species found in the area not seen before 10yrs ago (50 species in 10 families have had poleward shift into Tasmania)
  - European shorecrab introduced a century ago in Victoria, constrained to Victoria/South Australia to 1995
    - Since 2000 its populated all of Tasmania
- Environmental effects have impacts on fish stocks
  - Looked at growth rates (as recorded in otoliths)
  - If live <250m then growth rates increasing over last 50yrs (up to 50% faster); midwater depths (500–1000m) fish see no change in growth rates; deep water (>1000m) see slow down in growth rates (by as much as 70% in some oreos)
  - Using deepwater corals to get deepwater temperature proxies
  - Found growth rates track with water temperature cycle and trend at surface; at depth see fluctuation in temperature being matched by temperature fluctuation (which has oscillation but also downward trend)
  - Looking at long-term temperature proxies, it seems Orange Roughy were growing 100% faster 200 years ago; while shallow water fish were growing at about 40% of current growth prior to 1920.
- Probably recruitment impacts of environmental change too, not just growth
- Implications for catchability and availability?
- Possible that predation and competition release also contributing to the increase in growth rates?
  - Partly, but old otoliths show change happened before fishing impacted the system
  - Also opposite signal depth where equally impacted
- Other implication of strong temperature differential?
  - Stronger stratification so nutrient supply implications?
- Multiple mechanisms for changing in temperature differential
  - Possible warmer water lighter and rising so deepwater cold coming in under it so colder water higher on slope and so are cold water species
  - Strict depth based closures may breakdown as result
- Three water masses, Indian, Pacific and Antarctic and south-east on interface so if zonal winds strength high everything pushed north so we see big cooling change, if equatorial winds stronger everything pushed south so see big warming change

  - Such signals weak elsewhere as not sitting on the intersection point
  - Suggest may want more flexible management method so can respond to it rather than using management methods developed in more static areas

Jemery Day talk – examples of environmental factors taken into account in other fisheries

- ENSO = best known global climate variability
  - No clear signal between ENSO and fish populations though, so lag and may be caused by it, but others actually “anticipate it” so links unclear
- Range of environmental forces considered ranges depending on location including
  - Temperature
  - Salinity
  - Sea surface height (related to upwelling strength)
- Causal influences or coincidences?
- Need to consider spatial scale carefully (must use appropriate scales relative to ecology of species; salmon fine scale in rivers, tuna large scale etc)
  - Considering spatial and temporal correlations help avoid spurious relationships
- Effect of environment can differ with location (e.g. warm anomalies increase survivorship in Alaska, decrease in Washington State, and signal lost altogether if go over the entire area)
- Fluctuating environment may be important for allowing coexistence of multiple species and chance for recruitment success
- Regime shifts are big system changes, with species showing large scale dominance restructuring
  - Largely reported in northern hemisphere
  - Not cyclic but more abrupt and long lasting
- Australian species cycles
  - Tuna response to thermocline and warm core eddies
  - Tiger flathead, temperature related (??)
  - Gemfish response to cold water currents and warm core eddies
  - Blue grenadier’s recruitment cycle
  - Patagonian toothfish cycle
  - Orange Roughy 50 year cycle linked to bottom water temperature
- NZ Blue grenadier cycles
  - Linked to oceanography, but not consistent enough to find persistent effect due to SST/winds/SOI/depth mixed layer etc when review updated
- Be careful of spurious relationships (e.g. London Gold price is best correlated explanatory variable with Alaskan Pollock recruitment!)

Royal Red Prawn

- Mainly caught from about Greenwell Point north, in 200–300 fathoms
- Best fishing is in the Summer months – fishing can be good from November to about June or July, depending on currents
- Peak catches occur when 2-3 knots of current is pushing north to south, bringing the warmer water down the coast
- Full moon best
- The fishing shuts down when a cold current pushes from the south – the current/tide can change suddenly
- In terms of temperature, half or even quarter degree changes in temperature can turn the fishing on or off
- Current running of 4-5 knots helps to pick them off the bottom (so surface current, but reach the bottom) - stronger catches when southern change coming
- The EAC appears to be a major influencing factor – bringing warm water and creating eddies that seem to produce good fishing when conditions are right (need water temperature)
- Strong market orientation too (in terms of targeting and catches)

Industry reps for focus: Kevin Gray, Mark Bell

Ocean jackets (Chinaman leatherjacket)

East coast

- During the summer months when water warms, the jackets move in, and many other species such as squid, cuttlefish, flathead etc disperse – it seems the jackets just move in and displace everything else (shark, angel shark not impacted)
- Jackets increased substantially in numbers over the last 5 years – dominate the system
- 2-3 years ago many were 3cm long and getting caught in prawn gear, but now big enough for main trawl gear, like back in the 1960s when displaced other target fish
- Not seen in current numbers since probably 1960s – with cold water change the leatherjackets disappeared and other target species came back
- Eating or displacing other (juvenile) target species?
- Saw starved dead leatherjackets floating at surface over last couple of years (exhausted food supply?)

Eden/Lakes

- Turned up in force 3 years ago (maybe as many as 5 years ago), across a large range of year classes (although some suggestion that it was the large fish that moved in first – maybe that was further north?)
- In 35-40 fathoms, very large shots can be taken at the moment – 60 tonnes off Eden in 35-50 fathoms
- Generally 45-65 fathom is highest concentration, present day and night (though night shots seem to be biggest catches off Eden)
- Many of the fish seem to be "skin and bone", like they haven't got enough food to eat
- During a trawl shot, other target species have often been damaged by the jackets eating them, usually the fish protruding from the meshes of the net
- It seems when the jackets moved in, the mirror dory followed

West coast

- Jackets were worse 3-5 years ago, not as bad now
- When present, very similar problems to the east coast now

SA/GAB

- 5-6 years ago jackets seem to have reduced in numbers (disappeared?), not as bad now. Why? Rise in water temperature? South Australian leatherjackets left about time they turned up in eastern coast
- Used to destroy traps and crayfish lines and eat fish such as blue eye off drop lines. They invaded fouled nets and ate the contents.
- With trawl they would swim parallel to trawl and steal from the cod end
- In the early winter months, fishers noticed they seem to move to the outer shelf, possibly to spawn?
- In the early 1990's, SA prawn fishers blamed reduced prawn catches to jacket boom
- The jackets seem to be worse around feed like if pilchard schools are around
- GAB trawlers reported even now, if a full moon, would not dare shoot inside 140m or huge shots could be taken
- Caught by trappers in the day time and trawlers at night
- Found in shallower water in the GAB than in the East coast (inside 140m)
- West of the Bight is particularly bad for small jackets

- Bad in late 1970s off SA outside 70m

All areas:

- Jackets seem to move into the recently trawled areas – it seems to attract the fish, possibly by stirring up the bottom and discarding
- There has been an observed west – east “migration” or availability effect of jacket populations, however when there were heaps they were everywhere in all sizes
- Historical data suggests there were lots jackets in the 1920s and 1930s through to the 1950s and lower water temperatures then. Fishing operations targeted jackets in this period. Leatherjacket catch matched/exceeded flathead catch through to late 1940s
- Early winter, move off shelf (200 fathoms) possibly to spawn.
- Possibly become pelagic at some stage and maybe the pelagic fish have moved from west to east?
- Potentially a 3000t fishery.
- Will school with other species, even pelagics (e.g. mirroring surface swimming tuna; seen around bait fish schools)
- 35 fathom seen spot on sounder and pulled up 60t leatherjacket
- Caught far off shelf so could go pelagic for large scale migrations.
- Is this temperature driven redistribution? Does it apply to other species
- On outer shelf in winter months to spawn (inshore trappers would see decline May-June)
- Diel patterns? In east bad day or night, but in SA trappers get them in day and deeper trawlers at night (so trawlers could work in day and not get them, but nothing to catch as all else eaten or left)

Industry reps for focus: Mark Bell, John Jarvis, Tim Parsons

Mirror dory

- When the jackets moved in, the mirrors seemed to follow
- Now both not as available (just this year)
- See patterns of big fish “just turning up” (across the fishery rather than in east vs west case like leatherjackets), but tend to only hang around for a couple of years\
- Smaller fish more persistent year to year in summer months in shallow-moderate depths on decadal scales, though over many decades can see changes in distribution of even these
- Other species turn up coincidentally, like squid (warm water preference, so when thermocline is deeper and warmer water through the water column)
- Again find them when not much else around (so is it because all else left)
- Possibly from NZ? Deepwater currents at about 22 deg S do flow NZ to Australia, so possible route (caught as far north as Port Stephens, can’t work north of this) – then move south with intruding warm water?
- Why just turn up east/west without being caught along potential migration routes?
- Mirrors in force from Sydney to St Helens, across a range of year classes but many large fish
- Currently big fish off Storm Bay
- Not so many large fish on West coast now – were there 3-4 years ago – lower catches in the east at the same time (squid also)
- Again, possibility of west-east movement of fish? Or fish available everywhere (availability effect rather than fish moving around the fishery)?
- When good squid numbers, more mirrors seem to be around
- Turned up in Portland and Eden 2001/2 and 2002/3 in Portland
- Mirrors usually full of whitebait or small squid or lanternfish
- Move in as eddys hit the shelf
- Hypotheses that warmer water may be helping availability – in the west fishers observed when the thermocline is higher and water temp is 15 degrees at depth (16.5-17 degrees at surface) catches seem to be good
- Spawn after gemfish
- Do they aggregate or disaggregate in some years?

Industry reps for focus: Mark Bell, John Jarvis

Squid

- Year 2000 was a very poor year, with uncharacteristically calm winter and warm water (Portland, Queenscliff, King Island). Only cold water was in Hobart (Storm Bay in 2000)
- Last year Portland was bad and Queenscliff was good
- A very good year was 1996 when water was cold (jig), with trawlers also reporting larger than average shots in that year in 150–200 fathom. Could fish a very small area.
- Jig catches are more variable than trawl catches. Catchability variable (so can have high biomass and low catch rate on a day-to-day basis, so low catch one day, but high next day). Jig seems very variable and trawls more stable, but trawl only more stable across entire fishery, do see variability at any one location.
- Possible correlation with strong westerly's = good years
- Squid also associated with areas of high krill abundance
- Krill and squid possibly associated with the frontal index (change of warm and cold water)
- Strong food chain links identified, e.g. abundance of krill = more squid, mackerel, and other target species, but predicting when and where these events occur very difficult!
- Should look at frontal index and relationship to catches over time, noting for jig and east coast trawl, catches would generally correlate to availability. Like sitting on fronts/eddy edges.
- Locally, squid is a good indicator for presence of other quota species.
- Best catches of squid and all else when eddy hits shelf, when it leaves again everything else goes too
- Dedicated Vic squid fisheries do best in clear water
- NSW flathead fishers find they can target squid in dirty water where they are feeding on juvenile cardinalfish
- Eddies full of small forage (squid, mesopelagics)
- Best temps for squid 18 degrees off Queenscliff, 16.5 degrees of Portland. 14 degrees and below, catches drop off
- Noted Japanese and Korean squid fishers analyse thermoclines (when do they hit the bottom?) and salinity data and know how to fish them. Koreans caught 7000–8000t per year when they were allowed here
- 4 days before and after the full moon gives the lowest catches
- January/February typically medium sized, then March/April schools of very small squid (1000s tonnes, but too small to be marketable); April/May jiggers seeing no big fish, but trawlers were picking up spent adults on the bottom
- Discarding high as market gets swamped easily in GAB, not in the east (where all kept and landed)
- Good time series of catches and locations kept by jiggers, so compare with last 10 years of CARS environmental data to see if can find correlates or mechanisms
- New machines and computerising so optimise jig method and depth etc to maximise catch
- Possibly conditions at depth (not surface) determining where squid are.
- Maybe tied into couta biomass too - another component of a larger species complex that cue on the same signals?

Industry reps for focus: Louis Hatzimihalis, Stuart Richey

Barracouta

- Last few years in Eden, recreational catches increasing
- Opposite in Portland, with catches not as high over last 3 years or so
- 1995-96 high catches in Portland
- GAB trawlers reported increased availability at the shelf edge last year
- No strong environmental drivers identified
- Follow boom-bust cycles on 5+ year cycle too
- Currently at peak (based on recreational catches)

Jellies, Salps

- Salps pathway not highly nutritional, fish appear to eat when in abundance
- Evident that when jellies are thick, catches of target species drop right off
- Last 4-5 years there have been quite a few jellies around Portland to Lakes (at 30 fathoms), but biggest years were early 1990's, especially 1993 (condoms but also smaller jellies with "little eyes") – usually only in blue water
- Blue eye reportedly feed on the condoms, but still take bait
- Ling won't eat them – won't come off the bottom
- In the GAB, jellies and krill don't seem to be as abundant on the shelf (but shallower fishing usually) – salps too pelagic?
- Present east of KI a couple of years ago
- South Tas 7 years ago – 2 years later were biggest red tides
- Red tide temperature dependent 2 years ago off St Helens (moving south in last decade with temperature increase?)
- Currently big salps but few of them
- Portland they go up and down to the bottom – no fish with them
- In the early 90s like soup in Tas (Bruny to Freycinet)
- Early-mid 90s – present in Everard and Horseshoe
- Late 80s of Eden would gum up nets – Bermagui south to Everard. In gill nets every August – hangs in mesh
- Snotty's eat them (full of them!) - when thick off Lakes, snotties seem to fire up
- Trawlers have observed the jellies are often in the cold water, underneath the thermocline which shows on the sounder. Tight temperature bands – or low oxygen for jellies?
- When thick off Lakes, snotties seem to fire up
- Circulate an identification chart to all fishers so that salps can be identified and reported in logbooks for future analysis
- Jellies
  - Can drive biomass dynamics (some species target it and some avoid it)
  - Blooms can grow too big for fish to target quickly
  - Salps are a big component of this, often see squid associated with them
  - Can see boom and bust cycles and fish targeting them (spewing out mouth of blue eye etc as landed). Big blooms in early 1980s and early 1990s

Krill

The importance of krill in the food chain was discussed in some detail, with all fishers agreeing that high krill abundance drives availability and activity of many other species. If krill abundance could be predicted, it would greatly assist fisher's ability to effectively target a range of other species.

GAB

- 1992 was a huge year, seemed to be one off event, redfish were spewing krill
- This year krill in abundance off Port Linclon up to 300m off land and could be linked to the strong upwelling events there
- Also this year some fishers have speculated that high krill abundance triggered large schools of pilchards and mackerel and then other predators followed, e.g., gummy shark caught in cray pots (possibly meaning high concentrations of gummy's?)
- From KI to 132 degrees and even to Robe SA, high productivity upwellings, wind driven events (noted data available to observe these events over time)

Portland

- Krill mainly inside 50 fathom
- Queenscliff to Cape Otway, thick for 4 years with salmon, mackerels, pilchards couta
- Comes in on upwelling

East coast Tas

- Don't see krill (but may be there however)

East coast (Eden north)

- This year a big year, whales sitting off east coast for about 2 months due to krill availability (haven't been seen for 6 years previously)
- Krill generally more abundant during winter, with balls of krill visible on sounders on the bottom
- Fishers described when "black water" around, get a build up of krill off Jervis Bay, seems to occur inshore in a back eddy of cold, nutrient rich water (john dory water) – current from the north, inshore

Blue eye

- Won't catch much if the current is too strong – perhaps because gear wont stay on the bottom for long
- October/November fish tend to settle on the grounds, smaller fish in 2kg class over summer (15-17 degree water best). Won't swim through Bass Strait – but settle either side of Tasmania at the same time
- Apparent large recruitment across the fishery this year throughout eastern Bass Strait/NE Tas. Residential stocks lost, but significant new recruitment bulking it up in last 6 weeks – fishery survives on annual influx of new "fishery recruits"
- 1997 also a good year. 1991/2 were good years on the east coast of Tas
- Same size fish settle together – not necessarily the same age – first year settling on ocean floor in 1.5-2kg – aged somewhere between 2 and 5 years old
- Mix of residential fish (evenly spread around) and schooling fish which settle at some stage
- Transients fish following fronts?
- Not sure what is driving recruitment - possibly floating seaweed mats providing habitat, as juveniles have been observed associated with these features? Many fishers sceptical. Called Lanternfish as juveniles - then metamorphisis to Blue Eye. Pelagic under seaweed rafts when young.
- Worth checking wave heights/stormy years correlation with recruitment 3-4 years later?
- Decreased catchability when killer whales are around
- In the GAB, one fisher observed the water was dirty green with not much life –when the water turned clear and blue, the blue eye settled and catches increased
- The same fisher believes he observed the altimetry charts and the water change (temperature?) was associated with a front moving through
- Species is distributed around the globe at this latitude
- 3 inch long blue eye caught at depth by rough boats in August

Industry reps for focus: Will Mure, Leigh Claydon, Chris Currie, Peter Kenny

Flathead

East

- Feed (juvenile cardinals or whitebait) and tide/currents drive them
- Better catches during spring/summer when current from the south (clockwise eddy inshore) in 30 – 40 fathoms (seems to be a back eddy of dirtier, colder water 17-18 degrees, dirty green, into clearer warmer north to south current of around 22 degrees) back eddy indicates cooler upwelling inshore (if main warmer EAC is offshore, catch is poor here; if EAC hits shore then no point going out at all; use satellite pictures to decide whether to fish or not)
- if windy and currents from the north with clear water pushing through then not present (Dec-Easter; after Easter better) – i.e. not sitting in EAC
- The main eddies seem to occur off Jervis Bay and Montague Is
- In winter, fish more dispersed in 70–80 fathom - less fishing for flathead as weather poor so chase other species like Royal Red prawns instead
- Lots of fish from 1980–1985

Eden/Ulladulla

- Distinct run in summer and typical fishing patterns in other months described as runs also. Multiple seasonal runs (3-4)
- In summer, need strong tide with dirty cold water one side and warm clear water the other – fish that zone and 10 miles each side for highest catch rates – direction of current does not matter. Fish sit just off the edge of this front
- Can seem to "follow" fish down to Green Cape and back. Fish migrate south (Ulladulla catches peak 3 weeks before Eden etc) and then at summers end reverse and go north (same fish swimming down or conditions that make fish available; bit of both)
- Fishers suggested it was more likely conditions driving availability/catchability that the same fish running down the coast – fish all seem to turn up at the same time
- The "winter run" sees fish disperse but large fish become available (especially in the last 3-4 years) in 130–140 fathom, dirty green water, 16.5 degrees at the surface. For 2000–2005 look for feed layers, with current running north/north-west – prior to 2000 fished more on top of shelf
- Spring/autumn fish dispersed over all ground with no aggregation
- Late summer follow EAC eddies as far as top of Horseshoe, but then move north again after that
- Clear water - catch at night; dirty water - catch in day (maybe catchability as fish may be net avoiding)
- If wind swings from SW to NE then shuts off
- Moon plays a large factor in all areas – full moon = increased catches

Eastern Tas

- Usually caught shallower than off NSW – last year to 150 fathom in the Strait – deepest they have been seen
- Winter-spring 120–150 fathom

Lakes

- Prior to 1985 fishery quiet in, but took off after that

West (Portland)

- In winter, fish deeper in over 100 fathom (big fish stay on the shelf edge for a couple of months of the year at variable times of the year)
- Only caught at night on the full moon
- With surface and deeper currents often opposing each other, very difficult to observe and fish to currents
- Has observed that for a range of species, catches can improve or get worse at a certain depth depending on where the thermocline (where temperature drops about 5 degrees quickly – say in 10 fathoms) is touching down e.g., generally better catches when the thermocline is up on the shelf typically 13 degrees in 100 fathom – when thermocline deeper could be 17 degrees in 100 fathom and have to fish deeper for the cold water
- Recently thermocline has been sitting in deeper and deeper water
- Fished to 350 fathoms 3 years ago when no fish were around
- Stay home when there is an easterly or south-easterly (Portland or West Tas) – north-easterly is not so bad
- Barometer low, easterly wind, gas bladders shrink, hungrier fish? Can this affect catchability?

Seine fleet (Lakes?)

- Summer fishery from November starts peak in catches
- Fishers work an eddy off Lakes which can be moving shelf to shore then back again
- Can't catch flathead in the dark whereas trawlers can
- Catch a lot when north-easterly wind
- Look for feed layers and target fish there
- Only really fish the day
- No small fish for three years in a row, but back this year
- Catch every month of the year – always full of roe and spawn
- Fishery size will make searching difficult (can miss line of flathead by 5 fathoms so used to be that one boat found them and then rest of boats came in, but now too few boats to search effectively)
- 4 different stocks?

In general

- Flathead seem to be everywhere in all habitats, small flathead change distribution (further south when missing from traditional grounds) so may be environmentally driven
- Flathead caught through the year with roe, so maybe spawn year through
- Alternatively multiple stocks with different spawning dates/places
- Many sizes can spawn (small fish through to big)
- In 1920s saw spawning aggregations in summer, but off Eden in winter there are big roe-ed up females (possibly sex and size based schools?)

Industry reps for focus: Fritz Drenkhahn, Kevin Gray, Peter Clark

Redfish (east coast)

East

- Good year last year, with good currents from the south/south-east at 0.5-1 knot
- Mid winter peak catches typically, used to be after the gemfish run July-Aug
- Shuts down as current comes from the North/NE, as seen this year (current coming from north all winter and hitting the bottom so nothing there) – only good catches occurred this year with south-east running current, in 200 fathoms
- Also feed related – krill and lantern fish in abundance are followed by redfish moving in (in the south/Eden)
- Need forage on bottom (krill, lanternfish, small fish) then bigger fish like Redfish turn up and are catchable
- Follow the mesopelagics in with eddies spinning onto the shelf (bringing deeper water mesopelagics onto shelf) and catchable as eddy begins to leave the shelf
- On edge of eddy (maybe pelagic fish coming in onto shelf)
- Or catchability switch given fact all sizes appear in big numbers all at once

Eden

- Fishers reported best catches occur when a southerly current eddy forms off the coast (dirty water), seems to bring lightfish (lantern fish) from 2000 fathom in cold water
- Best temp for reds from Eden north 16.5-16.8 degrees SST

In general

- Very poor catches in 1989 – 1992 when the fish just didn't seem to be around at all. In contrast, 1993 was a very good year, redfish turned up across all size ranges. Perfect temperature from Sydney to Babel Island – 16-17 degrees
- Environmental conditions in 1993 should be checked against catches. Check catch rates for a range of species as 1993 was a standout year for most species.
- Redfish seem to have moved south over time, possibly with the warm water. Catches were reported off Storm Bay recently and off Babel Island there did not used to be redfish there in early 90's – now common.
- Can move like a blanket – catch from Sydney to Eden all on the same day –like a pelagic fish?
- From September, there can be 3 or 4 big pulses in some years – but can be months apart (in some cases all turn on everywhere at once; in other cases different peaks at different times of the year)
- Some operators catch them in the summer
- Juvenile redfish, caught by seiners targeting whiting, sitting in balls over rock outcrops near Lakes Entrance
- Squid, Redfish and flathead often both found booming simultaneously as all following same forage; so if forage there all there

Industry reps for focus: Fritz Drenkhahn, Kevin Gray, other

Ling

GAB

- Unknown - almost no Ling trawled west of Kangaroo Island (less and less further west)
- Thermocline deeper than “standard” fishing depths in GAB
- Not really targeting it and don’t trawl enough to get it as avoiding deeper rougher ground
- Long liners catch ling, on hard ground, in deeper water off main shelf-slope break

Portland/West

- Catches going down for trawlers for 3 years
- Sept – Oct historically best fishing, next to canyons in 200–400 fathom, spawning run on west coast of Tas – tight spring spawners in canyons
- 3 years ago and previous, all deepwater fish were outside 350–400 fathom with the cold water (approx 10 degrees) – the last few years and this year, the thermocline has moved up onto the shelf and deepwater fish are shallower
- Drivers not as well known, more available in winter (during spawning runs un canyons) but there to some (small) degree all year

Lakes Entrance

- May to Sept/Oct best time of year
- Seem to follow the cooler water current from the south (SST 16 degrees, bottom temp approx 10 degrees in 150 – 300 fathom (extreme of 8-12 degrees)), arrive ahead of the gemfish on currents from the south
- Not too bad this year – spawning ground closures seems to help stock
- Winter for main catch
- Follow feed line,

Eden

- Southerly current best – and current out to sea
- Fuller the moon, fish seem to move in shallower – in deeper water with less moon
- May/June run, then return run Oct/Nov
- This year was a big year in Eden
- Runs going north before gemfish and return south in about November

East

- Best catches in winter when cold water running from the south, generally depths of 250 – 350 fathom
- Peak catches tend to be over the full moon
- Not seen as much Ling
- Winter fishery, but not huge (redfish more attractive target)
- Good feed layer, coming to full moon (after moon gone), in 350 fathoms

Industry reps for focus: Chris Currie, Tom Bibby, Will Mure

Blue grenadier

Discussion focused on possible drivers of recruitment.

- 1993 (year of huge recruitment) marked by screaming gales and huge spawning runs that split nets (few fishable days, but filled up when did get out, and also very easy to find)
- 1995 small fish absolutely everywhere (nuisance and were discarded in all seasons); juvenile fish moved from southern spawning grounds to more north-westerly settling/adolescent/adult grounds (fisherman had to stay ahead of this slow 2 year spread so as to avoid being swamped by them); seem to have gone east before west as seen fairly quickly in the east when still avoiding them in the west
- In 1994/1995 stayed in east and off Tassie through the year rather than moving off seasonally
- Prevailing winds in 1993 should be checked – remember gales from the west most winter and very hard to get out fishing. Large recruitment in 1993. Tended to fish east rather than west in 1993?
- Fish everywhere in west Tas in 1993, did not need to go far south to find huge marks (when it was OK to go to sea)
- 3 years ago in Portland, couldn't catch ling (wet year).
- "Something going on now", with many small fish showing up in the last 2 years (3 years ago, no small fish at all)
- The run seems to be larger fish show west and west Tas June/July/Aug, then move down around southern Tas, up the east coast of Tas spring then East coast Jan/Feb and disperse (no run back)
- East coast fishers reported large fish can be available all year in the deep
- Feed on light fish in the west
- Feed on sauries, imperial garfish and whitebait 1999/2000 in the summer on east coast of Tas (no lanternfish around)
- Like eating mesopelagics and small cardinalfish, will eat red bait/sauries/imperial garfish if no mesopelagics available
- Link to NZ fish?
- This year pattern of catch and distribution more like early 1980s when available all year at same locations rather than large scale movements
- In mild winters stay in spot and not move off, not known why (maybe forage dependent)
- Wet years find it harder to find fish in fishing grounds (and if present not catchable). Check rainfall trends against catches?
- Big bycatch on line now too
- In very deepwater always see the odd one through the year (Japanese long liners used to pick up a few tonne in 150 mile off south-east Tassie below Hobart in open water)
- Go south in spring after spawn (mid Winter), before heading up east coast of Tas (late spring/early summer) before vanish and then just "reappear" in western Vic by February (maybe move offshore and cycle round to the west?)
- Maybe go off coast on same eddy bringing gemfish into the shelf?

Industry reps for focus: Chris Currie, Tom Bibby, Will Mure

Silver warehou (previously known as spotted warehou)

Fishers struggled to identify environmental drivers with availability, recruitment etc.

Portland/West

- Always present (but didn't used to be so?) – disappear Nov-Jan
- Prefer 12 degrees on the bottom (warmer than grenadier) – middle of thermocline (maybe following forage)
- Used to feed largely on jellies (why called snotties), now not (empty when caught so new food unknown)
- Large fish not as abundant across the fishery as pre 1995
- When abundant, it happens everywhere, west in February then move east
- Big spawning runs on the east coast (after gemfish) – early July
- Moving further north on inshore cold water currents, further south in general (so range extension following cold water tongues
- Bigger fish rare on shelf now (in deeper now), but heaps on shelf in good years
- Size based schooling
- Seen with mackerel and couta
- Best years: 1986 off Eden, could not get away from them from 60 – 250 fathom for two months - early 1990s and 1997-98, big years of medium sized fish off Hobart particularly. Especially inshore
- Avoid high catch areas as price is not good – no effort in finding them for the last two years. In November (when they are hard to find), worth targeting then

Industry reps for focus: John Jarvis, Fritz Drenkhahn

Blue warehou

West

- Appears to be more in last couple of years - natural refuge schooling over the hard bottom. In some years come off this and available to trawl (maybe spatial competition/limitation)
- 1992/3 were big years
- Don't see small fish off Portland

East Tas

- Until 1994, used to turn up in numbers on 1st moon in November south of Bruny Island – now just patchy (post 1994 this has stopped happening)

Eden/East

- Feed and moon drive availability (lead up to full moon best)
- 16.5 degree SST (approx 13 degrees on the bottom)
- Previous to early 1980's there but not thick, in mid to late 80's off Lakes, 1000's of t caught
- Small fish seen off Eden
- Seasonal (3 months) on narrow strip of ground

In general

- Environmental drivers for blue warehou unknown, but seems to be increasing trend (at least in catch)
- Not targeted anymore as no quota so less knowledge of drivers (as fishers not interested)
- 10 year cycle (?) of big years of blue warehou
- Will actually steam away from them (same with snotties as not as high value)
- School-up off Portland and Tassie
- Catch medium size inshore on handlines recreationally in April (before available on shelf) and winter (in Tassie)
- Bigger fish caught in Tassie, small fish in western Vic (but lots of them)
- Dense concentrations, so can miss them easily
- On bottom feeding in rough ground at night for couple of hours (often just as moon cleared the horizon)
- Related to moon and feed availability (also can be hard to find in high leatherjacket year as fishers full of those before see warehou)
- Small juveniles will follow cold water tongue inshore as pushed north (happened this year, but rarer)
- In east non-trawl targeting reef caught them traditionally on rough inshore, but now not seeing them (local depletion of residential fish?)
- Do seem to just turn on/off (appear/disappear) in east and west
- Small fish just turn up at already 1-2 yrs old and where adult population producing them?
- Do they live in GAB between Tassie and Kangaroo Island on rough (untrawlable ground) between 1 and 300 fathoms?
- Mesh netters and shark fisherman not seeing them
- Same species caught off South America?

Nothing can really generalise or point to - problem species!

Morwong

East

- Not seen in NSW much if at all now (some small fish seen at night, but not much), but used to get them back in 1970s-early 1980s (100 boxes in a couple of shots of small-moderately sized fish)
- Reduced catches in recent years – fishers reported as soon as targeting occurred off Babel Is, catches declined significantly
- Warming water could also be detrimentally impacting catches, as morwong catches are best in cold water 14-16 degrees
- Seems to be some small fish moving into catch composition – perhaps as recruitment pulse
- Trawlers catch in clear waters – week either side of full moon
- New moon – better in deeper water
- In paddocks catch in clear at night
- Biggest catches when fish moving from one reef to another

Seine

- Reports that in the 70's, catches could be taken by seine gear at night off Babel Is but this is no longer the case
- No longer targeted by seine

Eden/Lakes

- Catch rates went down in the early 80's – boats moved south to Babel and targeted morwong in numbers
- Look for milky/dirty water in autumn for peak catches for seiners
- April/May as water cooled down they turned up off Everard along banks and reefs "in gutters" moving north with cool currents
- Later move to night fishery (no catch in day time)
- This two part fishery disappeared (once more extensive southern fisheries established) and warmer summer waters on later 1980s and early 1990s (so distribution shifted south and fish caught before they could move north)
- Seems recent good recruitment (small fish present and slowly growing towards marketable size)
- September spawning run
- Gabo island/further south: smaller fish (harder to sell)
- Sold more under "snapper" or "sea bream" but once have to be sold as Morwong harder to sell

West

- Fishers believe morwong haven't moved to areas like off Portland, just more vessels recently there to catch fish where they've always been
- Best catches seem to occur when the colder water thermocline gets deeper, possibly forcing shelf species out to the shelf break where they are more available (notice with flathead, bugs, morwong etc)
- Thermocline gets deeper December to Feb

Robe/SA

- Higher catches noticeable last year
- Possibly “dead”, low nutrient, high salinity water moving off the shelf and pushing them out over the narrow strip of fishing grounds?

In general

- Differential catchability too (some times trawl will catch them when seine won’t)
- Response to changes in other fisheries, resulting in more morwong caught and poor (as market flooded)
- Reports in west of higher spawning numbers may be an artefact of more fisherman targeting them now

Industry reps for focus: John Jarvis, Tom Bibby, Fonga

Gummy shark

SA/GAB

- Trawlers reported catches fairly low but steady, trawl grounds seem to be on outside of main gummy grounds (in shallower water)
- Catches seem to increase in the west GAB in winter
- State operators have reported plenty around (e.g. caught in pots) and that target by following change in water temp (charts)
- Best catches when availability and catchability coincide – looks like coming to the top of a ten year cycle
- 1995 was a high catch year, 2000 quite low
- Mid 1980's also a high year
- Fishers reported targeting the "feeding front" – just in front of a change in water temp where food can be seen on the sounder
- If no apparent front, look for patches of water with a different water temp than the surrounding areas
- If in homogeneous water body and find one small patch that stands out as different (different water temp) then see peak in catch rate there
- Availability: recruitment related
- Catchability = when won't take hook when trawls catch fish; driven by food source and relative prey composition. Opportunistic but do have preferences so can have found a food source but not the preferred one), spanner crabs, bait fish.
- As mutton birds leave (snacking on bait fish as leave) gummys come in to eat bait fish too
- Will fill up dropline for snapper so have to set suboptimally for snapper due to gummy quota exceeding threat

Bass Strait

- Last three years better each year, size and numbers improving
- Winter fishing improves on new and full moons – fish seem to become more active
- Temp not so important, though catches improve in summer months (more lethargic in winter so nets not effective though trawl still work)
- Some fishers look for dirtier water where there is generally more bait and therefore gummy shark
- Apparently when mutton birds leave Flinders Is, the gummies show up
- Around Gabo seem fatter and shorter than rest of Bass Strait (form NSW/east coast stock?)

East coast

- Good east coast year; due to management working or because Bass Strait currents pushing colder water north?
- Seems to be all one cohort (have changed fishing approach so maybe confounding)
- Possibly better management as quota harder to find as being used. Getting bigger catches with shorter lines now (less boats, big closures so stock just better off?)
- May be benefiting from competition release (school sharks and whiskery sharks removed by fishing)
- Need dirty water to get them in trawl

Industry reps for focus: Peter Risely, Brian Daff, Rod Casement

School shark

Fishers suggested that there are quite a few around and that they shouldn't be on any endangered list – south of Tas one fisher is catching up to 50% school shark when targeting gummys. If discarding is made illegal then quota restrictions could see gummy fishery closed down.

In terms of environmental influences:

- School shark are always full of redbait, mackerel, rubyfish, small blue warehou squid etc – associated with schools of bait
- Generally caught in 16.5-18 degree water, therefore depths change markedly depending on temperature
- Less strict preferences, but in any case if finding them in a temperature band/depth contour and steam to new spot then will find them again in same temperature/depth combination (but that combination can change time to time)
- Often found 250–300 fathoms off western bass strait islands
- Endangered and bycatch only
- Have to steam away form them to avoid filling up quota on them and restricting gummy catch as can't afford to take more
- Is global stock refilling local stocks? Better off than if local only?

Industry reps for focus: Peter Risely, Brian Daff, Rod Casement

Bight redfish

- Cyclical trend in availability of Bight redfish – is it availability of redfish vs deepwater flathead?
- Seems to be linked to long-term changes in water temp and or currents and upwelling events – so cooler water forces redfish inshore and flathead up onto shelf? Redfish are caught inshore and flathead deeper
- Maybe salinity fluctuations
- Not as many environmental drivers, as less freshwater input etc (maybe look at upwelling and Leeuwin current strength instead)
- When Leeuwin stronger see different more pelagic species (like sailfish and western gemfish, tiger sharks and turtles) coming down and across
- Any correlation between "unusual species" present/strong Leeuwin and catch rates of flathead and redfish
- Pilchard die offs really due to disease or due to upwelling consequences (different sized pilchard to normally seen, first March one in 1995 around Australia and second one in November constrained, flathead full of pilchards, ditto other one off Tas years before)
- Probably linked to Leeuwin current and/or Bonnie upwelling
- Cooler water tends to force Bight redfish further inshore
- Quota management has gone up
- More spawning aggregation formation
- Seems juveniles inshore or in untrawlable or locked up grounds
- If not spawning will have to target rough ground to find them
- Can only utilise at certain times (Jan-April) - rest of time in interior of Bight on rough ground
- Full moons and hard bottoms – sometimes catch too many, don't want to exceed quota
- Better at night near bottom, lift off bottom in full daylight (to feed)
- 2003 was a good year – redfish around to Port MacDonnell
- Long term (5-7 yr) cycles may be present

Industry reps for focus: Semi Skoljarev, Tim Parsons

Deepwater flathead

- Targeted more than Redfish
- Best catches in 126 – 132 E (mainly due to available inshore area of the GABTF)
- At both 126 and 132 E, (bend on either end of top of Bight (where inverted U happens on shelf break)) small eddy structure, attracting bait and producing increased catch rates of deepwater flathead
- Sit near edges a bit off the bottom
- Multiple boats work same site
- Either aggregated (easy to hit) or in dispersed strips (when have to paddock plough and if miss strip don't get them)
- Come up off the bottom and uncatchable (often at night) aggressively chasing mackerel
- Catches pick up Nov/Dec as Leuwin current strengthens and brings more warm water across the Bight
- Less boat coverage so no clear distribution patterns and patchy monitoring so can lose them sometimes (moving elsewhere or just at different depths?)
- Don't see many very small fish near outer shelf (not in commercial quantities), small bit offshore
- Spawn Nov-Dec in west
- Range to Portland in the east
- No shallower than 90m – little ones out over the shelf (other flathead species go shallower)
- Anomaly in catch rates (dramatically higher) in 1995, the same year as the pilchard kill availability or recruitment spike (model assumes later, fisherman did say were all the same size so maybe cohort of 10–12 yr olds being hit but not seen either side of the period and "came on" across the Bight simultaneously)
- Saw them without pilchards too so can't be pilchards alone (though easy to find them near pilchards)
- Saw schooling up and tight marks so catch rates amazing
- 1995 was also big Gummy shark year in SA (so environmental component too?)
- Ageing suggests was pulse moving through but not that alone as peak itself can't explain it
- Worth correlating with western gemfish on the shelf as only rarely seen so may be similar driver (or targeting issues)
- Grounds don't shift much with what is available, more change targeting preference depending on whether most preferred there or not (rather than go elsewhere like in east)
- Steaming times make it patchy to keep track of trends in runs
- Harder to pick off trip sights from logbook (cf eastern practices) rather more trial and error scouting on the grounds (also want to avoid uncleared ground where lose nets)
- Will extend as far as western Vic and then around to Fremantle (with "desert" in middle off Robe inshore and no trawl grounds off Esperance where steep drop off);
- Look at Leuwin current over time and possibly salinity
- Generally better catches when westerlies blowing than with northerly or easterlies

Industry reps for focus: Semi Skoljarev, Tim Parsons

School whiting

- Sporadic, moon? March-July more fish
- Catchability probably water temperature related
- If water above 18 degrees (Nov-March), not as marketable (problem with export quality - noted not an environmental influence!)
- Weed on beach below 22 fathoms clogs the nets – hard to see on the sounder – lower catchability
- Water temperature is only critical for fish quality
- Very variable catchability (sounder says they're there and can't pick them up)
- Don't always show up on sounders and still get large catches
- Can catch them to 30 m – deeper further north (40–60 fathoms maybe distance off coast or water temperature)
- Move quickly – up to Qld border and down to Tas
- Big part of food chain (eaten by shark, flathead), when small considered baitfish effectively
- Spawned a few times by time 7", with roe by time 4" (and full of roe year round)
- No known drivers as no generalisation
- Dark on bottom, day off bottom USUALLY BUT NOT ALWAYS (so usually night time catch but not always)
- Rough sea would keep them on the bottom, but currents, forage, light, day period all involved but not clear or consistent
- Whiting leave when leatherjackets there (or eaten by them?)
- Seismic activity by oil exploration scares them off
- Recreational fishers target whiting on edge of river plumes and off beaches
- Few west of Otway? (like sandy habitat and less there)
- May be worth investigating east coast rainfall trends against catch rates – but doesn't seem to be flood related dynamic

Industry reps for focus: Peter Clarke, Wayne Cheers

Scallops

- No real drivers identified, but must be linked to good years for spat settlement in areas and food availability
- Suggested look for eddies or similar with temp charts over time
- Good on east coast Tas, Lakes and Babel and probably King Island too, as 2-3 good spawnings and settlings – Banks Strait next year
- 40–50 fathoms off Edystone Point
- Good settlement year causes unknown (maybe nutrients in water and currents and temperatures)
- Wide settlement across the entire area from Marion Bay and Triabunna which haven't been fished for decades, but also areas where fished recently
- Can move up to 2 miles a day so chase plankton fields (so always off Babel as currents coming through, but in Port Phillip Bay see more variable currents so patchier availability/catchability)
- Seem to always settle in same spots (on current channels)
- Poor years might actually be when washed off shelf and good years so just more surviving to settling and less washed off shelf?
- Have structured spat surveys now (being done by fishers)
- All over Bass Strait (growth not as good off Tamar River, may be due to freshwater inflow and waters there)
- Folk lore was if couta there scallops not
- Pilchards eat the larvae, gummy eat the adults
- Paddock fishing = almost rotational fishing as clear one little patch per year and move to new patch in next year
- Very variable growth through range, can take few years in one spot but 1-2 year in another to grow to saucer size (best = live in amongst the big sponges called "elephant turds") and if leave them asteroids may eat them out
- Age constant across the Strait, even if size varies (smaller in deeper)
- Less younger stuff coming through even though lots of adult there so don't understand why
- Cyclical boom and bust (naturally driven rather than fishing and management) -drivers unknown
- Catchability changes a lot some times day fishery, some times at night; changes with currents
- Drop lines who lose and recover weights will find few tiny ones settled in 200 fathoms

Industry reps for focus: Louis Hatzimihalis, Stuart Richey

Rock lobster

Try to identify why there appears to have been excellent puerulus settlement in 2001 (noting the SA project focused more on inshore species such as rock lobster).

- Different drivers north to south
- Stock structure change means in south they don't grow, but have higher than virgin egg production
- Early run in south
- White bodied as living deeper
- Suggestion that too many females and not enough food (but cull not politically palatable)
- In north grow quickly (even if transplanted from south)
- Redder as shallower
- Average size larger
- Temperature and food driven
- Catches last longer into the year (as far as March and April)
- Wedge tails (thinner and spindlier legs) = recruitment fishery
- Maria Island size structure different inside and outside of MPA (more big ones inside MPA)
- Centrostephanus barrens could impact on settlement (due to barren formation)
- Big puerulus settlement in 1995 and no big ones since
- When lots of salps around lobsters don't pot well and crap peurelus presence
- Barry Bruce buoy study looked at effect of current change on settlement
- 12 month cycle to get back to shelf
- Shifting south and west-east (Zeehan bringing them across from southern SA)
- Sardi does puerulus count in SA (also seem them on aquaculture infrastructure)
- Driver for success of spawning in different parts of SA unknown (could be distance from coast related)
- Old fisherman talk of 7-yr cycle
- Good catches are moon related (better catches on specific moon phase so avoid the off phase) especially in deeper water
- Mid 1980– mid 1990s didn't get fish up to 5 mile offshore, but next year (1996) got full pots of all sizes so why suddenly turn on?
- Start of good 5-6 year period
- Last year: good catch rates off Tasman Island and eastern Tas
- This year: poor there but average around rest of Tas
- Can't fish in the west in rough water, but first day of flat after rough weather have good catch rates
- Some places in east coast will only find catchable lobster in rough weather
- Some times catchability tide related, will pot on one tide only and seasonal (poor before March)
- Prey of seals, but so far doesn't seem to have dented catch rate of local population too much
- With moon up in winter catchability off Babel island is poor (so don't go there)
- In SA at least this due to predators being more active so lobsters stay home instead of coming out to hunt
- Also depth related (if too shallow and dirty they won't come out, if too deep and clear too favourable to predators so won't come out) so only a small window left where catchable

Industry reps for focus: Neil Stump

Small pelagics and Mackerel

- Species with wider ranges of depth preferences may be hardier (no matter what thermocline doing its in their range)
  - Shallower water species may be more susceptible to enviro changes (as no where else to go) so appear more variable
- Many shelf species catchable when eddy hits the shelf and brings mesopelagic fish onto shelf – need feed present to get good catch
- 1993 was stand out year for all fish species and all size classes not just recruitment
- 90% of target species caught 14-16.5 degrees
- Week before the moon and week of full moon = best for shelf fish; new moon in the depth (especially in winter)
- For all fisheries and all fish in Tas if have east or south-easterly wind (especially south-east) then don't bother go fishing (slightly better if north-east)
- Follow thermocline through year, fish seem to cue on it ("shallow water" on one side and "deep water" on other side)
  - From 80–400 fathoms
    - Thin strip physically (as such a strong drop off)
    - If thermocline deeper (upwelling driven) then shelf species dragged to shelf edge (means more accessible to trawl which is depth restricted so can't access too shallow), of shallower than deep water species sit up near break (means more accessible to shelf trawl)
  - Seen as feed layer on sounder and 5 degree change in 10 fathoms recorded by net monitor (internal waves at this depth, bounces gear around so makes fishing harder too)
- Inshore species may have one driver being freshwater rivers and freshwater pooling on surface
  - When get big river flush get dirty forage layer where flood hits the shelf and fish hit it
  - Fish need certain salinity for successful spawn so may see recruitment correlating with river run-off and rainfall (at least locally)
    - Big storms in run-up to November Snapper recruitment in Port Phillip Bay fails
- Strong ENSO years
  - King George Whiting big numbers
  - Drought on land = drought at sea (less run off of nutrients)

Patterns of recruitment in different fish stocks - Neil Klaer

- Database of environmental and recruitment patterns for use in assessment models
- Including NZ species too
- Looking for common patterns across the species rather than just within species
  - Via standardization and cross correlation
    - Residuals scaled so mean absolute value = 1 and sum of residuals = 0
    - Any matching standout years in many species
  - Once found common groups, look for environmental forcing that correlates in standout years too
    - Zonal winds stands out for Australian species, but not NZ
  - Look at mean trend across all species
    - NZ had a standout year in all species in 1993
    - Australia had big years 1993-1994; maybe a poor year in 2000 too
  - Can break it up spatially too (easier to find stronger signals and physical drivers if do that)

Atlantis modelling - Beth Fulton

- “what-if” game playing nature of the exercise anyone can propose scenarios .

Collection of environmental data by fishers and general discussion - Ian Knuckey

- Use fisherman from around south-east Australia to collect local environmental information to see what drivers are.
  - So can be incorporated into assessment (can’t be done fishery independent)
  - Done on volunteer basis across the fishery
  - Also give optional entry in logbooks so enter it if want to (electronic logbook software may be cheap and best way of doing this)
- Ensure old datasets are interigated to make most of them
- Tap older fishers from previous generations
  - Less gadget dependence more natural observation dependent
  - Interview them (and one-on-one as wouldn’t get info out of them in forum)
- Concern regarding nursery habitat acknowledged but beyond scope of this project
  - Could be a problem if is actually becoming a major driver that overwhelms others (no indication that is necessarily the case, but is a risk)
- Ken – does seem to be match between marks fisherman look for and major oceanography
  - In west = seasonal strength of Leeuwin current (time series of current strength available for correlation with catch rates)
  - Western Victoria = different current directions at different depths and interface important (and eddies generated) important (and as eddy generated flow can change quickly)
    - Have oceanography time series to play with
  - Have ENSO series to compare against
  - Tas : multiple current intersection
  - East: EAC and counter currents/upwellings behind headlands (patches of high nutrients attract food and fish)
    - Wind forcing important too (will switch off upwelling if switches from northerly to southerly) which is what fisherman see
    - Dispersion period for fishery matches spring bloom period
    - Eddy spin off = productive area
- Availability/catchability is much bigger issue than recruitment (more available information on possible availability/catchability drivers than recruitment)
  - Maybe due to information frequency, see catchability/availability day-to-day and within year but recruitment is year-to-year and maybe even only once per decade so series much shorter

General Points

- Some species like grenadier, ling, etc have a large depth range, therefore probably less susceptible to water temp changes at depth than shelf species that need to move shallower or out to shelf break/slope depending on where favoured water temperature meets the bottom.
- Temperature loggers – skippers interested in having them available to fit on nets. Project team to follow up.
- Should look at all historical info and reports –there is a wealth of information already out there, especially within CSIRO, Kapala survey
- Possible strong links to availability/catchability of a range of species and prevailing winds

- The EAC and Leuwin/Zeehan currents and related eddies and high nutrient area upwellings appear to drive many species
- Warming effect of southern ocean – what is the impact?
- Fronts are important
- Availability vs recruitment
- Older skippers and retired skippers and crew would hold a wealth of information as they fished more with environmental observations

WORKSHOP PARTICIPANTS

Day 1

Name	Interest/organisation
Peter Clarke	Danish Seine
Semi Skoljarev	GABTF owner/operator
Tim Parsons	Trawl skipper (mainly GAB)
Leigh Claydon	Dropline (Tas)
Chris Currie	Auto Longline (and Tuna)
Will Mure	Auto Longline (Tasmania)
Peter Kenny	Dropline, rocklobster (Port Lincoln SA)
Fritz Drenkhahn	SETF (Eden)
John Jarvis	SETF (Eden)
Kevin Gray	SETF (Greenwell Point)
Mark Bell	SETF (Greenwell Point)
Tom Bibby	SETF (Portland)
Tony Guarnaccia	SETF (Lakes Entrance)
Brian Daff	Shark (Lakes Entrance)
Peter Riseley	Shark (Robe SA)
Rod Casement	Shark/SETF (Lakes Entrance)
Louis Hatzimihalis	Squid/Scallop
Neil Stump	TFIC President, Rock lobster, scallop
Michael Miriklis	SETF owner, processor
Margaret Tober	SETF (Portland)
Bert Tober	SETF (Portland)
Ian Knuckey	Principle Investigator, Scientist
Scott Foster	CSIRO - statistician
Neil Klaer	CSIRO – stock assessment scientist
Jemery Day	CSIRO - stock assessment scientist
Ken Ridgway	CSIRO - oceanographer
Beth Fulton	CSIRO - ecosystem modeller
Ron Thresher	CSIRO – ecologist
Jim Dell	CSIRO - postgrad: interests in working on industry input on environmental effects on pelagic fisheries
Melissa Brown	AFMA (morning only)
Jeff Moore	Workshop coordinator

WORKSHOP PARTICIPANTS

Day 2

Name	Interest/organisation
Peter Clarke	Danish Seine
Semi Skoljarev	GABTF owner/operator
Tim Parsons	Trawl skipper (mainly GAB)
Leigh Claydon	Dropline (Tas)
Chris Currie	Auto Longline (and Tuna)
Will Mure	Auto Longline, dropline (Tasmania)
Peter Kenny	Dropline, rocklobster (Port Lincoln SA)
Fritz Drenkhahn	SETF (Eden)
John Jarvis	SETF (Eden)
Kevin Gray	SETF (Greenwell Point)
Mark Bell	SETF (Greenwell Point)
Tom Bibby	SETF (Portland)
Tony Guarnaccia	SETF (Lakes Entrance)
Brian Daff	Shark (Lakes Entrance)
Peter Riseley	Shark (Robe SA)
Rod Casement	Shark/SETF (Lakes Entrance)
Louis Hatzimihalis	Squid/Scallop
Neil Stump	Rock lobster, scallop, TFIC President
Michael Miriklis	SETF owner, processor
Margaret Tober	SETF (Portland)
Bert Tober	SETF (Portland)
Ian Knuckey	Principle Investigator, Scientist
Scott Foster	CSIRO - statistician
Neil Klaer	CSIRO - stock assessment scientist
Jemery Day	CSIRO - stock assessment scientist
Ken Ridgway	CSIRO - oceanographer
Beth Fulton	CSIRO - ecosystem modeller
Jim Dell	CSIRO - postgrad: interests in working on industry input on environmental effects on pelagic fisheries
Jeff Moore	Workshop coordinator

APPENDIX 8 QUANTIFYING THE EFFECTS OF ENVIRONMENTAL FACTORS ON CATCH RATES IN THE SOUTHERN AND EASTERN SCALEFISH AND SHARK FISHERY: 1986 TO 2006 - DATA SUMMARY AND FITS

Min Zhu and Jemery Day

This appendix provides correlation based data summaries for each fish species/gear type, mostly for analysis I performed in Chapter 0, with a range of tables and some plots giving information on the fit of the GLMM. The Spearman rank correlation, which is a rank based method for calculating correlation, is reported as it is more robust than Pearson correlation.

For each species/gear type and for each analysis, six tables are produced:

1. The first table lists the means and standard errors of predictors by zone, which give an indication of the variation of the environmental variables within and between zones.
2. The second table lists correlations of the predictors with the log scale CPUE. If correlations for a particular environmental variable with log scale CPUE are very low, this variable is unlikely to be included in the GLMM analysis. In contrast, if the correlation is high, then the variable is more likely to be included in the GLMM analysis. However, inclusion of a highly correlated environmental variable in the GLMM analysis is not guaranteed, especially if another variable highly correlated with the first has already been incorporated in the GLMM analysis.
3. The third table lists pairs of highly correlated variables, with corresponding Spearman rank correlations greater than 0.7. This table can be used to look at groups of variables where inclusion of one variable in the analysis may incorporate most of the variation encompassed in other variables. The variable incorporated is the variable that explains the most variation statistically, and if they are highly correlated, the incorporation of one variable can exclude the later incorporation of others.
4. The fourth table lists the correlation of environmental variables with average trawl depth, a variable that is included early in the GLMM analysis.
5. The fifth table lists the correlation of environmental variables with the seasonal trend from the final model. Seasonal trend is also included early in the GLMM analysis. The fourth and fifth tables can be used to highlight environmental variables that may explain some variation in catch rates, but which can be excluded due to the early inclusion of the variables trawl depth and season, which may act as effective proxies for these environmental parameters.
6. The sixth table lists the correlation of environmental variables with the long-term trend from the final model.

The parameter estimates for the periodic trend are also listed in a table, for both Analysis I and Analysis II.

In addition to these summary tables, plots of residuals from the GLMM analysis are provided showing the contribution of the fit from depth and seasonal terms, for both Analysis I and Analysis II.

Tiger flathead Danish seine

Table 48. Tiger flathead Danish seine - Summary of means and standard errors of predictors by zone. NA means there was no data available in that corresponding zone.

Variable	Stat	Zone10	Zone20	Zone30	Zone50	Zone60
Trawl_depth	mean	71.25	98.08	86.83	65.35	44.44
	sd	29.35	27.07	33.71	13.28	12.84
CARS_depth_temp	mean	15.69	13.84	14.05	14.97	14.87
	sd	1.64	0.9	0.76	0.81	1.46
CARS_depth_sal	mean	35.42	35.37	35.12	35.43	35.51
	sd	0.06	0.05	0.04	0.07	0.08
CARS_depth_DO	mean	4.82	5.29	5.35	5.39	5.42
	sd	0.28	0.33	0.22	0.16	0.3
CARS_depth_SiO2	mean	2.49	2.27	1.88	1.12	1.57
	sd	0.56	0.51	0.7	0.23	0.47
CARS_depth_PO4	mean	0.51	0.47	0.46	0.35	0.33
	sd	0.13	0.1	0.15	0.06	0.07
CARS_depth_NO3	mean	5.05	5.78	4.18	1.79	2.42
	sd	1.71	1.96	2.63	0.91	1.35
CARS_surf_temp	mean	19.17	15.67	15.65	16.57	16
	sd	2.03	2.04	0.44	1.46	2.1
CARS_surf_sal	mean	35.52	35.47	35.01	35.49	35.51
	sd	0.06	0.07	0.18	0.02	0.09
CARS_surf_DO	mean	5.28	5.66	5.65	5.55	5.65
	sd	0.22	0.18	0.08	0.14	0.16
CARS_surf_SiO2	mean	1.08	1.25	1.05	0.93	1.12
	sd	0.31	0.18	0.28	0.16	0.17
CARS_surf_PO4	mean	0.21	0.29	0.23	0.28	0.26
	sd	0.07	0.08	0.05	0.05	0.07
CARS_surf_NO3	mean	0.66	1.69	0.82	0.59	0.79
	sd	0.55	1.05	0.46	0.28	0.83
CARS_surf_Chlo	mean	0.52	0.64	0.64	0.56	0.71
	sd	0.2	0.2	0.19	0.12	0.29
SST_6day	mean	20.8	16.41	NA	16.31	16.03
	sd	1.17	2.19	NA	2.03	2.45
Temp_depth	mean	16.89	14.12	NA	14.91	14.92
	sd	1.41	0.91	NA	0.86	1.61
SeaWiFS_Chlo_A	mean	NA	0.49	NA	0.37	0.56
	sd	NA	0.43	NA	0.2	0.46
Altimetry	mean	0.01	0.02	NA	0.01	0.01
	sd	0.04	0.06	NA	0.08	0.07
SST_frontal_density	mean	0	0.93	NA	0	0.3
	sd	0	1.86	NA	0	1.04
Magnetic_Anomaly	mean	104.99	-16.82	-68.27	59.84	-9.36
	sd	82.82	91.89	35.11	81.47	64.32
MLD_synTS	mean	13.94	25.61	NA	24.77	22.73
	sd	0.87	20.71	NA	13.97	13.05
SOI	mean	-0.23	-2.62	1.56	-1.82	-2.69
	sd	13.47	11.07	4.13	11.55	10.85
NewMoon	mean	-0.03	-0.01	0.09	-0.02	0.01
	sd	0.7	0.71	0.66	0.71	0.71
SprMoon	mean	-0.01	0	-0.13	0	0
	sd	0.72	0.7	0.76	0.71	0.71

Table 49. Tiger flathead Danish seine - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.011	CARS_depth_temp	-0.013
NewMoon	-0.017	SOI	0.035
Altimetry	-0.028	Temp_depth	0.021
CARS_surf_PO4	-0.041	CARS_surf_Chlo	-0.097
SST_frontal_density	0.096	CARS_surf_SiO2	0.065
CARS_surf_NO3	0.098	MLD_synTS	-0.132
SeaWiFS_Chlo_A	-0.159	CARS_surf_temp	0.196
Magnetic_Anomaly	-0.173	CARS_surf_sal	-0.206
CARS_surf_DO	-0.204	SST_6day	0.262
CARS_depth_PO4	0.337	CARS_depth_DO	-0.345
CARS_depth_SiO2	0.446	CARS_depth_NO3	0.448
Trawl_depth	0.509	CARS_depth_sal	-0.474

Table 50. Tiger flathead Danish seine - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_NO3	0.766	CARS_depth_SiO2	CARS_depth_NO3	0.874
Trawl_depth	CARS_depth_PO4	0.749	CARS_depth_PO4	CARS_depth_NO3	0.804
Trawl_depth	CARS_depth_sal	-0.762	CARS_surf_temp	CARS_surf_DO	-0.909
CARS_depth_temp	CARS_surf_DO	-0.783	CARS_surf_temp	CARS_surf_NO3	-0.73
CARS_depth_temp	CARS_surf_NO3	-0.774	CARS_surf_temp	Temp_depth	0.721
CARS_depth_temp	CARS_surf_temp	0.792	CARS_surf_temp	SST_6day	0.907
CARS_depth_temp	Temp_depth	0.907	CARS_surf_DO	Temp_depth	-0.707
CARS_depth_sal	CARS_depth_NO3	-0.767	CARS_surf_DO	SST_6day	-0.8
CARS_depth_DO	CARS_surf_DO	0.862	CARS_surf_SiO2	CARS_surf_NO3	0.755
CARS_depth_DO	CARS_surf_temp	-0.884	CARS_surf_PO4	CARS_surf_NO3	0.766
CARS_depth_DO	SST_6day	-0.852	CARS_surf_NO3	Temp_depth	-0.714
SST_6day	Temp_depth	0.706			

Table 51. Tiger flathead Danish seine - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.009	Magnetic_Anomaly	-0.204
NewMoon	-0.01	CARS_surf_SiO2	0.253
CARS_surf_temp	-0.026	CARS_surf_sal	-0.272
SOI	0.028	CARS_depth_DO	-0.276
CARS_surf_DO	-0.031	Temp_depth	-0.319
Altimetry	0.039	CARS_depth_temp	-0.381
SST_6day	0.106	CARS_surf_NO3	0.42
MLD_synTS	0.111	CARS_depth_SiO2	0.633
CARS_surf_Chlo	-0.161	CARS_depth_PO4	0.749
CARS_surf_PO4	0.165	CARS_depth_sal	-0.762
SST_frontal_density	0.188	CARS_depth_NO3	0.766
SeaWiFS_Chlo_A	-0.191		

Table 52. Tiger flathead Danish seine - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
CARS_depth_sal	0.006	CARS_surf_SiO2	0.242
Magnetic_Anomaly	-0.03	CARS_surf_sal	-0.279
SprMoon	0.032	MLD_synTS	0.292
NewMoon	-0.034	CARS_surf_PO4	0.387
SeaWiFS_Chlo_A	-0.053	CARS_surf_Chlo	-0.395
CARS_depth_NO3	0.063	CARS_surf_NO3	0.506
SOI	0.078	Temp_depth	-0.598
SST_frontal_density	0.079	SST_6day	-0.621
Trawl_depth	0.085	CARS_depth_temp	-0.639
Altimetry	-0.121	CARS_surf_temp	-0.674
CARS_depth_SiO2	-0.219	CARS_surf_DO	0.676
CARS_depth_PO4	0.226	CARS_depth_DO	0.686

Table 53. Tiger flathead Danish seine - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
CARS_depth_NO3	0.001	CARS_depth_PO4	-0.021
CARS_surf_SiO2	-0.004	CARS_depth_DO	-0.021
NewMoon	0.005	CARS_surf_Chlo	-0.024
CARS_surf_sal	-0.006	SprMoon	0.027
CARS_depth_SiO2	-0.006	CARS_surf_temp	0.028
Trawl_depth	-0.012	SeaWiFS_Chlo_A	0.029
CARS_surf_PO4	0.015	CARS_depth_temp	0.03
Temp_depth	0.016	CARS_surf_DO	-0.033
Magnetic_Anomaly	0.019	Altimetry	0.038
CARS_surf_NO3	-0.019	SOI	0.061
CARS_depth_sal	-0.019	MLD_synTS	0.062
SST_6day	0.021	SST_frontal_density	0.075

Analysis I Tiger flathead Danish seine

Table 54. Tiger flathead Danish seine - Parameter estimates for periodic trend (1986 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.03	0.009	0.001
sin(2πt)	-0.151	0.01	0
cos(4πt)	0.092	0.005	0
sin(4πt)	-0.002	0.005	0.74
cos(6πt)	-0.014	0.004	0.002
sin(6πt)	0.017	0.004	0
cos(8πt)	-0.008	0.004	0.078
sin(8πt)	-0.034	0.004	0
	Smooth Terms	DF	
	ns(eTime)	16	0
	Ns(Trawl_depth)	9	0
Variance Explained = 40.54%			

Figure 92 shows the basic model fitting checks. Figure 93 shows the modelled seasonal effects and Figure 94 plots the partial contribution of the trawl depth to log-scale CPUE.

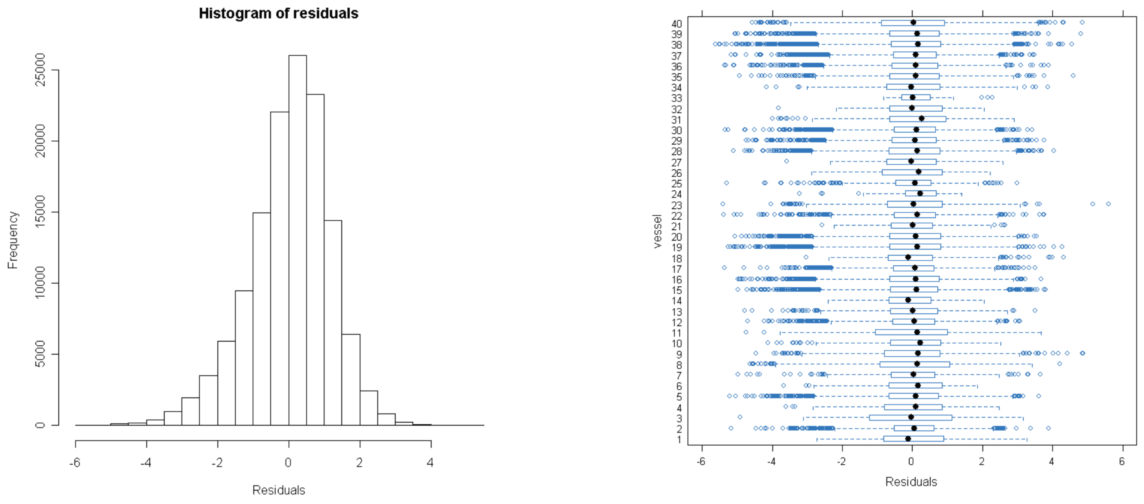


Figure 92. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

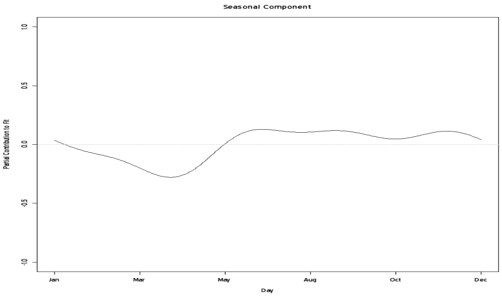


Figure 93. Plot showing the contribution of the seasonal trend to the model fit to log-scaled CPUE, with January on the left and December on the right, suggesting that catch rates are lowest seasonally in April.

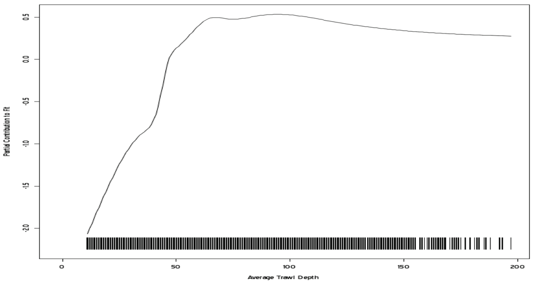


Figure 94. Plot showing the partial contribution of average trawl depth to the model fit to log-scale CPUE.

Analysis II Tiger flathead Danish seine

Table 55. Tiger flathead Danish seine - Parameter estimates for periodic trend (1997 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.291	0.016	0
sin(2πt)	0.390	0.021	0
cos(4πt)	0.232	0.008	0
sin(4πt)	-0.166	0.01	0
cos(6πt)	-0.014	0.006	0.294
sin(6πt)	0.016	0.006	0.007
cos(8πt)	-0.017	0.006	0.009
sin(8πt)	-0.021	0.006	0
	Smooth Terms	DF	
	ns(eTime)	9	0
	ns(Trawl_depth)	5	0
Variance Explained = 28.01%			

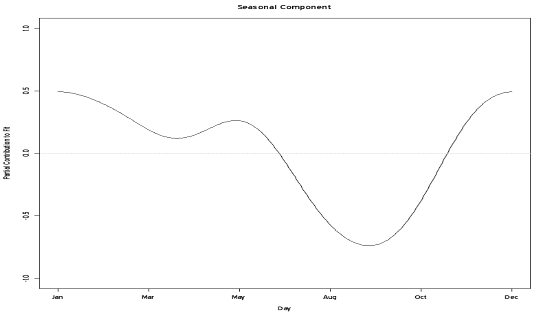


Figure 95. Plot showing the contribution of the seasonal trend to the model fit to log-scale CPUE suggesting that catch rates are lowest seasonally in September.

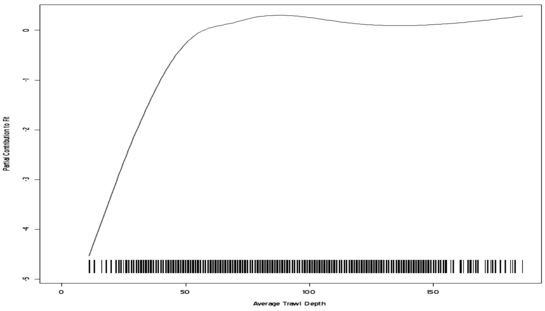


Figure 96. Plot showing the partial contribution of average trawl depth to the model fit to log-scale CPUE.

Flathead otter trawl

Table 56. Flathead otter trawl - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone10	Zone20	Zone30	Zone40	Zone50	Zone60
Trawl_depth	mean	100.79	121	118.68	163.35	212.42	46.01
	sd	51.14	38.03	22.54	34.81	83	15.8
CARS_depth_temp	mean	14.93	13.83	13	11.97	12.99	14.76
	sd	1.54	0.96	0.79	0.91	1.19	1.5
CARS_depth_sal	mean	35.39	35.36	35.15	35.07	35.29	35.52
	sd	0.08	0.06	0.07	0.1	0.17	0.08
CARS_depth_DO	mean	4.9	5.22	5.33	5.76	5.53	5.46
	sd	0.34	0.33	0.29	0.2	0.11	0.29
CARS_depth_SiO2	mean	2.7	2.38	2.51	1.89	1.44	1.55
	sd	0.65	0.48	0.51	0.66	0.73	0.49
CARS_depth_PO4	mean	0.56	0.53	0.6	0.59	0.55	0.33
	sd	0.14	0.11	0.1	0.12	0.19	0.08
CARS_depth_NO3	mean	5.52	6.05	6.16	7	5.91	2.4
	sd	2.27	2.04	1.8	2.48	3.52	1.51
CARS_surf_temp	mean	18.25	16.13	15.19	13.66	15.02	15.7
	sd	2.3	2.09	1.57	1.17	1.26	2.12
CARS_surf_sal	mean	35.53	35.48	35.15	34.93	35.45	35.51
	sd	0.06	0.06	0.14	0.25	0.08	0.08
CARS_surf_DO	mean	5.36	5.6	5.7	5.97	5.74	5.66
	sd	0.23	0.23	0.2	0.23	0.2	0.16
CARS_surf_SiO2	mean	1.18	1.26	1.09	1.17	0.77	1.12
	sd	0.34	0.23	0.4	0.46	0.17	0.18
CARS_surf_PO4	mean	0.24	0.28	0.26	0.32	0.2	0.26
	sd	0.07	0.08	0.11	0.1	0.05	0.07
CARS_surf_NO3	mean	0.93	1.4	1.13	1.68	0.64	0.94
	sd	0.66	0.91	1.02	0.98	0.29	0.9
CARS_surf_Chlo	mean	0.56	0.66	0.54	0.62	0.4	0.67
	sd	0.24	0.24	0.15	0.21	0.1	0.26
SST_6day	mean	18.77	16.55	15.7	13.88	15.2	15.82
	sd	2.52	2.12	2.1	1.26	1.63	2.42
Temp_depth	mean	15.43	14.07	13.28	11.88	13	14.98
	sd	1.83	1.03	0.99	0.99	1.39	1.66
SeaWiFS_Chlo_A	mean	0.5	0.51	0.41	0.61	0.29	0.52
	sd	0.75	0.47	0.22	0.58	0.13	0.48
Altimetry	mean	0.03	0.03	0.01	0	0.01	0.01
	sd	0.08	0.06	0.05	0.05	0.06	0.08
SST_frontal_density	mean	0.62	0.92	0.15	0.1	0.48	0.3
	sd	1.35	1.79	0.49	0.35	1.24	1.11
Magnetic_Anomaly	mean	97.24	58.71	-11.61	21.66	53.72	-16.77
	sd	119.53	95.63	68.09	92.63	82.02	56.7
MLD_synTS	mean	18.58	25.19	26.5	31	30.64	23.86
	sd	8.86	18.85	11.71	27.68	16.97	15.14
SOI	mean	-2.09	-2.54	-1.68	-2.46	-3.16	-2.22
	sd	10.49	10.46	10.83	8.26	10.86	11.34
NewMoon	mean	-0.01	-0.03	-0.03	0	0	-0.02
	sd	0.71	0.71	0.7	0.71	0.7	0.7
SprMoon	mean	0	0	0	0	-0.02	-0.01
	sd	0.7	0.71	0.71	0.71	0.7	0.7

Table 57. Flathead otter trawl - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.001	NewMoon	-0.008
Temp_depth	0.009	CARS_surf_Chlo	-0.011
CARS_depth_temp	-0.012	SOI	0.012
SeaWiFS_Chlo_A	0.012	SeaWiFS_Turbidity	0.014
Trawl_depth	-0.018	CARS_depth_SiO2	-0.024
CARS_depth_NO3	-0.027	CARS_depth_PO4	-0.027
Altimetry	0.03	CARS_surf_NO3	0.028
SST_3day	-0.04	SST_frontal_density	0.034
CARS_surf_SiO2	0.053	SST_6day	-0.04
CARS_surf_sal	-0.056	CARS_depth_DO	0.054
CARS_depth_sal	-0.058	CARS_surf_temp	-0.058
CARS_surf_PO4	0.06	CARS_surf_DO	0.063
MLD_synTS	0.065	Magnetic_Anomaly	-0.111

Table 58. Flathead trawl - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_NO3	0.702
CARS_depth_temp	CARS_surf_DO	-0.735
CARS_depth_temp	Temp_depth	0.88
CARS_depth_DO	CARS_surf_DO	0.905
CARS_depth_DO	CARS_surf_temp	-0.924
CARS_depth_DO	SST_6day	-0.856
CARS_depth_SiO2	CARS_depth_PO4	0.762
CARS_depth_PO4	CARS_depth_NO3	0.818
CARS_surf_temp	CARS_surf_DO	-0.927
CARS_surf_temp	SST_6day	0.904
CARS_surf_temp	CARS_surf_NO3	-0.746
CARS_surf_temp	CARS_surf_PO4	-0.76
CARS_surf_DO	SST_6day	-0.839
CARS_surf_SiO2	CARS_surf_NO3	0.712
CARS_surf_PO4	CARS_surf_NO3	0.83

Table 59. Flathead trawl - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
SprMoon	0	CARS_surf_Chlo	-0.108
SOI	0.004	CARS_surf_temp	-0.142
CARS_surf_SiO2	-0.005	CARS_surf_NO3	0.154
Magnetic_Anomaly	0.017	SeaWiFS_Chlo_A	-0.179
NewMoon	-0.024	MLD_synTS	0.286
CARS_depth_DO	-0.024	CARS_depth_SiO2	0.306
Altimetry	-0.027	CARS_depth_temp	-0.461
CARS_surf_sal	0.033	Temp_depth	-0.519
SST_frontal_density	0.043	CARS_depth_sal	-0.533
CARS_surf_PO4	0.076	CARS_depth_PO4	0.58
CARS_surf_DO	0.092	CARS_depth_NO3	0.702
SST_6day	-0.097		

Table 60. Flathead otter trawl - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.004	CARS_depth_temp	0.206
NewMoon	0.008	CARS_depth_PO4	0.23
SST_frontal_density	-0.028	CARS_depth_sal	-0.331
CARS_surf_sal	-0.098	CARS_surf_Chlo	-0.433
Temp_depth	0.099	CARS_surf_DO	-0.445
Altimetry	-0.102	MLD_synTS	-0.494
Magnetic_Anomaly	-0.102	CARS_depth_DO	-0.514
Trawl_depth	-0.11	SST_6day	0.594
SOI	0.111	CARS_surf_temp	0.659
SeaWiFS_Chlo_A	-0.124	CARS_surf_SiO2	-0.68
CARS_depth_NO3	0.161	CARS_surf_PO4	-0.722
CARS_depth_SiO2	0.176	CARS_surf_NO3	-0.84

Table 61. Flathead otter trawl - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
Trawl_depth	-0.001	CARS_depth_PO4	0.022
NewMoon	-0.002	CARS_surf_sal	0.025
CARS_depth_temp	0.003	CARS_surf_DO	-0.028
CARS_surf_SiO2	0.003	CARS_surf_temp	0.032
CARS_depth_sal	0.004	CARS_depth_SiO2	0.038
CARS_surf_PO4	-0.011	SOI	-0.04
SprMoon	0.012	CARS_depth_DO	-0.041
CARS_surf_Chlo	-0.013	SST_frontal_density	0.053
SeaWiFS_Chlo_A	0.015	MLD_synTS	-0.067
CARS_depth_NO3	0.015	SST_6day	0.09
CARS_surf_NO3	-0.017	Temp_depth	0.12
Magnetic_Anomaly	0.021	Altimetry	0.231

Analysis I Tiger flathead otter trawl

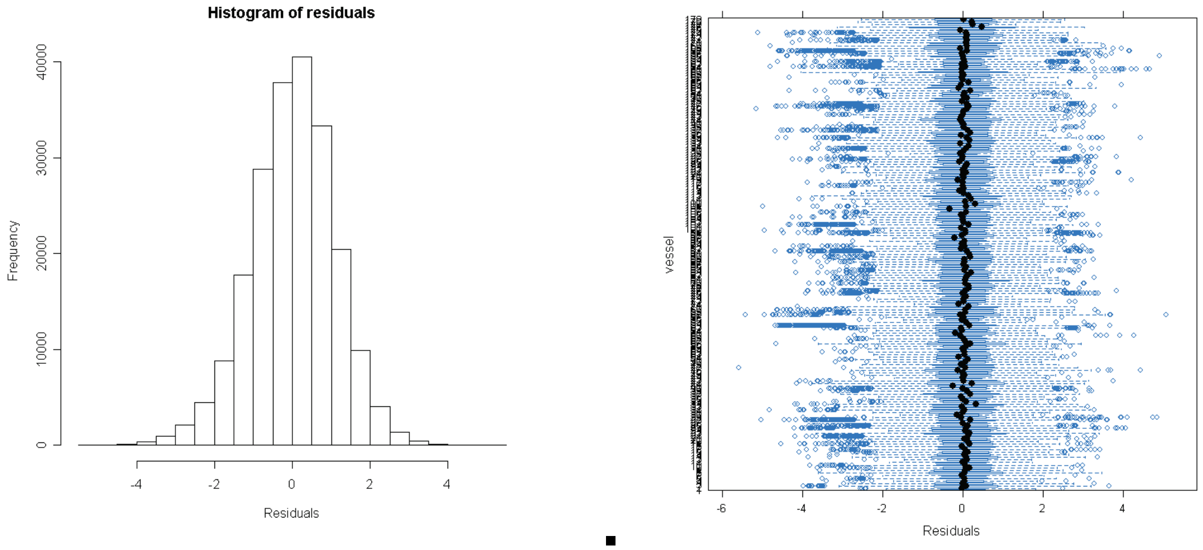
Table 62. Flathead otter trawl - Parameter estimates for periodic trend (1986 – 2006)

■

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.401	0.012	0
sin(2πt)	0.187	0.013	0
cos(4πt)	0.069	0.004	0
sin(4πt)	0.023	0.004	0
cos(6πt)	0.027	0.003	0
sin(6πt)	0.015	0.003	0
cos(8πt)	0.005	0.003	0.152
sin(8πt)	-0.005	0.003	0.126
	Smooth Terms	DF	
	ns(eTime)	16	0
	ns(Trawl_depth)	6	0
Variance Explained = 21.56%			

■

Figure 97 shows the basic model fitting checks. Figure 98 shows the modelled seasonal effects and Figure 99 plots the partial contribution of the trawl depth to log-scale CPUE.



■ ■

Figure 97. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

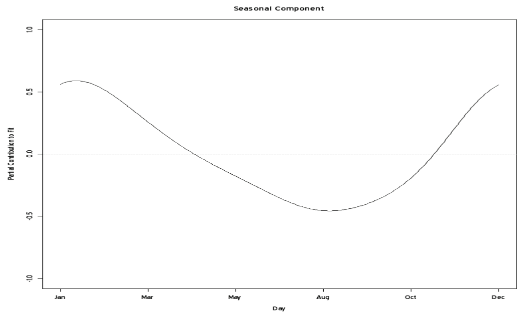


Figure 98. Plot showing the contribution of the seasonal trend to the log-scale CPUE suggesting that catch rates are lowest seasonally in August.

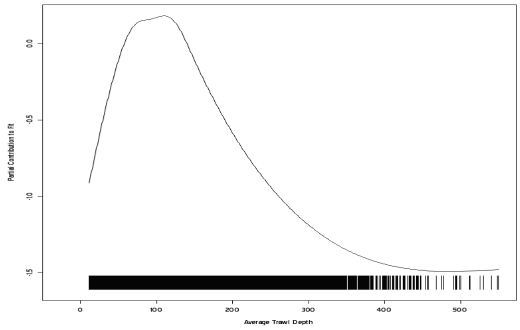


Figure 99. Plot showing the partial contribution of average trawl depth to the model fit to log-scale CPUE.

Analysis II Tiger flathead otter trawl

Table 63. Flathead otter trawl - Parameter estimates for periodic trend (1997 – 2006).

■

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.333	0.017	0
sin(2πt)	0.446	0.02	0
cos(4πt)	0.054	0.007	0
sin(4πt)	-0.041	0.007	0
cos(6πt)	0.038	0.006	0
sin(6πt)	0	0.006	0.963
cos(8πt)	0	0.006	0.939
sin(8πt)	-0.005	0.006	0.428
	Smooth Terms	DF	
	ns(eTime)	8	0
	ns(Trawl_depth)	4	0
Variance Explained = 29.42%			

■

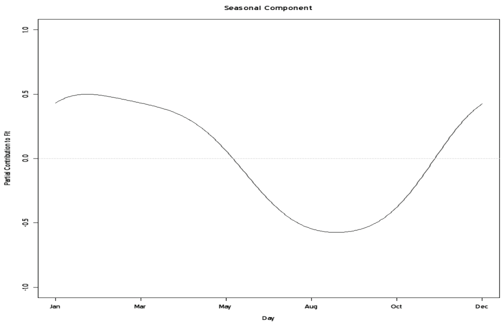


Figure 100. Plot showing the contribution of the seasonal trend to the model fit to CPUE suggesting that catch rates are lowest seasonally in September.

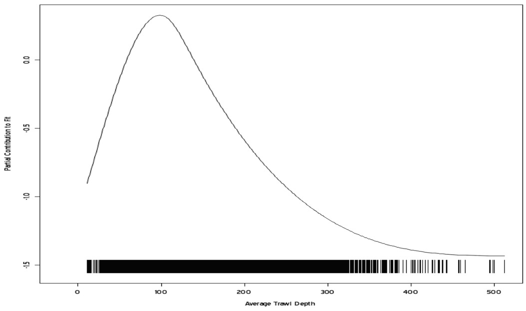


Figure 101. Plot showing the partial contribution of average trawl depth to the model fit to log-scale CPUE.

Blue grenadier spawning

Table 64. Blue grenadier spawning - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone40	Variable	Stat	Zone40
Trawl_depth	mean	475.24	CARS_surf_NO3	mean	1.81
	sd	158.73		sd	0.48
CARS_depth_temp	mean	9.72	CARS_surf_Chlo	mean	0.3
	sd	1.58		sd	0.05
CARS_depth_sal	mean	34.76	SST_6day	mean	13.58
	sd	0.2		sd	0.89
CARS_depth_DO	mean	5.49	Temp_depth	mean	9.79
	sd	0.29		sd	1.57
CARS_depth_SiO2	mean	5.41	SeaWiFS_Chlo_A	mean	0.2
	sd	5.46		sd	0.07
CARS_depth_PO4	mean	1.05	Altimetry	mean	0.06
	sd	0.32		sd	0.05
CARS_depth_NO3	mean	15.04	SST_frontal_density	mean	0.1
	sd	5.55		sd	0.35
CARS_surf_temp	mean	13.68	Magnetic_Anomaly	mean	51.62
	sd	0.65		sd	88
CARS_surf_sal	mean	35.18	MLD_synTS	mean	58.05
	sd	0.16		sd	31.79
CARS_surf_DO	mean	5.68	SOI	mean	-3.66
	sd	0.08		sd	8.67
CARS_surf_SiO2	mean	1.08	NewMoon	mean	0.02
	sd	0.16		sd	0.71
CARS_surf_PO4	mean	0.33	SprMoon	mean	0
	sd	0.06		sd	0.7

Table 65. Blue grenadier spawning - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SOI	0.001	eTime	0.004
CARS_surf_DO	-0.008	NewMoon	0.012
Altimetry	0.014	SST_frontal_density	-0.017
SprMoon	0.02	Magnetic_Anomaly	0.025
SST_3day	0.035	CARS_surf_PO4	-0.038
SST_6day	0.045	CARS_surf_temp	-0.061
SeaWiFS_Chlo_A	-0.067	CARS_surf_Chlo	-0.072
CARS_surf_NO3	0.081	SeaWiFS_Turbidity	-0.095
MLD_synTS	-0.137	CARS_surf_SiO2	0.224
CARS_surf_sal	-0.322	CARS_depth_DO	0.384
CARS_depth_PO4	-0.431	CARS_depth_SiO2	-0.441
CARS_depth_NO3	-0.459	Trawl_depth	-0.462
Temp_depth	0.486	CARS_depth_sal	0.492
CARS_depth_temp	0.499		

Table 66. Blue grenadier spawning - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_DO	-0.712	CARS_depth_DO	CARS_depth_NO3	-0.709
Trawl_depth	CARS_depth_NO3	0.988	CARS_depth_DO	CARS_depth_PO4	-0.707
Trawl_depth	CARS_depth_PO4	0.954	CARS_depth_DO	CARS_depth_SiO2	-0.708
Trawl_depth	CARS_depth_sal	-0.985	CARS_depth_SiO2	CARS_depth_NO3	0.983
Trawl_depth	CARS_depth_SiO2	0.962	CARS_depth_SiO2	CARS_depth_PO4	0.976
Trawl_depth	CARS_depth_temp	-0.983	CARS_depth_SiO2	Temp_depth	-0.901
Trawl_depth	Temp_depth	-0.935	CARS_depth_PO4	CARS_depth_NO3	0.971
CARS_depth_temp	CARS_depth_DO	0.701	CARS_depth_PO4	Temp_depth	-0.892
CARS_depth_temp	CARS_depth_NO3	-0.975	CARS_depth_NO3	Temp_depth	-0.93
CARS_depth_temp	CARS_depth_PO4	-0.929	CARS_surf_temp	CARS_surf_DO	-0.877
CARS_depth_temp	CARS_depth_sal	0.998	CARS_surf_temp	CARS_surf_NO3	-0.958
CARS_depth_temp	CARS_depth_SiO2	-0.94	CARS_surf_temp	CARS_surf_PO4	-0.858
CARS_depth_temp	Temp_depth	0.948	CARS_surf_sal	CARS_surf_SiO2	-0.828
CARS_depth_sal	CARS_depth_DO	0.702	CARS_surf_DO	CARS_surf_NO3	0.799
CARS_depth_sal	CARS_depth_NO3	-0.977	CARS_surf_DO	CARS_surf_PO4	0.736
CARS_depth_sal	CARS_depth_PO4	-0.932	CARS_surf_PO4	CARS_surf_NO3	0.815
CARS_depth_sal	CARS_depth_SiO2	-0.941	CARS_depth_sal	Temp_depth	0.948

Table 67. Blue grenadier spawning - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
Magnetic_Anomaly	0.001	CARS_surf_NO3	-0.169
SprMoon	-0.012	CARS_surf_temp	0.186
NewMoon	0.015	CARS_surf_sal	0.255
SST_frontal_density	-0.036	CARS_surf_SiO2	-0.262
SST_6day	0.036	CARS_depth_DO	-0.712
SeaWiFS_Chlo_A	0.062	Temp_depth	-0.935
SOI	0.081	CARS_depth_PO4	0.954
Altimetry	0.113	CARS_depth_SiO2	0.962
CARS_surf_Chlo	-0.114	CARS_depth_temp	-0.983
CARS_surf_PO4	-0.115	CARS_depth_sal	-0.985
CARS_surf_DO	-0.117	CARS_depth_NO3	0.988
MLD_synTS	0.165		

Analysis I Blue grenadier spawning

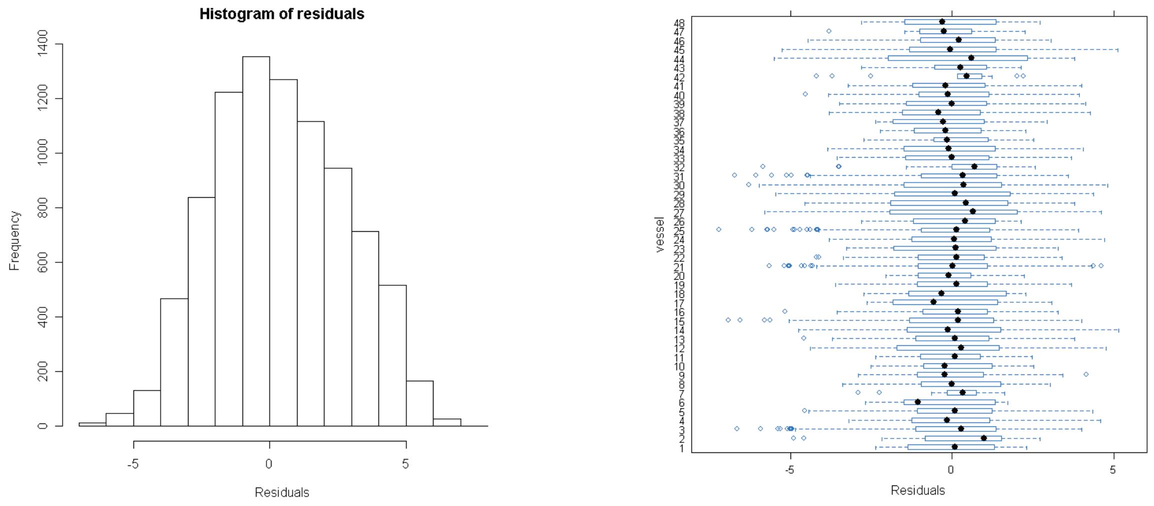


Figure 102. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable**.**

Figure 102 shows the basic model fitting checks. Figure 103 plots the partial contribution of the trawl depth to log-scale CPUE.

Table 68. Blue grenadier spawning - Parameter estimates (1986 – 2006).

Parametric Term	Estimate	SE	p-value
(Intercept)	-233.716	33.399	0
MONTH7	0.355	0.07	0
MONTH8	-0.06	0.095	0.525
DAY_NIGHTM	-1.091	0.06	0
DAY_NIGHTN	-0.177	0.081	0.028
DAY_NIGHTU	-0.016	0.291	0.957
CARS_depth_sal	9.172	0.9	0
CARS_surf_sal	-2.388	0.233	0
CARS_surf_SiO2	-2.273	0.264	0
CARS_surf_NO3	0.486	0.092	0
	Smooth Terms	DF	
	ns(Trawl_depth)	3	0

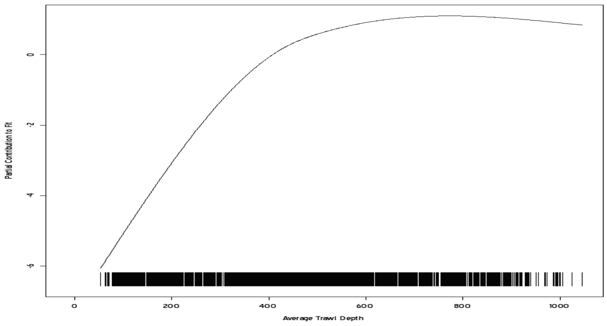


Figure 103. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Analysis II Blue grenadier spawning

Table 69. Blue grenadier spawning - Parameter estimates (1998 – 2006).

Parametric Term	Estimate	SE	p-value
(Intercept)	-432.313	53.584	0
MONTH7	0.454	0.105	0
MONTH8	0.375	0.147	0.002
DAY_NIGHTM	-0.936	0.079	0
DAY_NIGHTN	-0.316	0.104	0.002
DAY_NIGHTU	-0.535	0.887	0.547
Temp_depth	-0.275	0.071	0
CARS_depth_sal	14.592	1.425	0
SOI	0.022	0.007	0.003
CARS_surf_SiO2	-3.033	0.395	0
CARS_surf_NO3	0.619	0.134	0
CARS_depth_PO4	1.872	0.551	0.001
CARS_surf_sal	-2.116	0.347	0
	Smooth Terms	DF	
	ns(Trawl_depth)	2	0

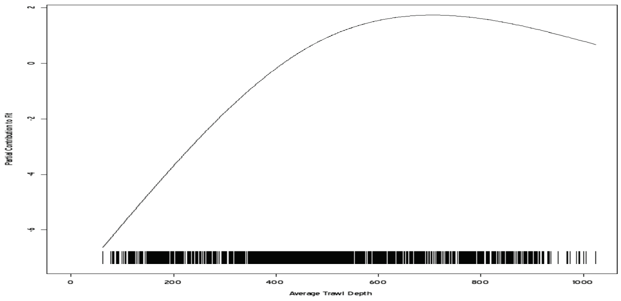


Figure 104. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Blue grenadier non-spawning

Table 70. Blue grenadier non-spawning - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone10	Zone20	Zone30	Zone40	Zone50	Zone60
Trawl_depth	mean	310.77	322.44	251.41	496.97	408.95	100.86
	sd	128.55	135.77	138.47	157.89	133.51	79.88
CARS_depth_temp	mean	12.03	11.6	11.49	8.93	10.27	13.8
	sd	1.74	1.7	1.58	1.34	1.55	1.21
CARS_depth_sal	mean	35.11	35.07	35	34.66	34.86	35.4
	sd	0.22	0.22	0.19	0.15	0.23	0.14
CARS_depth_DO	mean	4.81	4.95	5.18	5.49	5.47	5.36
	sd	0.19	0.25	0.28	0.35	0.17	0.28
CARS_depth_SiO2	mean	4.77	4.62	4.52	7.41	4.01	2.04
	sd	2.12	3.3	3.16	6.38	3.36	1.14
CARS_depth_PO4	mean	0.93	0.94	0.88	1.22	0.97	0.45
	sd	0.26	0.3	0.28	0.32	0.29	0.19
CARS_depth_NO3	mean	11.48	12.81	10.9	17.6	13.55	4.58
	sd	4.13	4.84	4.53	4.94	4.96	3.37
CARS_surf_temp	mean	17.38	16.24	15.6	14.7	15.81	15.23
	sd	1.61	1.97	1.39	1.58	1.41	1.77
CARS_surf_sal	mean	35.56	35.49	35.23	35.02	35.43	35.48
	sd	0.03	0.06	0.14	0.21	0.09	0.09
CARS_surf_DO	mean	5.39	5.55	5.67	5.82	5.62	5.67
	sd	0.17	0.22	0.2	0.21	0.22	0.17
CARS_surf_SiO2	mean	1.32	1.23	0.96	1.14	0.69	1.18
	sd	0.4	0.25	0.35	0.26	0.16	0.19
CARS_surf_PO4	mean	0.28	0.28	0.25	0.25	0.19	0.29
	sd	0.07	0.07	0.09	0.1	0.05	0.06
CARS_surf_NO3	mean	1.21	1.5	1.08	0.97	0.51	1.41
	sd	0.69	0.92	0.94	0.8	0.36	0.93
CARS_surf_Chlo	mean	0.51	0.54	0.52	0.48	0.33	0.54
	sd	0.16	0.19	0.12	0.1	0.08	0.17
SST_6day	mean	18.13	16.97	16.18	14.73	15.88	15.44
	sd	1.78	2.01	2.02	1.64	1.5	1.75
Temp_depth	mean	11.84	11.54	11.59	8.83	10.24	13.86
	sd	1.83	1.85	1.78	1.39	1.62	1.31
SeaWiFS_Chlo_A	mean	0.37	0.39	0.39	0.4	0.23	0.39
	sd	0.23	0.37	0.18	0.25	0.09	0.32
Altimetry	mean	0.01	0.03	0.01	-0.01	0.01	0.03
	sd	0.07	0.06	0.05	0.05	0.06	0.06
SST_frontal_density	mean	0.71	0.76	0.23	0.11	0.53	0.53
	sd	1.47	1.49	0.65	0.45	1.35	1.58
Magnetic_Anomaly	mean	106.61	38.76	45.17	47.4	58.35	-39.4
	sd	103.95	77.24	74.42	101.98	99.62	60.02
MLD_synTS	mean	23.25	24.59	28.17	27.78	28.1	33.92
	sd	11.25	16.69	14.2	19.79	14.08	23.66
SOI	mean	-1.21	-1.86	-1.33	-0.83	-2.4	-3.16
	sd	11.08	10.71	10.78	10.56	10.93	9.52
NewMoon	mean	-0.05	-0.01	0.02	0	0	-0.23
	sd	0.71	0.7	0.7	0.7	0.7	0.71
SprMoon	mean	0	-0.02	-0.02	-0.01	-0.03	0.12
	sd	0.71	0.71	0.71	0.71	0.7	0.73

Table 71. Blue grenadier non-spawning - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.005	Altimetry	0.007
SOI	-0.007	CARS_depth_SiO2	-0.008
SST_6day	-0.01	SST_3day	-0.016
CARS_surf_DO	-0.019	NewMoon	0.022
CARS_depth_PO4	0.03	Magnetic_Anomaly	-0.033
CARS_depth_NO3	0.038	Trawl_depth	0.042
CARS_surf_temp	0.042	SST_frontal_density	-0.048
MLD_synTS	0.054	Temp_depth	-0.063
CARS_depth_temp	-0.09	CARS_depth_sal	-0.096
CARS_surf_sal	-0.128	SeaWiFS_Turbidity	-0.139
CARS_surf_Chlo	-0.14	SeaWiFS_Chlo_A	-0.14
CARS_surf_PO4	-0.166	CARS_surf_NO3	-0.175
eTime	-0.19	CARS_surf_SiO2	-0.205
CARS_depth_DO	0.24		

Table 72. Blue grenadier non-spawning - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_NO3	0.956	CARS_depth_sal	CARS_depth_SiO2	-0.81
Trawl_depth	CARS_depth_PO4	0.916	CARS_depth_sal	Temp_depth	0.971
Trawl_depth	CARS_depth_sal	-0.942	CARS_depth_SiO2	CARS_depth_NO3	0.898
Trawl_depth	CARS_depth_SiO2	0.812	CARS_depth_SiO2	CARS_depth_PO4	0.941
Trawl_depth	CARS_depth_temp	-0.958	CARS_depth_SiO2	Temp_depth	-0.817
Trawl_depth	Temp_depth	-0.933	CARS_depth_PO4	CARS_depth_NO3	0.971
CARS_depth_temp	CARS_depth_NO3	-0.95	CARS_depth_PO4	Temp_depth	-0.914
CARS_depth_temp	CARS_depth_PO4	-0.917	CARS_depth_NO3	Temp_depth	-0.937
CARS_depth_temp	CARS_depth_sal	0.993	CARS_surf_temp	CARS_surf_DO	-0.822
CARS_depth_temp	CARS_depth_SiO2	-0.814	CARS_surf_temp	SST_6day	0.855
CARS_depth_temp	Temp_depth	0.977	CARS_surf_DO	SST_6day	-0.706
CARS_depth_sal	CARS_depth_NO3	-0.941	CARS_surf_PO4	CARS_surf_NO3	0.768
CARS_depth_sal	CARS_depth_PO4	-0.909			

Table 73. Blue grenadier non-spawning - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
SprMoon	0	SST_6day	-0.15
SOI	-0.001	CARS_surf_PO4	-0.153
NewMoon	-0.004	CARS_surf_NO3	-0.176
MLD_synTS	-0.026	CARS_surf_sal	-0.226
CARS_depth_DO	0.045	CARS_surf_Chlo	-0.262
CARS_surf_temp	-0.057	CARS_depth_SiO2	0.812
Magnetic_Anomaly	0.066	CARS_depth_PO4	0.916
SST_frontal_density	-0.091	Temp_depth	-0.933
Altimetry	-0.091	CARS_depth_sal	-0.942
CARS_surf_SiO2	-0.113	CARS_depth_NO3	0.956
CARS_surf_DO	0.118	CARS_depth_temp	-0.958
SeaWiFS_Chlo_A	-0.146		

Table 74. Blue grenadier non-spawning - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
NewMoon	0.006	CARS_depth_PO4	0.207
SprMoon	0.008	CARS_surf_sal	-0.208
CARS_depth_DO	-0.013	SeaWiFS_Chlo_A	-0.222
SOI	0.023	CARS_depth_SiO2	0.223
Magnetic_Anomaly	-0.026	MLD_synTS	-0.253
SST_frontal_density	-0.029	CARS_surf_SiO2	-0.384
Trawl_depth	0.032	CARS_surf_DO	-0.397
Altimetry	-0.055	CARS_surf_PO4	-0.418
CARS_depth_NO3	0.147	CARS_surf_Chlo	-0.434
Temp_depth	-0.157	SST_6day	0.582
CARS_depth_temp	-0.165	CARS_surf_NO3	-0.621
CARS_depth_sal	-0.202	CARS_surf_temp	0.646

Table 75. Blue grenadier non-spawning - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.006	CARS_surf_PO4	0.069
NewMoon	0.007	Temp_depth	0.069
SST_6day	0.009	CARS_depth_DO	-0.075
Magnetic_Anomaly	0.021	CARS_surf_temp	0.078
CARS_surf_Chlo	0.035	CARS_surf_SiO2	0.079
CARS_depth_SiO2	-0.047	CARS_depth_PO4	-0.081
MLD_synTS	0.047	CARS_depth_NO3	-0.097
SOI	0.048	Trawl_depth	-0.101
SST_frontal_density	0.049	CARS_surf_DO	-0.104
SeaWiFS_Chlo_A	0.063	CARS_depth_temp	0.129
Altimetry	0.063	CARS_depth_sal	0.135
CARS_surf_NO3	0.068	CARS_surf_sal	0.147

Analysis I Blue grenadier non-spawning

Table 76. Blue grenadier non-spawning - Parameter estimates for periodic trend (1986 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.196	0.009	0
sin(2πt)	0.403	0.009	0
cos(4πt)	0.213	0.007	0
sin(4πt)	-0.044	0.006	0
cos(6πt)	-0.039	0.006	0
sin(6πt)	0.018	0.006	0.004
cos(8πt)	-0.002	0.006	0.776
sin(8πt)	-0.012	0.006	0.044
	Smooth Terms	DF	
	ns(eTime)	9	0
	ns(Trawl_depth)	6	0
Variance Explained = 35.62%		n= 102696	

Figure 105 shows the basic model fitting checks. Figure 106 shows the modelled seasonal effects and Figure 107 plots the partial contribution of the trawl depth to log-scale CPUE.

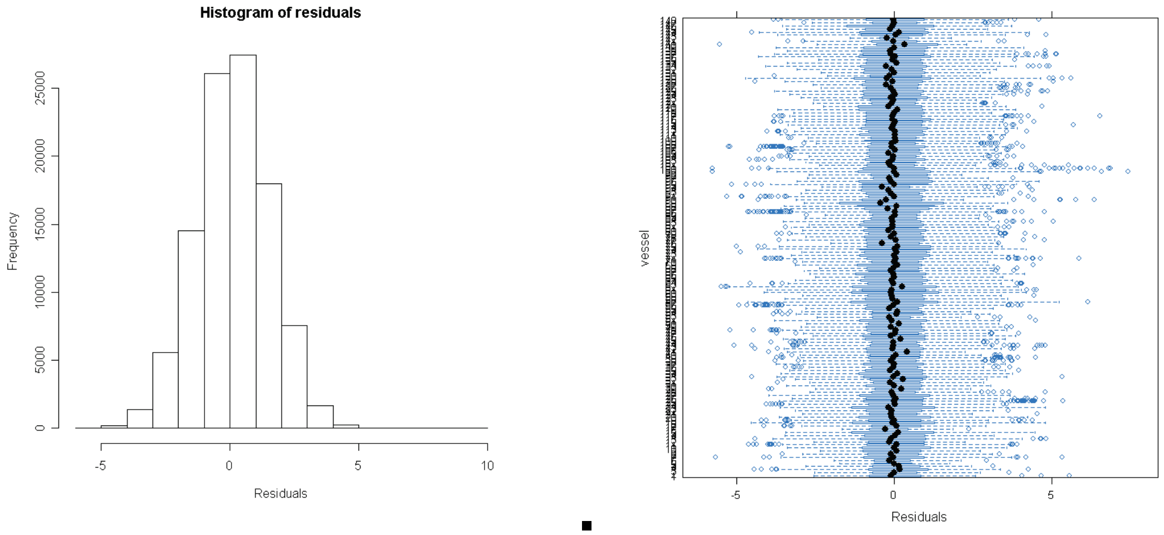


Figure 105. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

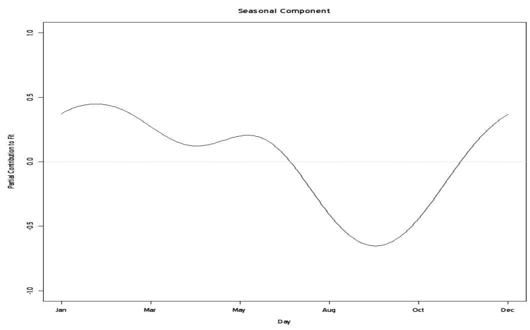


Figure 106. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in September.

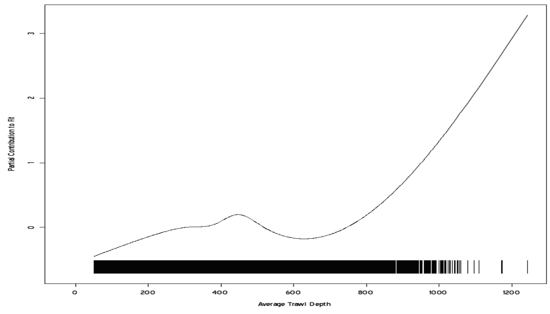


Figure 107. Plot showing the partial contribution of average trawl depth to the model fit to log-scale CPUE.

Analysis II Blue grenadier non-spawning

Table 77. Blue grenadier non-spawning - Parameter estimates for periodic trend (1997 – 2006).

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Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.251	0.015	0
sin(2πt)	0.343	0.016	0
cos(4πt)	0.134	0.009	0
sin(4πt)	-0.034	0.009	0
cos(6πt)	-0.035	0.009	0
sin(6πt)	0.002	0.008	0.853
cos(8πt)	-0.027	0.008	0.002
sin(8πt)	-0.019	0.008	0.02
	Smooth Terms	DF	
	ns(eTime)	5	0
	ns(Trawl_depth)	5	0
Variance Explained = 35.58%			

▪

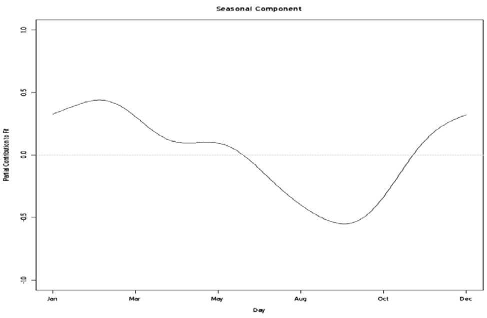

Figure 108. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in September.

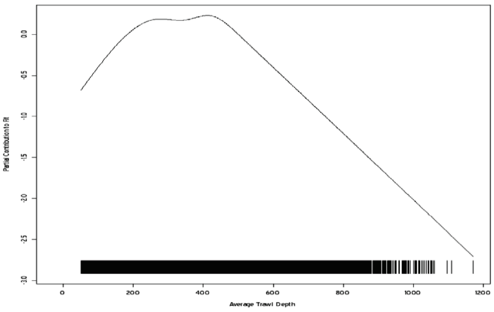

Figure 109. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Pink ling – East

Table 78. Pink ling east - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone10	Zone20	Zone30
Trawl_depth	mean	256.61	233.68	234.33
	sd	138.24	127.69	139.12
CARS_depth_temp	mean	12.74	12.62	11.7
	sd	2.02	1.63	1.57
CARS_depth_sal	mean	35.17	35.2	35.02
	sd	0.23	0.21	0.19
CARS_depth_DO	mean	4.79	5.05	5.22
	sd	0.26	0.31	0.3
CARS_depth_SiO2	mean	4.17	3.48	4.21
	sd	2.01	2.07	2.86
CARS_depth_PO4	mean	0.84	0.76	0.84
	sd	0.28	0.28	0.28
CARS_depth_NO3	mean	10.05	9.86	10.22
	sd	4.47	4.53	4.61
CARS_surf_temp	mean	18.39	16.32	15.41
	sd	2.23	2.15	1.54
CARS_surf_sal	mean	35.56	35.5	35.21
	sd	0.05	0.06	0.14
CARS_surf_DO	mean	5.3	5.55	5.68
	sd	0.22	0.23	0.2
CARS_surf_SiO2	mean	1.19	1.24	1.03
	sd	0.37	0.24	0.4
CARS_surf_PO4	mean	0.24	0.28	0.26
	sd	0.08	0.08	0.1
CARS_surf_NO3	mean	0.99	1.45	1.17
	sd	0.7	0.94	1.02
CARS_surf_Chlo	mean	0.48	0.58	0.53
	sd	0.19	0.22	0.13
SST_6day	mean	19	16.96	15.98
	sd	2.45	2.17	2.11
Temp_depth	mean	12.82	12.78	11.85
	sd	2.22	1.78	1.77
SeaWiFS_Chlo_A	mean	0.35	0.43	0.4
	sd	0.34	0.4	0.19
Altimetry	mean	0.03	0.03	0.01
	sd	0.08	0.06	0.05
SST_frontal_density	mean	0.65	0.78	0.24
	sd	1.37	1.56	0.74
Magnetic_Anomaly	mean	120.59	56.18	42.54
	sd	120.99	88.11	80.29
MLD_synTS	mean	22.27	24.6	29.52
	sd	11.89	18.5	17
SOI	mean	-2.22	-2.36	-1.29
	sd	10.74	10.46	10.72
NewMoon	mean	-0.02	-0.03	-0.01
	sd	0.71	0.71	0.7
SprMoon	mean	0	0	-0.02
	sd	0.71	0.71	0.7

Table 79. Pink ling east - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.001	MLD_synTS	0.083
Magnetic_Anomaly	0.002	SeaWiFS_Chlo_A	-0.131
NewMoon	-0.002	CARS_surf_sal	0.138
CARS_surf_SiO2	-0.003	CARS_depth_DO	-0.15
SST_6day	0.005	CARS_surf_Chlo	-0.166
CARS_surf_temp	0.006	CARS_depth_temp	-0.354
SST_frontal_density	-0.019	CARS_depth_sal	-0.359
Altimetry	-0.026	CARS_depth_SiO2	0.38
SOI	-0.029	Temp_depth	-0.384
CARS_surf_PO4	0.039	CARS_depth_PO4	0.398
CARS_surf_NO3	0.06	CARS_depth_NO3	0.405
CARS_surf_DO	-0.063	Trawl_depth	0.457

Table 80. Pink ling east - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_NO3	0.934	CARS_depth_DO	SST_6day	-0.774
Trawl_depth	CARS_depth_PO4	0.923	CARS_depth_SiO2	CARS_depth_NO3	0.92
Trawl_depth	CARS_depth_sal	-0.891	CARS_depth_SiO2	CARS_depth_PO4	0.945
Trawl_depth	CARS_depth_SiO2	0.866	CARS_depth_SiO2	Temp_depth	-0.775
Trawl_depth	CARS_depth_temp	-0.873	CARS_depth_PO4	CARS_depth_NO3	0.954
Trawl_depth	Temp_depth	-0.851	CARS_depth_PO4	Temp_depth	-0.839
CARS_depth_temp	CARS_depth_NO3	-0.861	CARS_depth_NO3	Temp_depth	-0.839
CARS_depth_temp	CARS_depth_PO4	-0.856	CARS_surf_temp	CARS_surf_DO	-0.916
CARS_depth_temp	CARS_depth_sal	0.933	CARS_surf_temp	SST_6day	0.889
CARS_depth_temp	CARS_depth_SiO2	-0.803	CARS_surf_temp	CARS_surf_NO3	-0.804
CARS_depth_temp	Temp_depth	0.94	CARS_surf_temp	CARS_surf_PO4	-0.781
CARS_depth_sal	CARS_depth_NO3	-0.922	CARS_surf_sal	CARS_surf_DO	-0.78
CARS_depth_sal	CARS_depth_PO4	-0.929	CARS_surf_DO	SST_6day	-0.818
CARS_depth_sal	CARS_depth_SiO2	-0.88	CARS_surf_DO	CARS_surf_Chlo	0.738
CARS_depth_sal	Temp_depth	0.897	CARS_surf_PO4	CARS_surf_NO3	0.863
CARS_depth_DO	CARS_surf_DO	0.845	CARS_surf_NO3	SST_6day	-0.715
CARS_depth_DO	CARS_surf_temp	-0.836			

Table 81. Pink ling east - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
CARS_surf_NO3	0	CARS_surf_DO	-0.186
SprMoon	-0.009	CARS_surf_sal	0.215
Altimetry	0.009	CARS_surf_Chlo	-0.24
SST_frontal_density	-0.014	SeaWiFS_Chlo_A	-0.248
SOI	0.022	CARS_depth_DO	-0.465
Magnetic_Anomaly	0.024	Temp_depth	-0.851
NewMoon	0.024	CARS_depth_SiO2	0.866
CARS_surf_PO4	-0.03	CARS_depth_temp	-0.873
MLD_synTS	0.032	CARS_depth_sal	-0.891
CARS_surf_SiO2	-0.073	CARS_depth_PO4	0.923
CARS_surf_temp	0.135	CARS_depth_NO3	0.934
SST_6day	0.173		

Table 82. Pink ling east - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.012	SeaWiFS_Chlo_A	-0.069
Magnetic_Anomaly	0.015	CARS_surf_DO	0.089
NewMoon	-0.021	CARS_depth_SiO2	-0.103
CARS_depth_NO3	-0.031	CARS_surf_PO4	0.122
CARS_depth_temp	0.036	MLD_synTS	0.132
Altimetry	0.042	CARS_surf_sal	0.144
SST_frontal_density	-0.042	CARS_depth_DO	0.167
SOI	-0.046	CARS_surf_Chlo	-0.195
CARS_depth_sal	0.053	CARS_surf_SiO2	-0.203
CARS_depth_PO4	-0.056	CARS_surf_NO3	0.221
Trawl_depth	0.067	SST_6day	-0.226
Temp_depth	0.069	CARS_surf_temp	-0.228

Table 83. Pink ling east - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.003	MLD_synTS	0.063
NewMoon	0.006	CARS_surf_NO3	-0.063
CARS_depth_sal	-0.007	Temp_depth	-0.073
CARS_depth_temp	0.008	CARS_depth_SiO2	0.075
SST_frontal_density	-0.012	CARS_surf_PO4	-0.081
SST_6day	-0.015	CARS_surf_Chlo	-0.09
SOI	0.023	Magnetic_Anomaly	0.12
CARS_surf_SiO2	-0.041	CARS_surf_temp	0.147
CARS_depth_NO3	0.053	CARS_depth_DO	-0.162
Trawl_depth	0.053	CARS_surf_DO	-0.165
SeaWiFS_Chlo_A	-0.054	CARS_surf_sal	0.183
CARS_depth_PO4	0.058	Altimetry	-0.276

Analysis I Pink ling East

Table 84. Pink ling east - Parameter estimates for periodic trend (1986 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.039	0.006	0
sin(2πt)	-0.041	0.006	0
cos(4πt)	0.099	0.005	0
sin(4πt)	-0.119	0.005	0
cos(6πt)	0.003	0.005	0.611
sin(6πt)	0.027	0.005	0
cos(8πt)	-0.054	0.005	0
sin(8πt)	-0.021	0.005	0
	Smooth Terms	DF	
	ns(eTime)	12	0
	ns(Trawl_depth)	4	0
Variance Explained = 43.42%			

Figure 110 shows the basic model fitting checks. Figure 111 shows the modelled seasonal effects and Figure 112 plots the partial contribution of the trawl depth to log-scale CPUE.

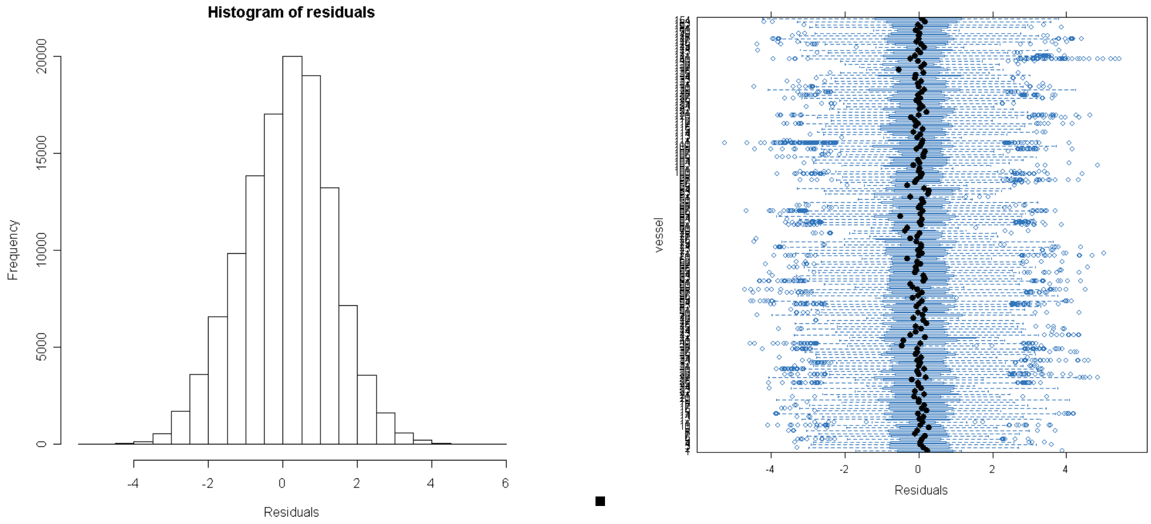

Figure 110. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

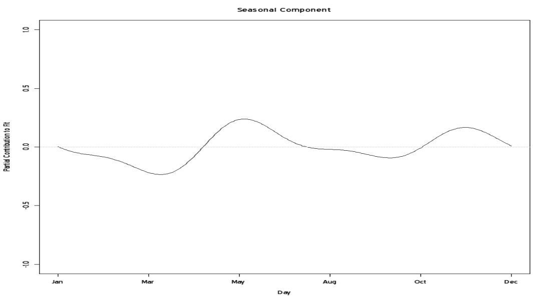

Figure 111. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in March.

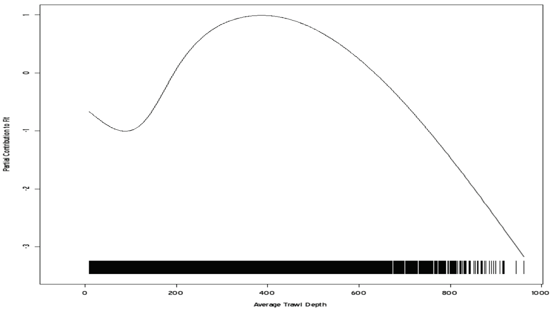

Figure 112. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Analysis II Pink ling East

Table 85. Pink ling east - Parameter estimates for periodic trend (1997 – 2006).

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Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.052	0.009	0
sin(2πt)	-0.189	0.01	0
cos(4πt)	0.093	0.007	0
sin(4πt)	-0.092	0.007	0
cos(6πt)	-0.003	0.007	0.68
sin(6πt)	0.067	0.007	0
cos(8πt)	-0.013	0.007	0.064
sin(8πt)	-0.034	0.007	0
	Smooth Terms	DF	
	ns(eTime)	8	0
	ns(Trawl_depth)	4	0
Variance Explained = 47.35%			

▪

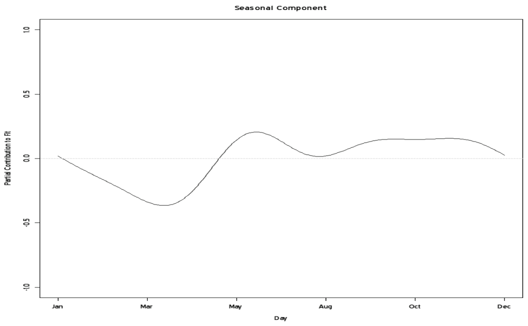

Figure 113. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in March.

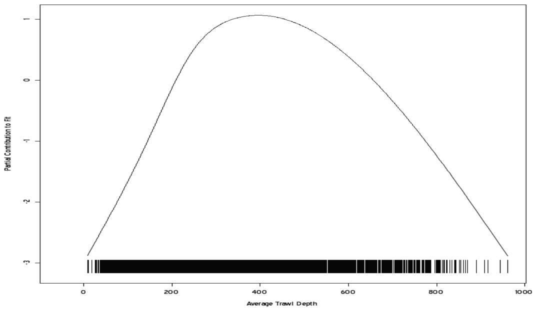

Figure 114. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Pink ling – West

Table 86. Pink ling west - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone40	Zone50
Trawl_depth	mean	485.31	416.25
	sd	134.7	123.28
CARS_depth_temp	mean	9.18	10.19
	sd	1.18	1.47
CARS_depth_sal	mean	34.68	34.85
	sd	0.15	0.23
CARS_depth_DO	mean	5.53	5.48
	sd	0.27	0.14
CARS_depth_SiO2	mean	6.07	3.85
	sd	4.29	2.29
CARS_depth_PO4	mean	1.15	0.99
	sd	0.27	0.27
CARS_depth_NO3	mean	16.69	13.81
	sd	4.32	4.58
CARS_surf_temp	mean	14.34	15.7
	sd	1.51	1.44
CARS_surf_sal	mean	35.06	35.43
	sd	0.22	0.09
CARS_surf_DO	mean	5.8	5.64
	sd	0.2	0.23
CARS_surf_SiO2	mean	1.14	0.71
	sd	0.25	0.18
CARS_surf_PO4	mean	0.27	0.2
	sd	0.1	0.05
CARS_surf_NO3	mean	1.21	0.54
	sd	0.82	0.38
CARS_surf_Chlo	mean	0.44	0.33
	sd	0.12	0.08
SST_6day	mean	14.37	15.75
	sd	1.58	1.54
Temp_depth	mean	9.17	10.14
	sd	1.22	1.49
SeaWiFS_Chlo_A	mean	0.37	0.23
	sd	0.26	0.09
Altimetry	mean	0.01	0.01
	sd	0.05	0.06
SST_frontal_density	mean	0.1	0.54
	sd	0.43	1.35
Magnetic_Anomaly	mean	47.97	65.65
	sd	97.78	100.01
MLD_synTS	mean	36.77	27.73
	sd	28.13	13.96
SOI	mean	-1.42	-2.32
	sd	10.07	10.85
NewMoon	mean	-0.01	-0.01
	sd	0.7	0.7
SprMoon	mean	-0.02	-0.02
SprMoon	sd	0.71	0.71

Table 87. Pink ling west - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.001	CARS_depth_sal	-0.089
NewMoon	-0.003	Altimetry	-0.099
MLD_synTS	0.011	SeaWiFS_Chlo_A	0.147
Magnetic_Anomaly	0.018	CARS_surf_Chlo	0.149
CARS_depth_PO4	0.043	CARS_surf_NO3	0.192
SOI	0.045	CARS_surf_SiO2	0.194
Temp_depth	-0.053	CARS_surf_PO4	0.202
CARS_depth_SiO2	0.054	CARS_surf_sal	-0.203
SST_frontal_density	-0.059	SST_6day	-0.21
CARS_depth_NO3	0.06	CARS_surf_DO	0.215
Trawl_depth	0.063	CARS_surf_temp	-0.216
CARS_depth_temp	-0.074	CARS_depth_DO	0.257

Table 88. Pink ling west - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_NO3	0.954	CARS_depth_sal	CARS_depth_SiO2	-0.965
Trawl_depth	CARS_depth_PO4	0.905	CARS_depth_sal	Temp_depth	0.956
Trawl_depth	CARS_depth_sal	-0.938	CARS_depth_SiO2	CARS_depth_NO3	0.945
Trawl_depth	CARS_depth_SiO2	0.879	CARS_depth_SiO2	CARS_depth_PO4	0.958
Trawl_depth	CARS_depth_temp	-0.949	CARS_depth_SiO2	Temp_depth	-0.937
Trawl_depth	Temp_depth	-0.9	CARS_depth_PO4	CARS_depth_NO3	0.969
CARS_depth_temp	CARS_depth_NO3	-0.977	CARS_depth_PO4	Temp_depth	-0.94
CARS_depth_temp	CARS_depth_PO4	-0.957	CARS_depth_NO3	Temp_depth	-0.943
CARS_depth_temp	CARS_depth_sal	0.994	CARS_surf_temp	CARS_surf_DO	-0.776
CARS_depth_temp	CARS_depth_SiO2	-0.966	CARS_surf_temp	CARS_surf_NO3	-0.856
CARS_depth_temp	Temp_depth	0.961	CARS_surf_temp	SST_6day	0.893
CARS_depth_sal	CARS_depth_NO3	-0.97	CARS_surf_PO4	CARS_surf_NO3	0.713
CARS_depth_sal	CARS_depth_PO4	-0.948	CARS_surf_NO3	SST_6day	-0.791

Table 89. Pink ling west - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
SOI	0	SST_6day	-0.103
NewMoon	-0.001	CARS_surf_PO4	0.118
SprMoon	0.005	CARS_surf_SiO2	0.175
SeaWiFS_Chlo_A	-0.006	CARS_surf_sal	-0.205
Altimetry	0.007	CARS_depth_DO	-0.34
MLD_synTS	0.01	CARS_depth_SiO2	0.879
CARS_surf_DO	0.03	Temp_depth	-0.9
CARS_surf_temp	-0.037	CARS_depth_PO4	0.905
Magnetic_Anomaly	0.038	CARS_depth_sal	-0.938
CARS_surf_Chlo	-0.051	CARS_depth_temp	-0.949
SST_frontal_density	-0.058	CARS_depth_NO3	0.954
CARS_surf_NO3	0.067		

Table 90. Pink ling west - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.001	SOI	0.091
NewMoon	-0.002	CARS_depth_PO4	-0.115
Magnetic_Anomaly	-0.025	CARS_surf_PO4	0.174
MLD_synTS	-0.026	CARS_depth_SiO2	-0.187
SST_frontal_density	0.026	CARS_depth_DO	0.307
Trawl_depth	-0.05	SeaWiFS_Chlo_A	0.308
CARS_surf_SiO2	0.074	Altimetry	-0.34
CARS_depth_sal	0.077	CARS_surf_Chlo	0.362
CARS_depth_NO3	-0.079	CARS_surf_NO3	0.455
Temp_depth	0.084	SST_6day	-0.534
CARS_surf_sal	-0.088	CARS_surf_temp	-0.664
CARS_depth_temp	0.09	CARS_surf_DO	0.743

Table 91. Pink ling west - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.004	SST_6day	-0.046
NewMoon	-0.005	CARS_surf_DO	-0.055
SST_frontal_density	-0.014	SeaWiFS_Chlo_A	0.059
CARS_surf_SiO2	-0.017	CARS_depth_SiO2	0.087
Altimetry	0.019	CARS_depth_sal	-0.095
MLD_synTS	0.024	CARS_depth_PO4	0.095
CARS_surf_NO3	-0.029	CARS_depth_temp	-0.098
CARS_surf_PO4	-0.032	CARS_depth_NO3	0.101
CARS_surf_Chlo	-0.032	CARS_depth_DO	-0.102
CARS_surf_temp	0.033	SOI	0.108
CARS_surf_sal	0.037	Trawl_depth	0.113
Magnetic_Anomaly	0.037	Temp_depth	-0.138

Analysis I Pink ling West

Table 92. Pink ling west - Parameter estimates for periodic trend (1986 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.068	0.01	0
sin(2πt)	-0.151	0.008	0
cos(4πt)	-0.027	0.007	0
sin(4πt)	-0.074	0.006	0
cos(6πt)	0.013	0.005	0.014
sin(6πt)	0.068	0.005	0
cos(8πt)	0.012	0.005	0.027
sin(8πt)	0.014	0.005	0.007
	Smooth Terms	DF	
	ns(eTime)	10	0
	ns(Trawl_depth)	4	0
Variance Explained = 29.34%			

Figure 115 shows the basic model fitting checks. Figure 116 shows the modelled seasonal effects and Figure 117 plots the partial contribution of the trawl depth to log-scale CPUE.

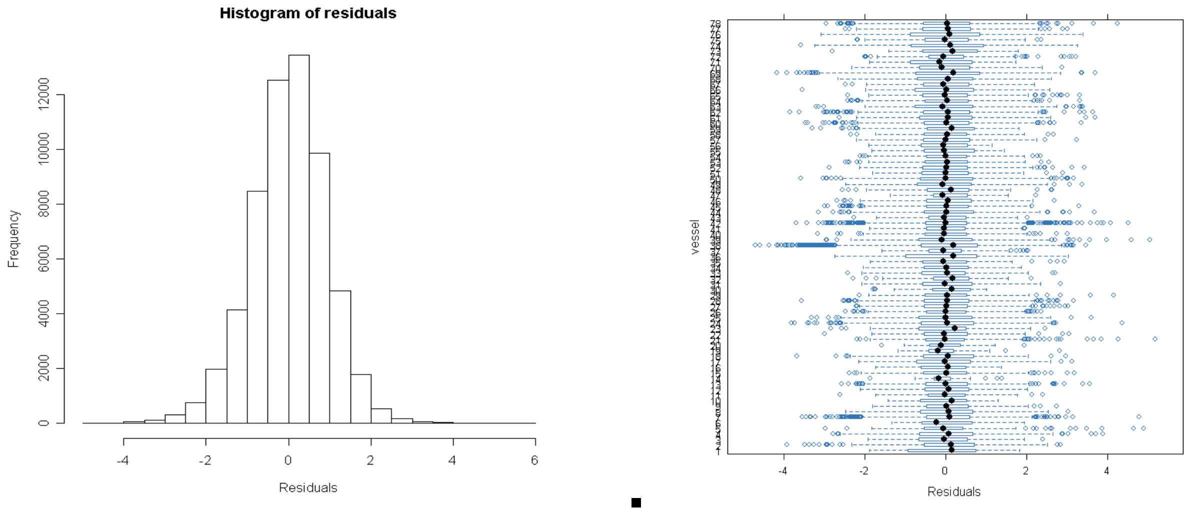

Figure 115. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

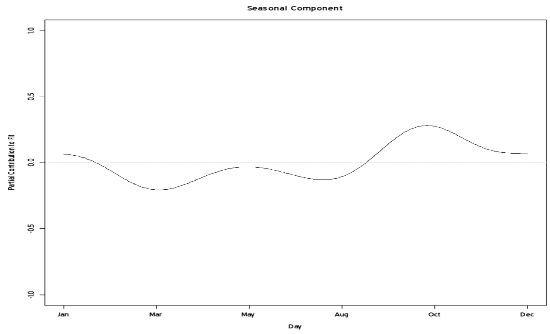

Figure 116. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in March.

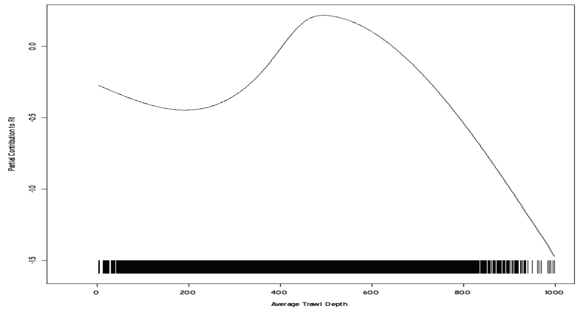

Figure 117. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Analysis II Pink ling West

Table 93. Pink ling west - Parameter estimates for periodic trend (1997 – 2006).

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Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	0.147	0.017	0
sin(2πt)	-0.09	0.011	0
cos(4πt)	-0.044	0.01	0
sin(4πt)	-0.075	0.008	0
cos(6πt)	0.023	0.008	0.003
sin(6πt)	0.061	0.007	0
cos(8πt)	-0.012	0.008	0.12
sin(8πt)	0.013	0.007	0.067
	Smooth Terms	DF	
	ns(eTime)	5	0
	ns(Trawl_depth)	4	0
Variance Explained = 30.54%			

▪

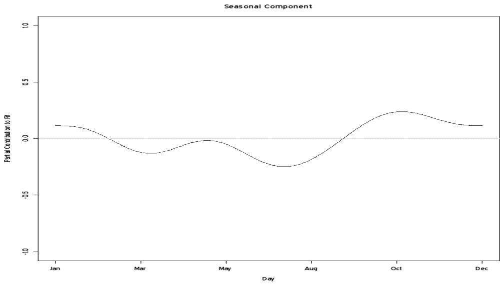

Figure 118. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in July.

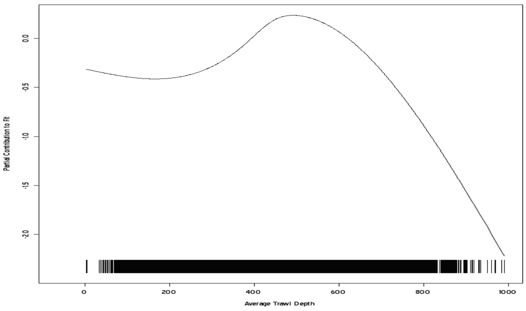

Figure 119. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Redfish

Table 94. Redfish - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone10	Zone20	Variable	Stat	Zone10	Zone20
Trawl_depth	mean	130.78	139.94	CARS_surf_NO3	mean	1.05	1.17
	sd	64.1	49.71		sd	0.68	0.7
CARS_depth_temp	mean	14.48	13.84	CARS_surf_Chlo	mean	0.55	0.66
	sd	1.41	1.07		sd	0.22	0.25
CARS_depth_sal	mean	35.37	35.36	SST_6day	mean	18.56	16.9
	sd	0.1	0.09		sd	2.43	2.09
CARS_depth_DO	mean	4.88	5.15	Temp_depth	mean	14.79	14.07
	sd	0.31	0.32		sd	1.58	1.12
CARS_depth_SiO2	mean	2.89	2.48	SeaWiFS_Chlo_A	mean	0.43	0.54
	sd	0.75	0.56		sd	0.5	0.51
CARS_depth_PO4	mean	0.61	0.56	Altimetry	mean	0.03	0.03
	sd	0.15	0.12		sd	0.08	0.07
CARS_depth_NO3	mean	6.52	6.29	SST_frontal_density	mean	0.69	0.77
	sd	2.33	2.2		sd	1.45	1.42
CARS_surf_temp	mean	17.99	16.47	Magnetic_Anomaly	mean	105.21	110.48
	sd	2.15	2.07		sd	127.36	68.19
CARS_surf_sal	mean	35.54	35.5	MLD_synTS	mean	20.77	23.24
	sd	0.05	0.07		sd	11.05	14.81
CARS_surf_DO	mean	5.36	5.56	SOI	mean	-2.87	-2.74
	sd	0.22	0.25		sd	10.33	10.6
CARS_surf_SiO2	mean	1.23	1.2	NewMoon	mean	-0.02	-0.03
	sd	0.38	0.24		sd	0.71	0.71
CARS_surf_PO4	mean	0.25	0.26	SprMoon	mean	0	0
	sd	0.08	0.06		sd	0.71	0.71

Table 95. Redfish - Correlation of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
NewMoon	-0.001	CARS_depth_PO4	0.1
SprMoon	0.004	CARS_depth_temp	0.1
SST_frontal_density	0.008	CARS_depth_SiO2	0.106
Altimetry	-0.013	CARS_depth_NO3	0.109
CARS_surf_SiO2	-0.015	Trawl_depth	0.12
Magnetic_Anomaly	0.021	CARS_surf_Chlo	-0.126
CARS_surf_NO3	-0.036	CARS_surf_temp	0.153
CARS_depth_sal	0.038	SST_6day	0.163
MLD_synTS	0.04	CARS_surf_DO	-0.169
SOI	-0.043	CARS_depth_DO	-0.172
CARS_surf_PO4	-0.056	SeaWiFS_Chlo_A	-0.178
Temp_depth	0.083	CARS_surf_sal	0.186

Table 96. Redfish - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
CARS_depth_temp	CARS_depth_sal	0.783	CARS_depth_PO4	CARS_depth_NO3	0.821
CARS_depth_temp	Temp_depth	0.834	CARS_surf_temp	CARS_surf_Chlo	-0.75
CARS_depth_sal	Temp_depth	0.706	CARS_surf_temp	CARS_surf_DO	-0.913
CARS_depth_sal	CARS_depth_PO4	-0.752	CARS_surf_temp	SST_6day	0.854
CARS_depth_DO	CARS_surf_Chlo	0.713	CARS_surf_temp	CARS_surf_NO3	-0.755
CARS_depth_DO	CARS_surf_DO	0.885	CARS_surf_temp	CARS_surf_PO4	-0.799
CARS_depth_DO	CARS_surf_temp	-0.892	CARS_surf_DO	CARS_surf_Chlo	0.814
CARS_depth_DO	SST_6day	-0.81	CARS_surf_DO	SST_6day	-0.807
CARS_depth_SiO2	CARS_depth_PO4	0.781	CARS_surf_PO4	CARS_surf_NO3	0.841
CARS_depth_SiO2	CARS_depth_NO3	0.743			

Table 97. Redfish - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
SprMoon	0	CARS_surf_Chlo	-0.132
CARS_surf_DO	-0.001	CARS_surf_NO3	0.14
NewMoon	-0.001	SeaWiFS_Chlo_A	-0.242
SST_frontal_density	0.034	CARS_surf_sal	0.253
Magnetic_Anomaly	0.035	MLD_synTS	0.293
SOI	0.048	CARS_depth_SiO2	0.366
SST_6day	0.051	Temp_depth	-0.474
CARS_surf_SiO2	0.059	CARS_depth_temp	-0.495
CARS_surf_temp	-0.072	CARS_depth_sal	-0.585
Altimetry	0.093	CARS_depth_PO4	0.595
CARS_surf_PO4	0.115	CARS_depth_NO3	0.668
CARS_depth_DO	-0.119		

Table 98. Redfish - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
CARS_depth_sal	0.002	CARS_surf_sal	-0.301
SOI	-0.003	SeaWiFS_Chlo_A	0.364
SprMoon	0.013	MLD_synTS	0.425
NewMoon	-0.013	CARS_depth_temp	-0.467
CARS_depth_PO4	-0.017	CARS_depth_DO	0.663
Magnetic_Anomaly	0.025	CARS_surf_Chlo	0.668
SST_frontal_density	0.063	CARS_surf_SiO2	0.679
CARS_depth_SiO2	0.067	SST_6day	-0.708
CARS_depth_NO3	-0.124	CARS_surf_DO	0.714
Trawl_depth	0.142	CARS_surf_temp	-0.854
Altimetry	-0.172	CARS_surf_PO4	0.857
Temp_depth	-0.265	CARS_surf_NO3	0.859

Table 99. Redfish - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	**Rank corr**	**Variable**	**Rank corr**
MLD_synTS	-0.003	SST_6day	-0.054
SprMoon	-0.004	CARS_surf_DO	-0.063
NewMoon	0.007	CARS_surf_NO3	-0.065
CARS_surf_sal	0.016	CARS_surf_PO4	-0.07
SeaWiFS_Chlo_A	-0.017	CARS_surf_temp	0.08
CARS_depth_SiO2	-0.024	CARS_depth_NO3	-0.091
CARS_surf_Chlo	-0.025	CARS_depth_PO4	-0.092
Temp_depth	0.031	CARS_depth_sal	0.123
CARS_surf_SiO2	-0.039	CARS_depth_temp	0.131
SST_frontal_density	-0.042	SOI	-0.159
Magnetic_Anomaly	0.047	Trawl_depth	-0.202
CARS_depth_DO	-0.049	Altimetry	-0.275

Analysis I Redfish

Table 100. Redfish - Parameter estimates for periodic trend (1986 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-1.46	0.047	0
sin(2πt)	-1.589	0.038	0
cos(4πt)	0.036	0.013	0.005
sin(4πt)	-0.014	0.013	0.275
cos(6πt)	0.052	0.008	0
sin(6πt)	-0.003	0.008	0.756
cos(8πt)	-0.017	0.008	0.032
sin(8πt)	0.024	0.008	0.003
	Smooth Terms	DF	
	ns(eTime)	10	0
	ns(Trawl_depth)	8	0
Variance Explained = 30.66%			

Figure 120 shows the basic model fitting checks. Figure 121 shows the modelled seasonal effects and Figure 122 plots the partial contribution of the trawl depth to log-scale CPUE.

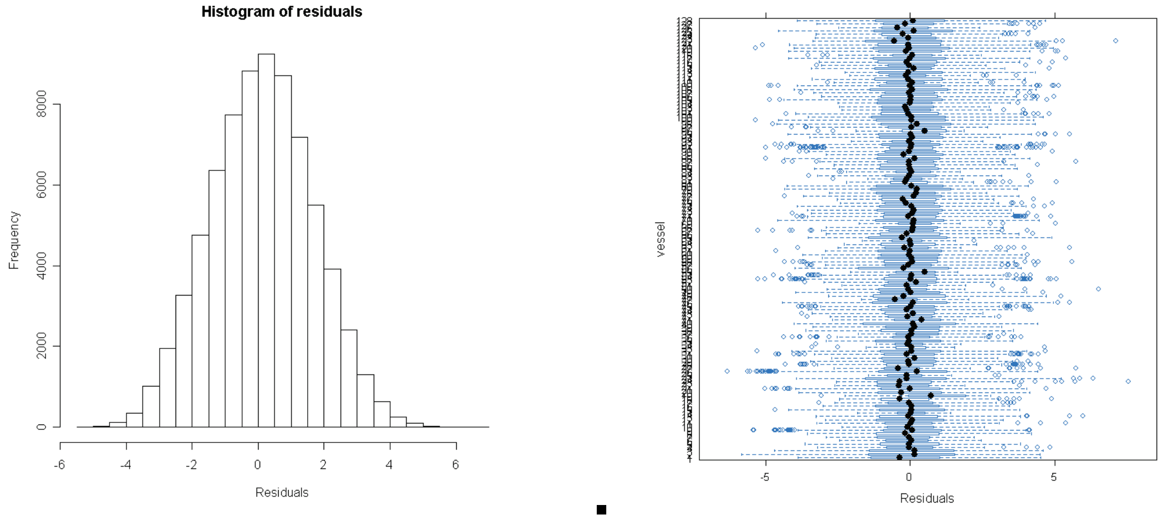

Figure 120. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

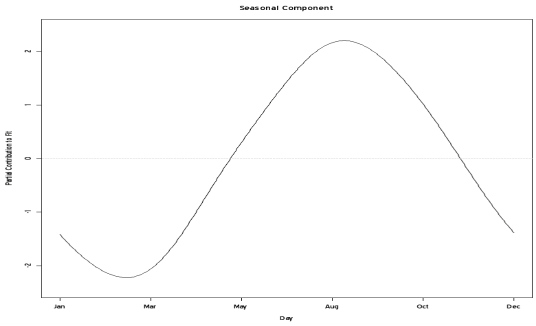

Figure 121. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in February.

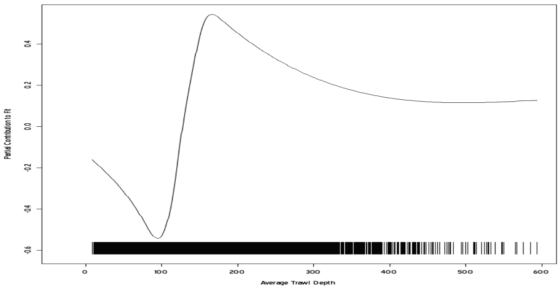

Figure 122. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Analysis II Redfish

Table 101. Redfish - Parameter estimates for periodic trend (1997 – 2006).

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Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.784	0.052	0
sin(2πt)	-1.403	0.052	0
cos(4πt)	-0.049	0.02	0.013
sin(4πt)	0.083	0.021	0
cos(6πt)	0.067	0.015	0
sin(6πt)	-0.025	0.014	0.078
cos(8πt)	0.016	0.014	0.242
sin(8πt)	0.025	0.014	0.068
	Smooth Terms	DF	
	ns(eTime)	5	0
	ns(Trawl_depth)	8	0
Variance Explained = 35.40%			

▪

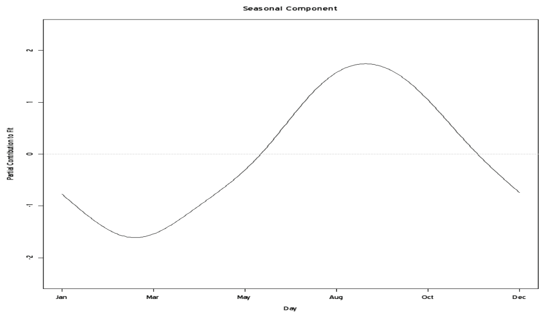

Figure 123. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in February.

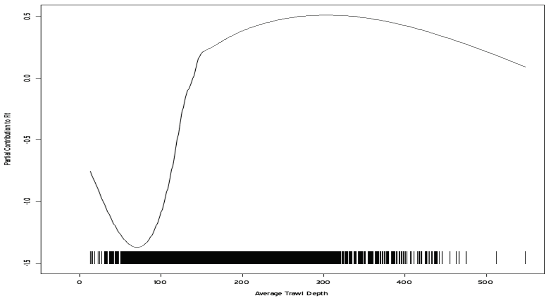

Figure 124. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Bight redfish

Table 102. Bight redfish - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone80	Variable	Stat	Zone80
Trawl_depth	mean	136.73	CARS_surf_SiO2	mean	1.29
	sd	18.48		sd	0.52
CARS_depth_temp	mean	15.49	CARS_surf_PO4	mean	0.15
	sd	0.7		sd	0.06
CARS_depth_sal	mean	35.57	CARS_surf_NO3	mean	0.26
	sd	0.08		sd	0.09
CARS_depth_DO	mean	5.42	CARS_surf_Chlo	mean	0.3
	sd	0.1		sd	0.06
CARS_depth_SiO2	mean	1.42	SST_6day	mean	18.23
	sd	0.38		sd	1.78
CARS_depth_PO4	mean	0.34	Temp_depth	mean	15.02
	sd	0.07		sd	1.11
CARS_depth_NO3	mean	1.76	SeaWiFS_Chlo_A	mean	0.19
	sd	0.81		sd	0.06
CARS_surf_temp	mean	18.29	Altimetry	mean	0.01
	sd	2.04		sd	0.06
CARS_surf_sal	mean	35.83	SST_frontal_density	mean	0.71
	sd	0.17		sd	1.71
CARS_surf_DO	mean	5.35	Magnetic_Anomaly	mean	-4.83
	sd	0.19		sd	190.85
NewMoon	mean	0.01	MLD_synTS	mean	36.41
	sd	0.71		sd	12.37
SprMoon	mean	0	SOI	mean	-2.48
	sd	0.71		sd	10.72

Table 103. Bight redfish - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.003	CARS_depth_NO3	0.098
CARS_depth_PO4	-0.003	SST_frontal_density	-0.128
Magnetic_Anomaly	0.007	CARS_depth_SiO2	0.141
CARS_surf_NO3	-0.014	SeaWiFS_Chlo_A	-0.144
CARS_depth_temp	-0.016	CARS_surf_PO4	-0.174
Trawl_depth	0.021	CARS_depth_DO	-0.187
SOI	0.022	CARS_surf_temp	0.229
CARS_depth_sal	0.041	CARS_surf_DO	-0.252
Temp_depth	-0.044	SST_6day	0.273
Altimetry	0.068	CARS_surf_SiO2	-0.279
MLD_synTS	0.084	CARS_surf_sal	0.282
NewMoon	-0.094		

Table 104. Bight redfish - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
CARS_depth_temp	CARS_depth_sal	0.788	CARS_surf_sal	CARS_surf_SiO2	-0.856
CARS_surf_temp	CARS_surf_DO	-0.887	CARS_surf_sal	SST_6day	0.828
CARS_surf_temp	CARS_surf_PO4	-0.731	CARS_surf_DO	CARS_surf_PO4	0.842
CARS_surf_temp	CARS_surf_sal	0.873	CARS_surf_DO	CARS_surf_SiO2	0.754
CARS_surf_temp	CARS_surf_SiO2	-0.738	CARS_surf_DO	SST_6day	-0.848
CARS_surf_temp	SST_6day	0.923	CARS_surf_SiO2	SST_6day	-0.709
CARS_surf_sal	CARS_surf_DO	-0.927	CARS_surf_PO4	SST_6day	-0.72
CARS_surf_sal	CARS_surf_PO4	-0.791			

Table 105. Bight redfish - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
NewMoon	-0.003	MLD_synTS	0.087
SprMoon	-0.009	CARS_surf_sal	0.093
SeaWiFS_Chlo_A	-0.014	CARS_depth_SiO2	0.103
SOI	-0.018	CARS_surf_SiO2	-0.105
CARS_surf_NO3	-0.021	CARS_surf_PO4	-0.12
SST_frontal_density	-0.033	CARS_surf_DO	-0.127
Magnetic_Anomaly	-0.036	Altimetry	0.188
CARS_surf_temp	0.047	CARS_depth_DO	-0.215
SST_6day	0.066	CARS_depth_temp	-0.452
CARS_depth_PO4	0.067	CARS_depth_sal	-0.48
Temp_depth	-0.085	CARS_depth_NO3	0.584

Table 106. Bight redfish - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.01	SeaWiFS_Chlo_A	0.294
NewMoon	0.012	CARS_depth_SiO2	-0.299
CARS_surf_NO3	0.018	CARS_depth_NO3	-0.356
CARS_depth_temp	0.033	CARS_surf_SiO2	-0.46
Magnetic_Anomaly	-0.041	CARS_depth_PO4	-0.484
SST_frontal_density	-0.09	CARS_surf_DO	-0.494
Trawl_depth	0.095	CARS_surf_PO4	-0.497
SOI	-0.096	CARS_surf_sal	0.499
CARS_depth_sal	0.124	Altimetry	0.508
CARS_surf_temp	0.197	MLD_synTS	0.57
Temp_depth	0.232	CARS_depth_DO	-0.615
SST_6day	0.241		

Table 107. Bight redfish - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
MLD_synTS	0	CARS_surf_NO3	0.035
CARS_depth_DO	-0.002	CARS_depth_temp	0.037
Magnetic_Anomaly	0.005	CARS_surf_SiO2	0.039
NewMoon	-0.008	CARS_surf_temp	-0.04
CARS_depth_PO4	-0.008	Altimetry	-0.052
CARS_depth_NO3	0.01	Temp_depth	0.06
CARS_depth_SiO2	0.014	SST_6day	0.063
SprMoon	-0.014	CARS_depth_sal	0.065
Trawl_depth	0.015	SeaWiFS_Chlo_A	-0.089
CARS_surf_sal	-0.019	SOI	-0.116
CARS_surf_DO	0.03	SST_frontal_density	-0.148
CARS_surf_PO4	0.032		

Analysis I Bight redfish

Table 108. Bight redfish - Parameter estimates for periodic trend (1989 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.21	0.024	0
sin(2πt)	0.203	0.025	0
cos(4πt)	-0.262	0.011	0
sin(4πt)	0.106	0.028	0
cos(6πt)	-0.076	0.01	0
sin(6πt)	-0.082	0.01	0
cos(8πt)	0.045	0.01	0
sin(8πt)	0.005	0.01	0.607
	Smooth Terms	DF	
	ns(eTime)	10	0
	ns(Trawl_depth)	3	0
Variance Explained = 28.83%			

Figure 125 shows the basic model fitting checks. Figure 126 shows the modelled seasonal effects and Figure 127 plots the partial contribution of the trawl depth to log-scale CPUE.

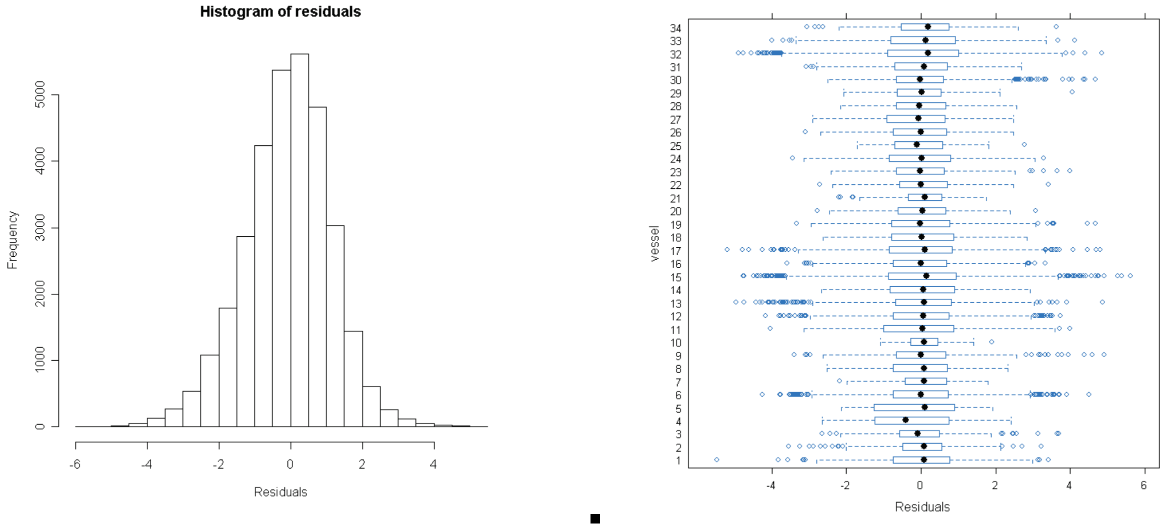

Figure 125. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

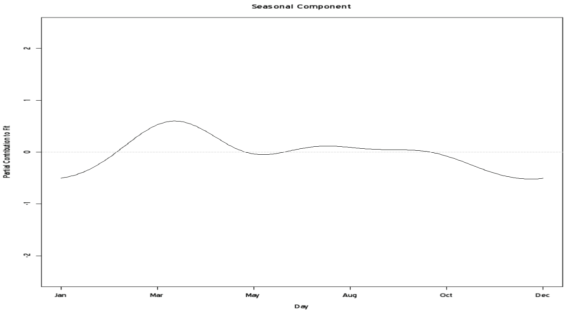

Figure 126. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in December.

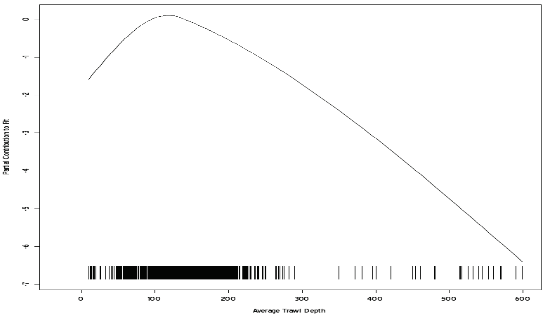

Figure 127. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Analysis II Bight redfish

Table 109. Bight redfish - Parameter estimates for periodic trend (1997 – 2006).

▪

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.296	0.034	0
sin(2πt)	0.105	0.041	0.011
cos(4πt)	-0.395	0.014	0
sin(4πt)	0.128	0.034	0
cos(6πt)	-0.085	0.012	0
sin(6πt)	-0.112	0.012	0
cos(8πt)	0.062	0.012	0
sin(8πt)	-0.012	0.012	0.327
	Smooth Terms	DF	
	ns(eTime)	6	0
	ns(Trawl_depth)	3	0
Variance Explained = 31.50%			

▪

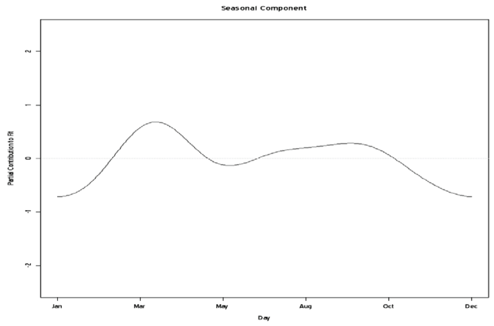

Figure 128. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in December.

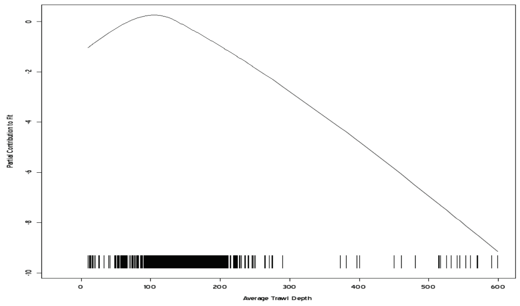

Figure 129. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Silver warehou

Table 110. Silver warehou - Summary of means and standard errors of predictors by zone. NA means no data available in that corresponding zone.

Variable	Stat	Zone10	Zone20	Zone30	Zone40	Zone50
Trawl_depth	mean	173.91	209.6	187.05	437.44	333.66
	sd	91.36	102.98	97.31	114.36	116.68
CARS_depth_temp	mean	13.62	12.82	12.12	9.59	11.34
	sd	1.2	1.24	1.27	1.05	1.6
CARS_depth_sal	mean	35.32	35.25	35.06	34.73	35.03
	sd	0.13	0.16	0.15	0.15	0.26
CARS_depth_DO	mean	5.05	5.15	5.32	5.62	5.5
	sd	0.29	0.29	0.27	0.14	0.09
CARS_depth_SiO2	mean	3.1	2.99	3.34	4.67	2.58
	sd	1.01	1.19	1.3	2.1	1.58
CARS_depth_PO4	mean	0.66	0.7	0.74	1.06	0.78
	sd	0.18	0.22	0.2	0.22	0.28
CARS_depth_NO3	mean	6.83	8.77	8.67	15.17	10.42
	sd	2.99	3.71	3.44	3.74	4.89
CARS_surf_temp	mean	16.89	15.79	15.14	14.16	15.33
	sd	1.89	1.93	1.53	1.48	1.42
CARS_surf_sal	mean	35.54	35.48	35.16	35.04	35.46
	sd	0.05	0.06	0.14	0.21	0.09
CARS_surf_DO	mean	5.48	5.61	5.73	5.81	5.67
	sd	0.22	0.22	0.21	0.19	0.23
CARS_surf_SiO2	mean	1.33	1.26	1.02	1.15	0.75
	sd	0.38	0.24	0.38	0.27	0.19
CARS_surf_PO4	mean	0.28	0.29	0.27	0.29	0.2
	sd	0.08	0.08	0.11	0.1	0.04
CARS_surf_NO3	mean	1.25	1.57	1.22	1.34	0.63
	sd	0.72	0.94	1.05	0.87	0.39
CARS_surf_Chlo	mean	0.6	0.63	0.55	0.45	0.35
	sd	0.24	0.24	0.14	0.13	0.07
SST_6day	mean	17.63	16.56	15.67	14.25	15.57
	sd	2.41	2.05	2.09	1.56	1.56
Temp_depth	mean	13.79	12.92	12.29	9.61	11.27
	sd	1.45	1.39	1.46	1.09	1.65
SeaWiFS_Chlo_A	mean	0.39	0.44	0.4	0.36	0.24
	sd	0.35	0.38	0.19	0.26	0.09
Altimetry	mean	0.02	0.02	0	0.01	0.02
	sd	0.08	0.06	0.05	0.05	0.06
SST_frontal_density	mean	0.72	0.78	0.23	0.12	0.46
	sd	1.51	1.55	0.71	0.43	1.19
Magnetic_Anomaly	mean	90.88	55.25	21.67	49.61	60.49
	sd	120.64	86.71	81.28	104.66	107.3
MLD_synTS	mean	24.4	24.89	27.72	37.59	30.92
	sd	13.36	18.92	14.93	28.79	15.91
SOI	mean	-2.02	-2.41	-1.13	-1.7	-2.38
	sd	9.32	10.03	10.76	9.67	10.07
NewMoon	mean	-0.03	-0.02	0	0.01	0
	sd	0.7	0.71	0.7	0.7	0.7
SprMoon	mean	-0.01	0	-0.03	-0.02	-0.02
	sd	0.7	0.71	0.71	0.7	0.71

Table 111. Silver warehou - Correlations of predictor variables with log scale CPUE.

Variable	Rank corr	Variable	Rank corr
SprMoon	0.002	CARS_depth_sal	-0.103
CARS_surf_SiO2	0.012	SST_frontal_density	-0.107
NewMoon	0.018	SeaWiFS_Chlo_A	-0.12
Altimetry	-0.02	CARS_depth_temp	-0.131
Magnetic_Anomaly	-0.021	Trawl_depth	0.134
SOI	-0.022	MLD_synTS	0.136
CARS_depth_PO4	0.023	CARS_surf_sal	-0.145
CARS_depth_NO3	0.04	CARS_surf_DO	0.162
CARS_depth_SiO2	-0.047	Temp_depth	-0.166
CARS_surf_PO4	0.059	CARS_surf_temp	-0.237
CARS_surf_Chlo	-0.062	CARS_depth_DO	0.26
CARS_surf_NO3	0.077	SST_6day	-0.265

Table 112. Silver warehou - Variable pairs with corresponding Spearman rank correlations > 0.7.

Variable1	Variable2	Rank Corr	Variable1	Variable2	Rank Corr
Trawl_depth	CARS_depth_NO3	0.902	CARS_depth_sal	CARS_depth_SiO2	-0.77
Trawl_depth	CARS_depth_PO4	0.876	CARS_depth_sal	Temp_depth	0.934
Trawl_depth	CARS_depth_sal	-0.874	CARS_depth_SiO2	CARS_depth_NO3	0.862
Trawl_depth	CARS_depth_SiO2	0.701	CARS_depth_SiO2	CARS_depth_PO4	0.9
Trawl_depth	CARS_depth_temp	-0.886	CARS_depth_SiO2	Temp_depth	-0.719
Trawl_depth	Temp_depth	-0.88	CARS_depth_PO4	CARS_depth_NO3	0.967
CARS_depth_temp	CARS_depth_NO3	-0.878	CARS_depth_PO4	Temp_depth	-0.862
CARS_depth_temp	CARS_depth_PO4	-0.862	CARS_depth_NO3	Temp_depth	-0.874
CARS_depth_temp	CARS_depth_sal	0.949	CARS_surf_temp	CARS_surf_DO	-0.808
CARS_depth_temp	CARS_depth_SiO2	-0.721	CARS_surf_temp	SST_6day	0.867
CARS_depth_temp	Temp_depth	0.965	CARS_surf_DO	SST_6day	-0.709
CARS_depth_sal	CARS_depth_NO3	-0.91	CARS_surf_PO4	CARS_surf_NO3	0.856
CARS_depth_sal	CARS_depth_PO4	-0.903			

Table 113. Silver warehou - Correlations of environmental variables with average trawl depth.

Variable	Rank corr	Variable	Rank corr
SprMoon	-0.002	SST_6day	-0.208
NewMoon	0.007	CARS_depth_DO	0.225
Magnetic_Anomaly	-0.011	CARS_surf_sal	-0.273
SOI	0.015	SeaWiFS_Chlo_A	-0.277
Altimetry	0.042	CARS_surf_Chlo	-0.447
CARS_surf_NO3	-0.072	CARS_depth_SiO2	0.701
CARS_surf_PO4	-0.089	CARS_depth_sal	-0.874
CARS_surf_DO	0.091	CARS_depth_PO4	0.876
MLD_synTS	0.152	Temp_depth	-0.88
CARS_surf_temp	-0.159	CARS_depth_temp	-0.886
SST_frontal_density	-0.163	CARS_depth_NO3	0.902
CARS_surf_SiO2	-0.189		

Table 114. Silver warehou - Correlations of environmental variables with fitted seasonal trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
SST_frontal_density	-0.003	CARS_depth_NO3	-0.241
SprMoon	0.006	CARS_surf_sal	0.272
NewMoon	0.007	CARS_depth_sal	0.272
Trawl_depth	-0.014	CARS_depth_PO4	-0.278
SeaWiFS_Chlo_A	-0.032	CARS_depth_SiO2	-0.3
Magnetic_Anomaly	0.07	CARS_surf_DO	0.305
SOI	-0.094	MLD_synTS	0.379
CARS_depth_temp	0.147	CARS_surf_SiO2	0.439
CARS_depth_DO	0.149	SST_6day	-0.575
Temp_depth	0.15	CARS_surf_PO4	0.585
CARS_surf_Chlo	0.192	CARS_surf_temp	-0.661
Altimetry	0.194	CARS_surf_NO3	0.723

Table 115. Silver warehou - Correlations of environmental variables with fitted long-term trend from the final model in Analysis I.

Variable	Rank corr	Variable	Rank corr
CARS_depth_DO	-0.001	CARS_surf_SiO2	0.079
SprMoon	0.002	SeaWiFS_Chlo_A	0.089
NewMoon	0.016	CARS_surf_sal	0.089
CARS_surf_temp	-0.028	SST_6day	-0.118
Magnetic_Anomaly	0.032	CARS_depth_SiO2	-0.147
SST_frontal_density	-0.034	CARS_depth_temp	0.167
CARS_surf_DO	0.042	CARS_surf_Chlo	0.173
SOI	-0.047	CARS_depth_PO4	-0.203
CARS_surf_PO4	0.048	CARS_depth_NO3	-0.203
Temp_depth	0.05	CARS_depth_sal	0.204
CARS_surf_NO3	0.062	Trawl_depth	-0.213
MLD_synTS	0.075	Altimetry	-0.274

Analysis I Silver warehou

Table 116. Silver warehou - Parameter estimates for periodic trend (1986 – 2006).

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.535	0.017	0
sin(2πt)	-0.423	0.023	0
cos(4πt)	0.026	0.008	0.001
sin(4πt)	0.27	0.008	0
cos(6πt)	0.068	0.008	0
sin(6πt)	-0.181	0.007	0
cos(8πt)	-0.031	0.007	0
sin(8πt)	0.072	0.007	0
	Smooth Terms	DF	
	ns(eTime)	10	0
	ns(Trawl_depth)	5	0
Variance Explained = 24.48%			

Figure 130 shows the basic model fitting checks. Figure 131 shows the modelled seasonal effects and Figure 132 shows the partial contribution of the trawl depth to log-scale CPUE.

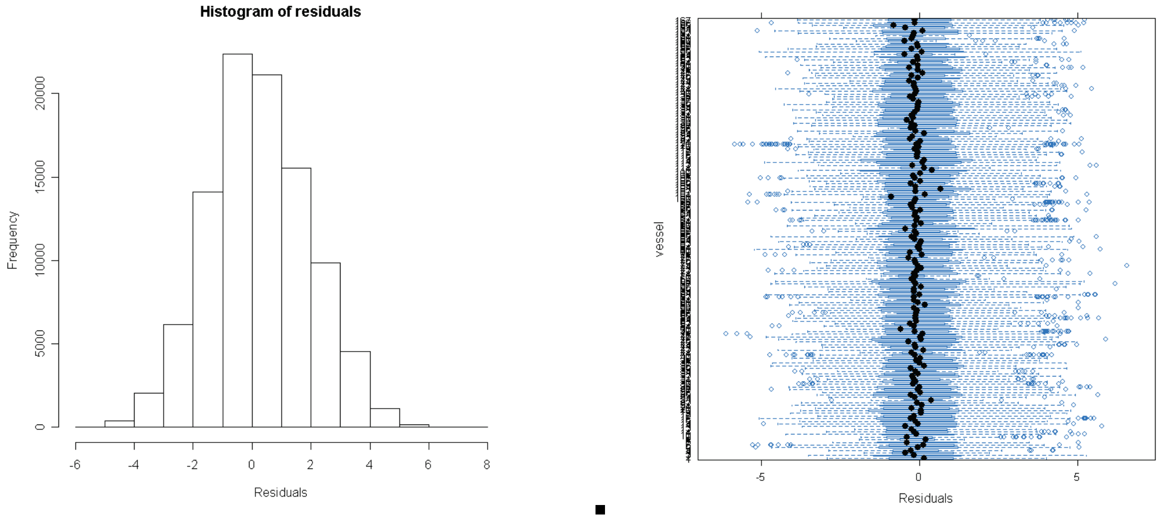

Figure 130. The left histogram of residuals appears approximately consistent with normality. The right panel shows boxplots of the residuals for vessels which also suggests that the model is reasonable.

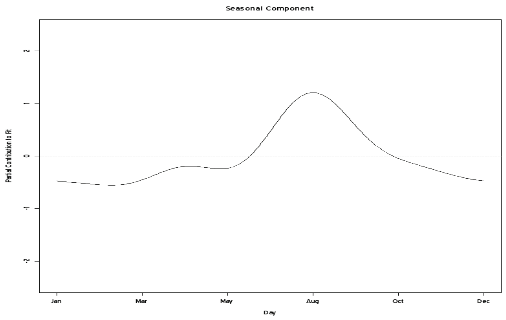

Figure 131. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in February.

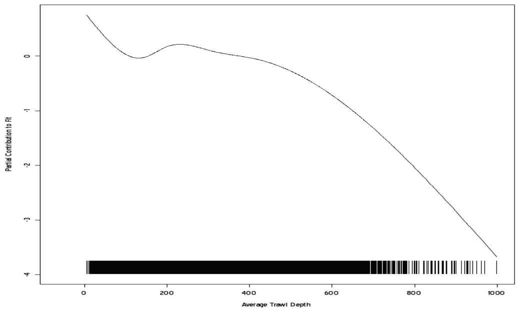

Figure 132. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

Analysis II Silver warehou

Table 117. Silver warehou - Parameter estimates for periodic trend (1997 – 2006).

■

Parametric Term	Estimate	SE	p-value
Periodic Trend			
cos(2πt)	-0.296	0.034	0
sin(2πt)	0.105	0.041	0.011
cos(4πt)	-0.395	0.014	0
sin(4πt)	0.128	0.034	0
cos(6πt)	-0.085	0.012	0
sin(6πt)	-0.112	0.012	0
cos(8πt)	0.062	0.012	0
sin(8πt)	-0.012	0.012	0.327
	Smooth Terms	DF	
	ns(eTime)	6	0
	ns(Trawl_depth)	3	0
Variance Explained = 28.2%			

■

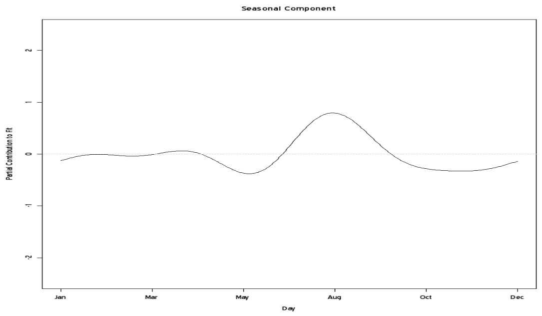

Figure 133. Plot showing the contribution of the seasonal trend to log-scaled CPUE suggesting that catch rates are lowest seasonally in May.

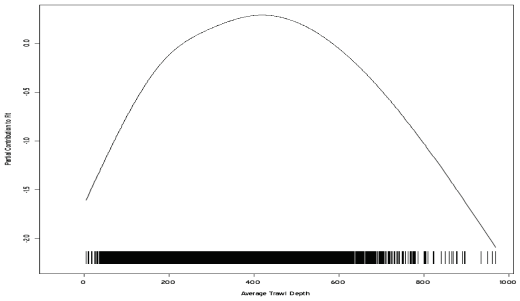

Figure 134. Plot showing the partial contribution of average trawl depth to log-scale CPUE.

APPENDIX 9 QUANTIFYING THE EFFECTS OF ENVIRONMENTAL FACTORS ON CATCH RATES IN THE SOUTHERN AND EASTERN SCALEFISH AND SHARK FISHERY: 1986 TO 2006 - DATA PLOTS

Jemery Day

This appendix provides a set of data plots for each fish species showing the raw data and giving a visual display of the relations between catch rates plotted against a range of environmental variables.

All plots in this appendix include the raw data, plotted in grey dots, overlaid with a contour plot to indicate the areas of high and low density and a series of quantile regression lines for the 5%, 25%, 50%, 75%, and 95% quantiles. This can show differences in the relationship between high and low catch rates and the particular environmental variable.

The range of plots is comprehensive for tiger flathead caught by the Danish seine fleet correlated with sea surface temperature, but for other combinations of species gear types and environmental variables, only the more interesting plots are shown.

Tiger flathead Danish seine - SST

This section shows the catch rate data for tiger flathead caught by the Danish seine fleet plotted against SST. The first plot shows all data combined and subsequent plots separate data by month, year, zone and latitude, and sometimes in combination. The correlation of catch rates of tiger flathead caught by the Danish seine fleet with SST was 0.262. While this is one of the higher correlations between catch rate and environmental variables, it is worth noting that this is not a strong correlation and does not indicate a strong relationship. The combined data (all years, all seasons and all areas) is shown in Figure 135, where all shots are included in a single plot. While it appears that there is some relationship, with an increase in catch rate associated with an increase in SST, there is a lot of scatter and there are many records with low catch rates and high SST and high catch rates and low SST. The slightly steeper slope for the 5% and 25% quantile regression lines suggests that any response to SST is greater when the catch rate is low.

The following comprehensive series of plots attempt to tease out any possible spatial or temporal differences in the response of catch rates to SST. Note that these plots represent exploratory data analysis and no statistical tests have been conducted to test for any differences in the correlation coefficients or for changes in the slope of any quantile regression lines. The increase in catch rate associated with an increase in SST appears to be stronger in winter months than in summer months (Figure 136). The ‘p’ shape of the distribution in the winter months suggests that when the SST is below a threshold of around 14ºC, the full range of catch rates is possible, but for SST above 14ºC, the very low catch rates are rarely obtained. This is clearest in August (middle row, 4th column) when the highest catch rates have little relationship with SST (the 95% quantile regression lines is almost flat) and the lowest catch rates have a stronger relationship with SST (the 5% and 25% quantile regression lines are the steepest). These plots suggest that there may be some interaction between season and zone, in any relationship between catch rate and SST.

Plotted by year (Figure 137), there appears to be very little relationship between SST and catch rate in some years (e.g. 1998), while in other years (e.g. 1995), the relationship appears to be stronger (at least for the lower catch rates – as shown by the slope of the 5%, 25% and 50% quantile regression lines).

In zone 20, it appears that SST has very little relationship with catch rate, but there appears to be a stronger effect of SST on catch rate in both zones 50 and 60 (Figure 138).

Differences between latitude bands seem small, with perhaps a suggestion that the relationship between SST and catch rate is stronger in the northern and southern latitudes compared to the relationship in the middle latitudes (between 38.133 and 38.333 degrees) (Figure 139).

Figure 140 shows catch rate plotted against SST by zone and month. These plots indicate that there is much more variation in the relationship of catch rate with SST in zone 60 than there is in zone 20 (zones 10 and 50 have fewer records). There is also some indication that catch rates are slightly higher in general in zone 20 than in zone 50 or 60. This plot clearly shows the seasonal effect on SST. Figure 141 shows catch rate plotted against SST by zone and year. These plots suggest that there is more annual variation in the relationship of catch rate with SST in zone 50 than in zone 20 or 60, but this may be a result of the much smaller number of shots in zone 50 compared to either zone 20 or 60.

Plots showing catch rates against SST by latitude and month indicate that while there is clear seasonal variation in the results (note the differences between the bottom row (Jan/Feb) and the third row (Jul/Aug), as has been demonstrated in other plots, any patterns in variation due to latitude (across each row) is not so clear (Figure 142). The same data plotted by latitude and year show patterns that are fairly consistent across regions and years (Figure 143). Perhaps the response to SST was greater in the most southern latitudes prior to 1998 compared to later years (compare the bottom two panels in the left column with the rest of the column), and perhaps there is a difference between areas in 2005 and 2006 (examine the top row) with an increase in response to SST in the more northern latitudes, but any effects are minimal.

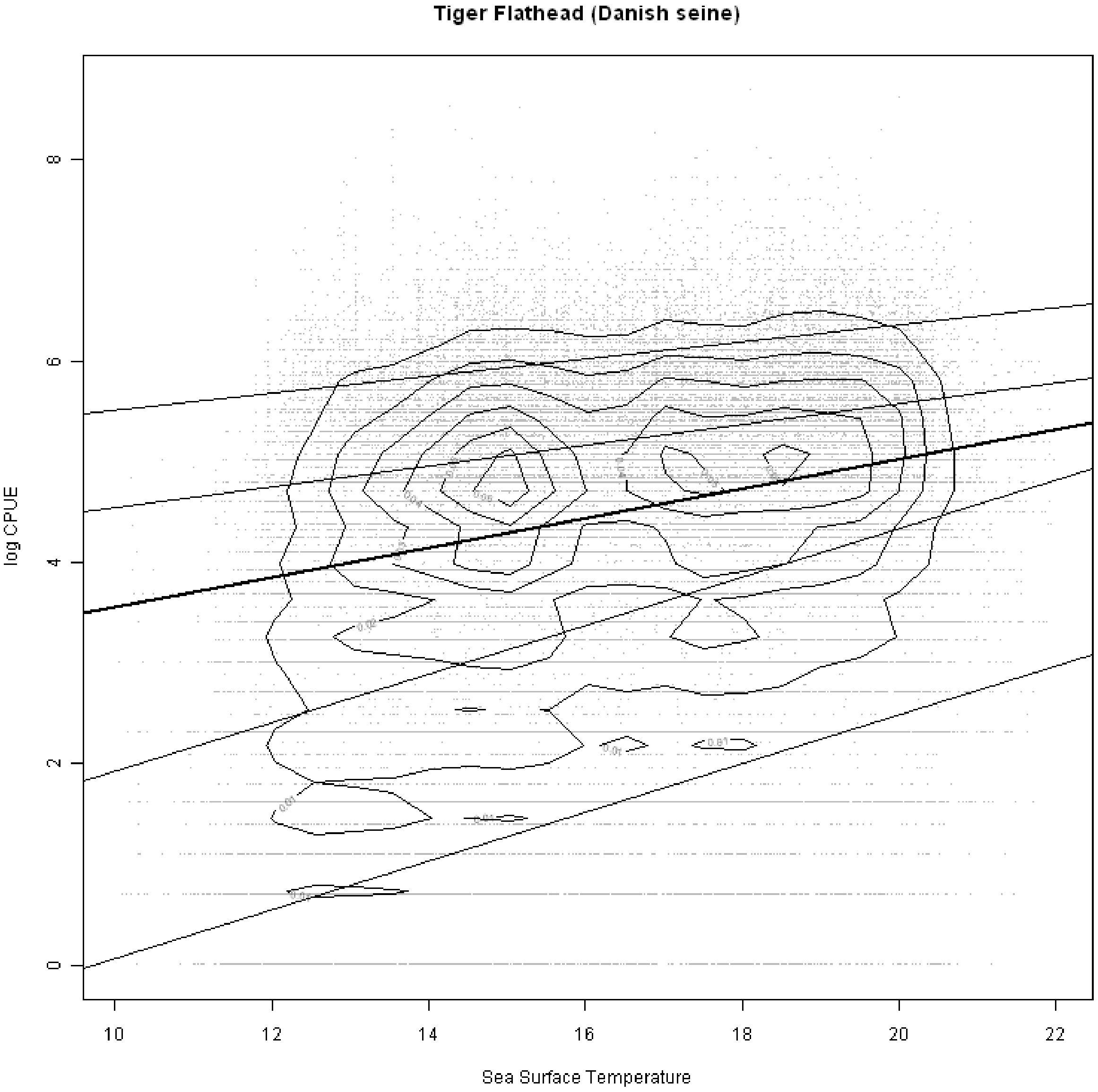

Figure 135. Tiger flathead (Danish seine) vs SST: log catch rate plotted against environmental variables. For all quantile regression lines plotted, there appears to be an increase in catch rate associated with an increase in SST.

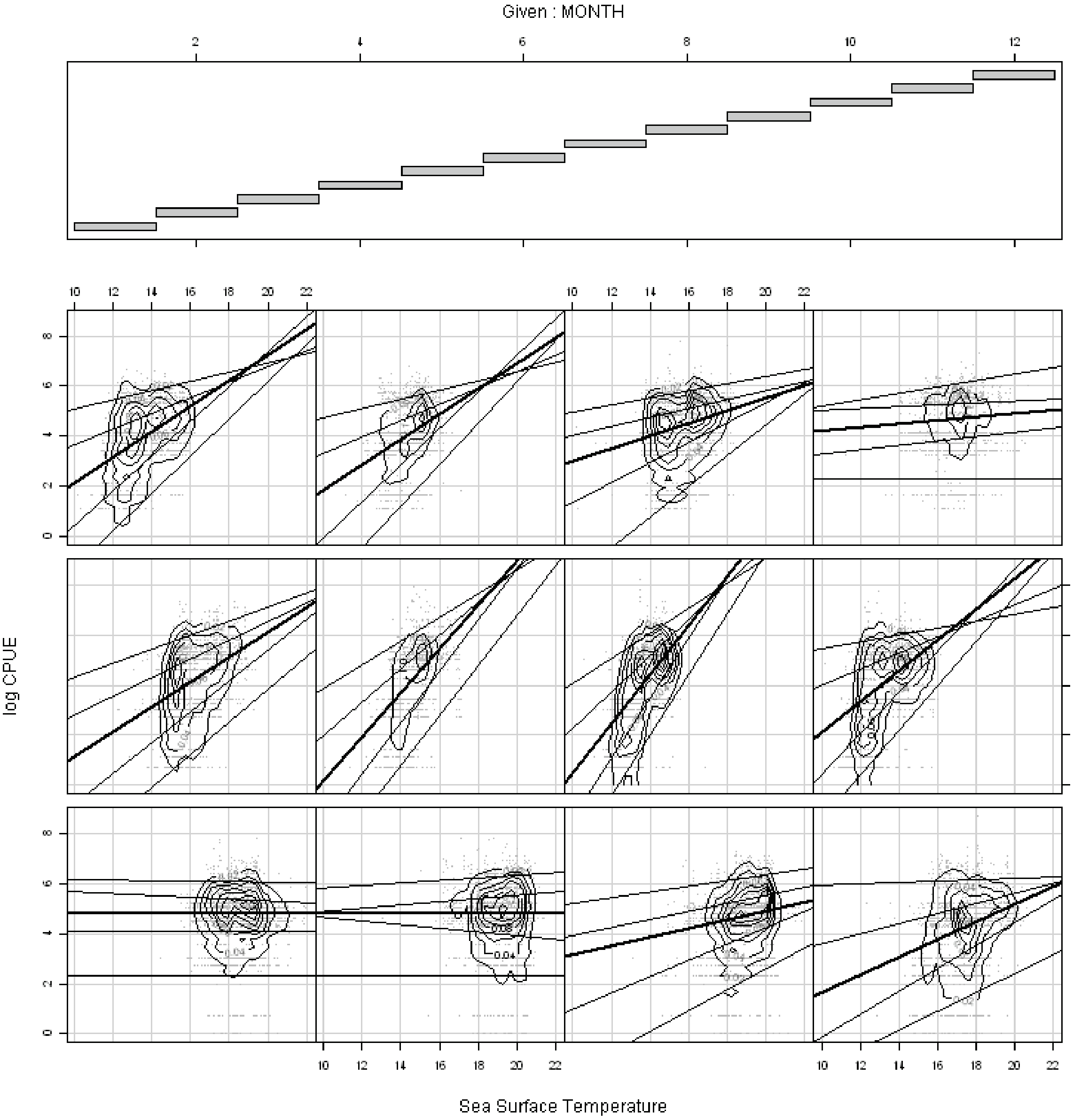

Figure 136. Tiger flathead (Danish seine) vs SST by month: log catch rate plotted against environmental variables. This plot shows the seasonal variation in any relationship between catch rate and environmental variables. The lower left corner corresponds to January, with February to the immediate right and then progressing left to right across each row successively and then up each row with the box on the right of the top row corresponding to December.

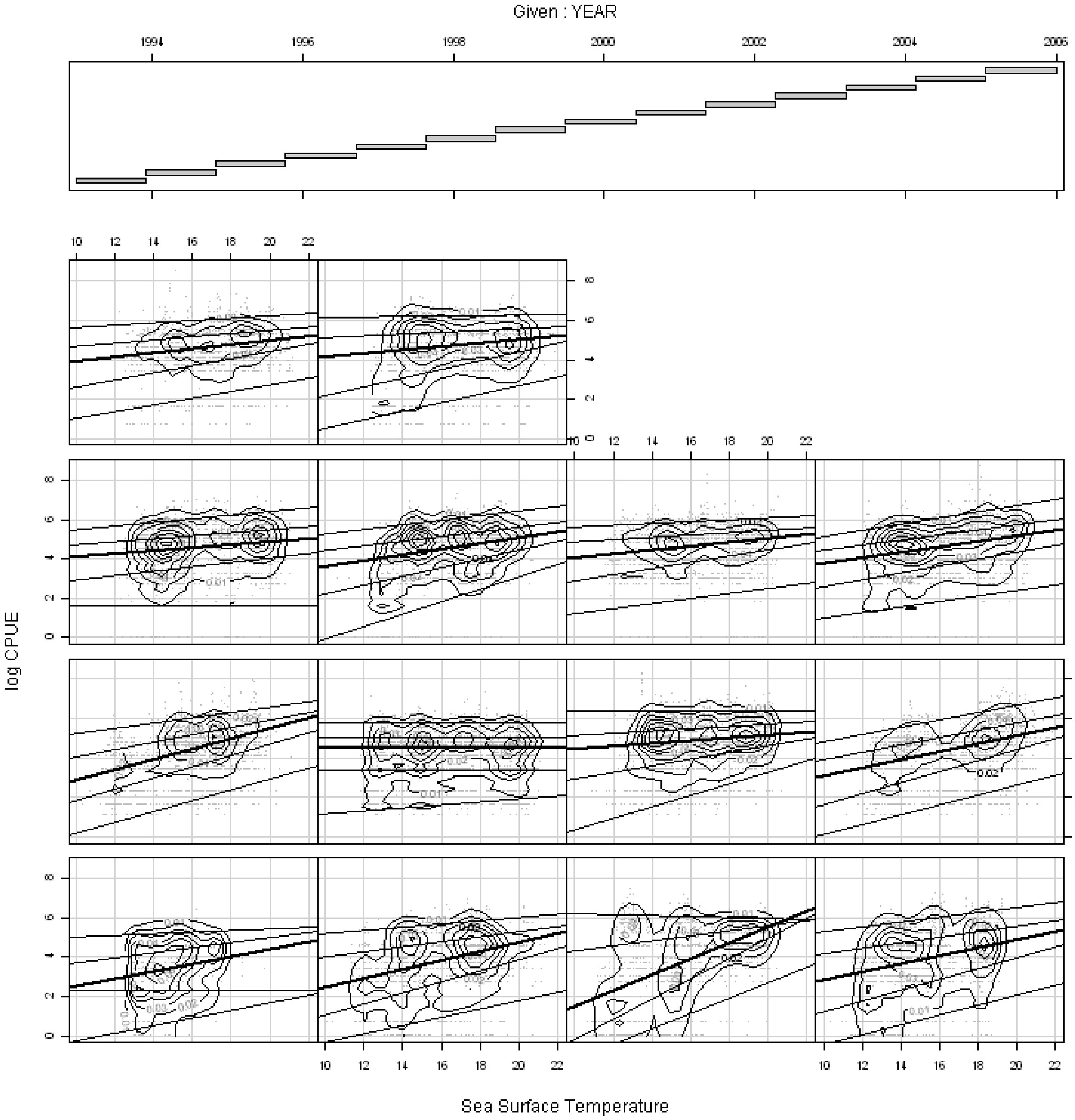

Figure 137. Tiger flathead (Danish seine) vs SST by year: log catch rate plotted against environmental variables. This plot shows the annual variation in the relationship between catch rate and environmental variables. The lower left corner corresponds to 1993, with 1994 to the immediate right and then progressing left to right across each row with the box on the right of the top row corresponding to 2006.

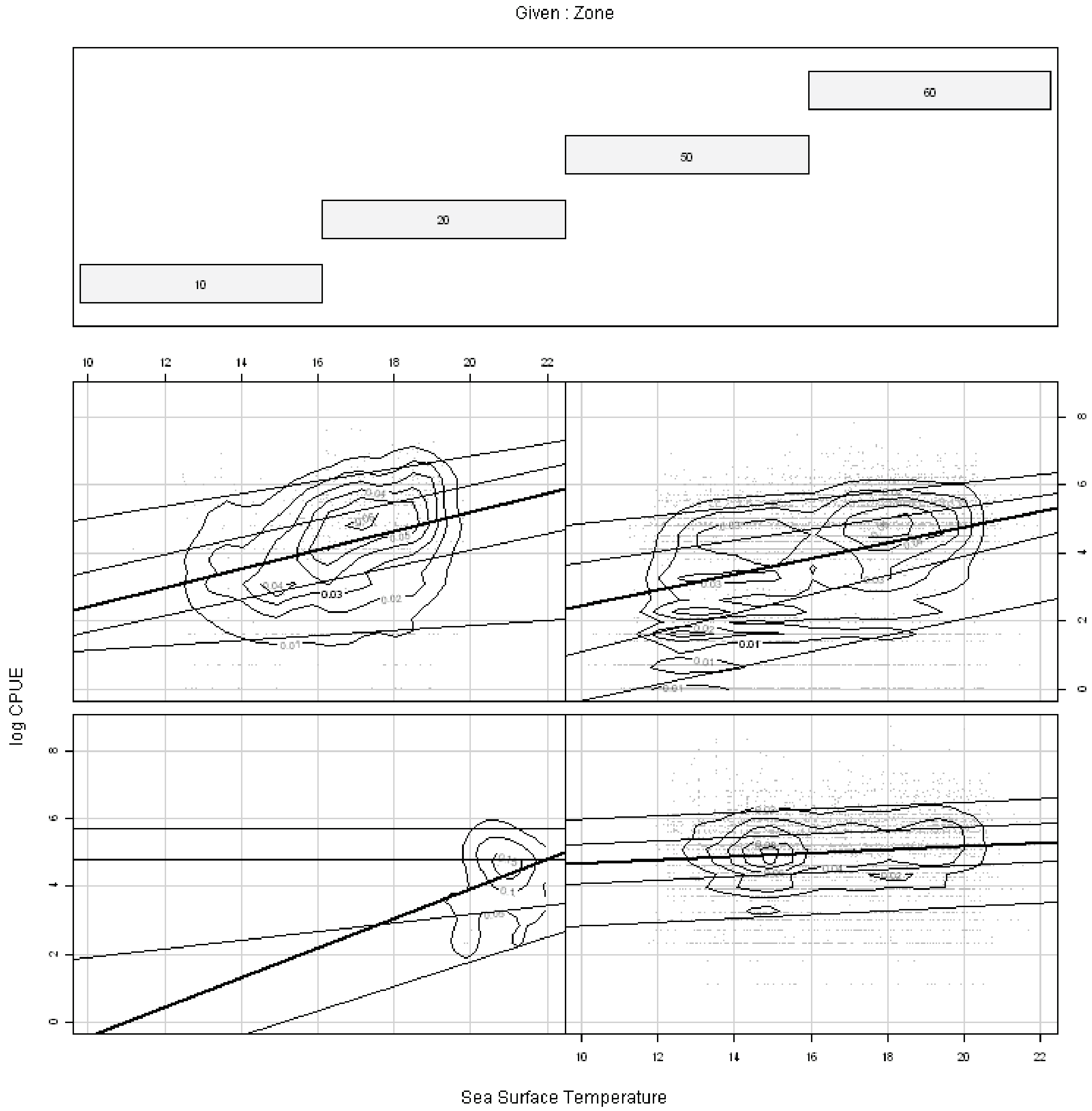

Figure 138. Tiger flathead (Danish seine) vs SST by zone: log catch rate plotted against environmental variables. This plot shows the spatial variation (by zone) in the relationship between catch rate and environmental variables. The lower left corner corresponds to zone 10 (less than 100 records), lower right is zone 20 (more than 40,000 records), top left is zone 50 (less than 4,000 records) and the top right is zone 60 (more than 50,000 records). Zone 10 has too few records to draw any sensible conclusion.

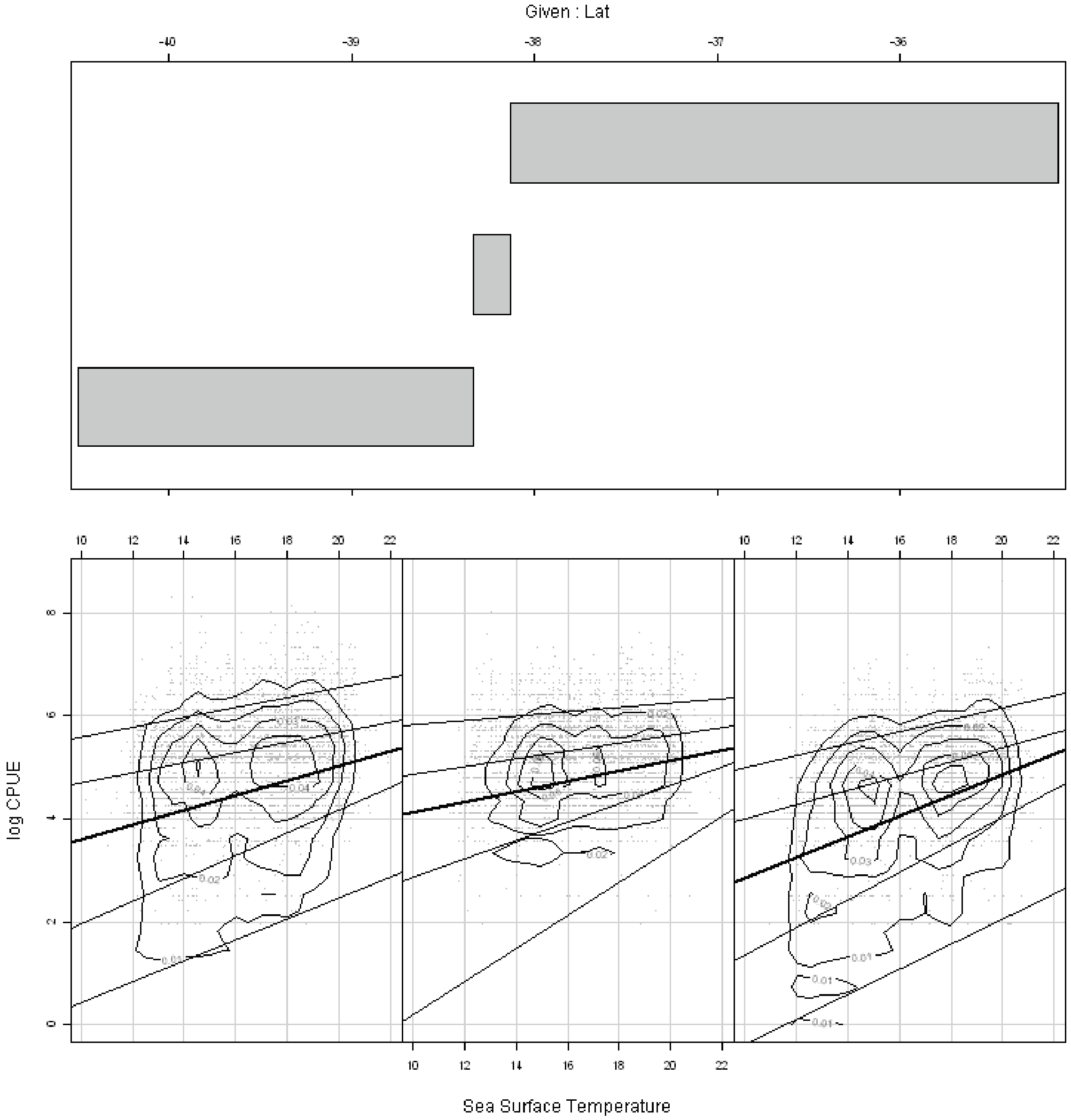

Figure 139: Tiger flathead (Danish seine) vs SST by latitude: log catch rate plotted against environmental variables. This plot shows the spatial variation (by latitude) in the relationship between catch rate and environmental variables. The left panel corresponds to southern latitudes (south of 38.333 degrees), and the right panel to northern latitudes (north of 38.133 degrees), with the split in latitude chosen to give an equal number of shots in each panel.

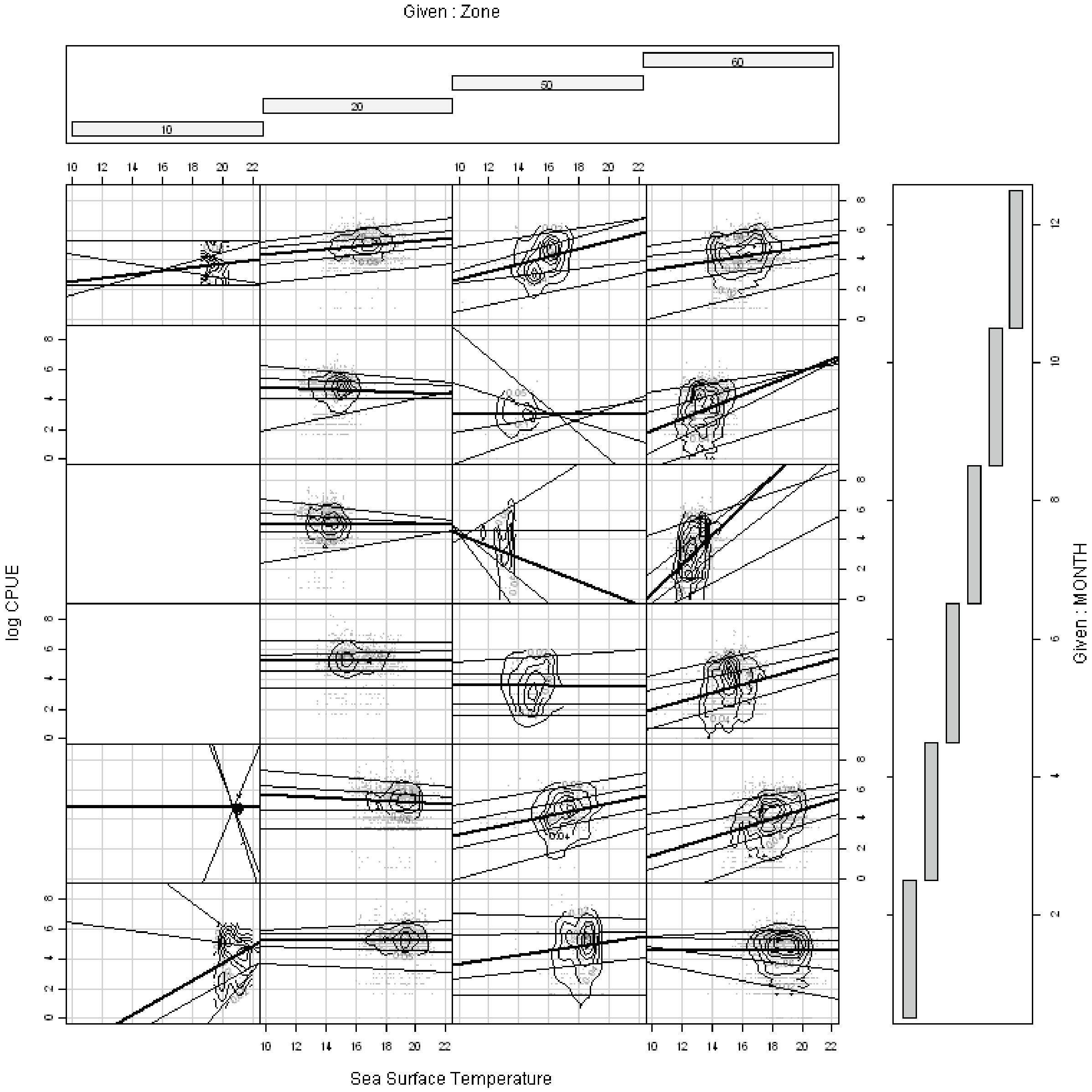

Figure 140. Tiger flathead (Danish seine) vs SST by zone and month: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

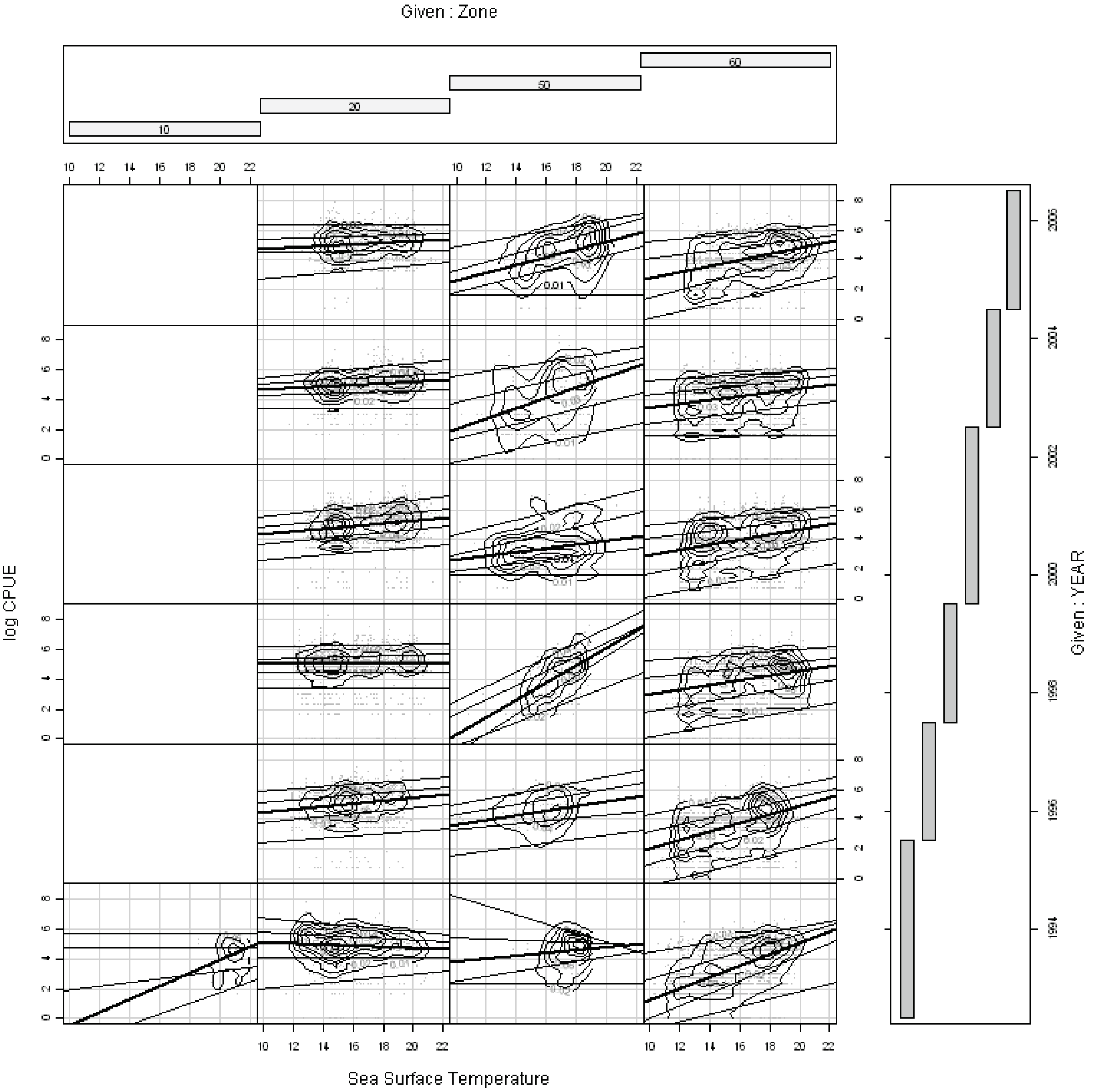

Figure 141. Tiger flathead (Danish seine) vs SST by zone and year: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two or three year blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two or three year time intervals (with the more recent years at the top).

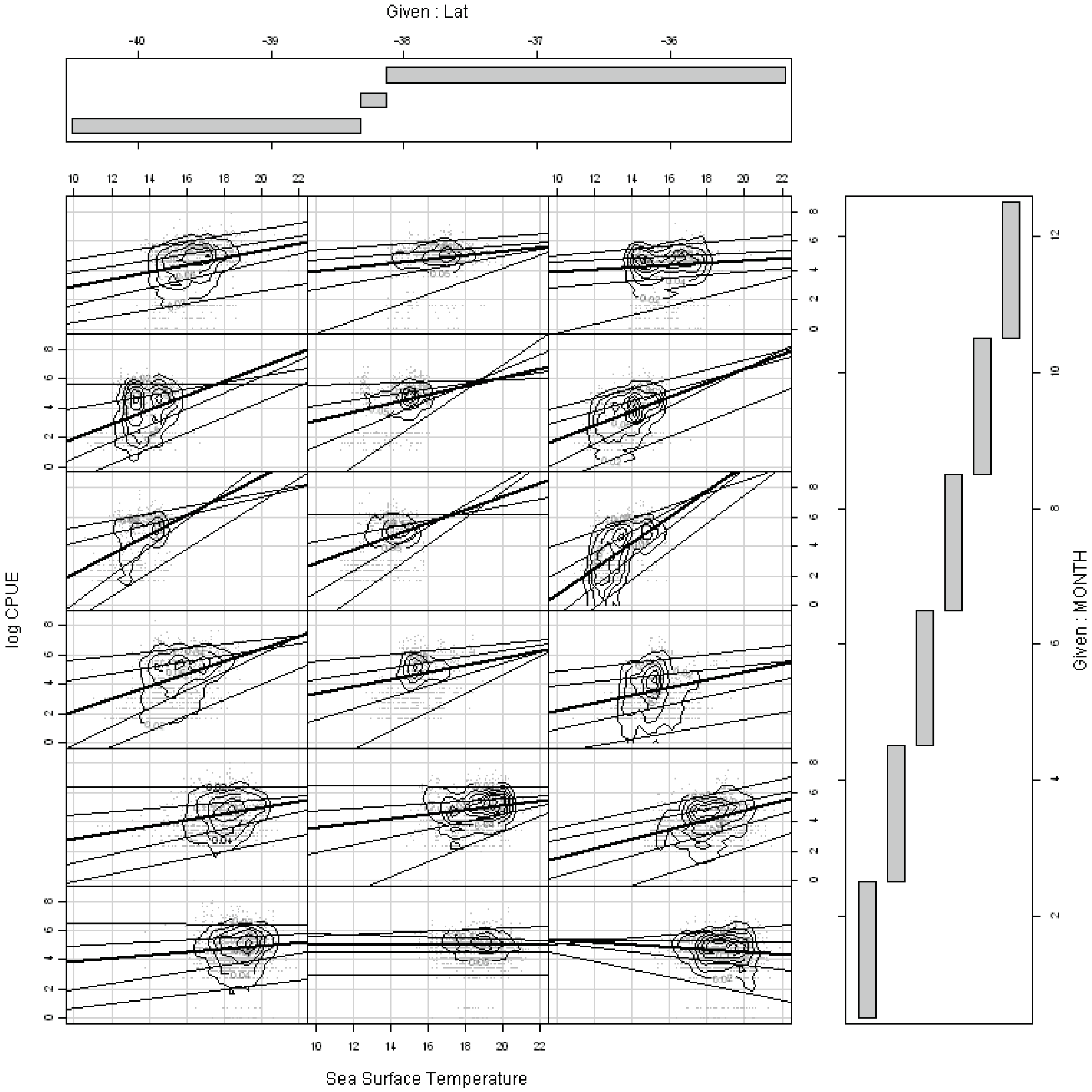

Figure 142. Tiger flathead (Danish seine) vs SST by latitude and month: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by latitude) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to latitudes: the left column corresponds to southern latitudes (south of 38.333 degrees), and the right column to northern latitudes (north of 38.133 degrees), with the split in latitude to give an equal number of shots in each column. The rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

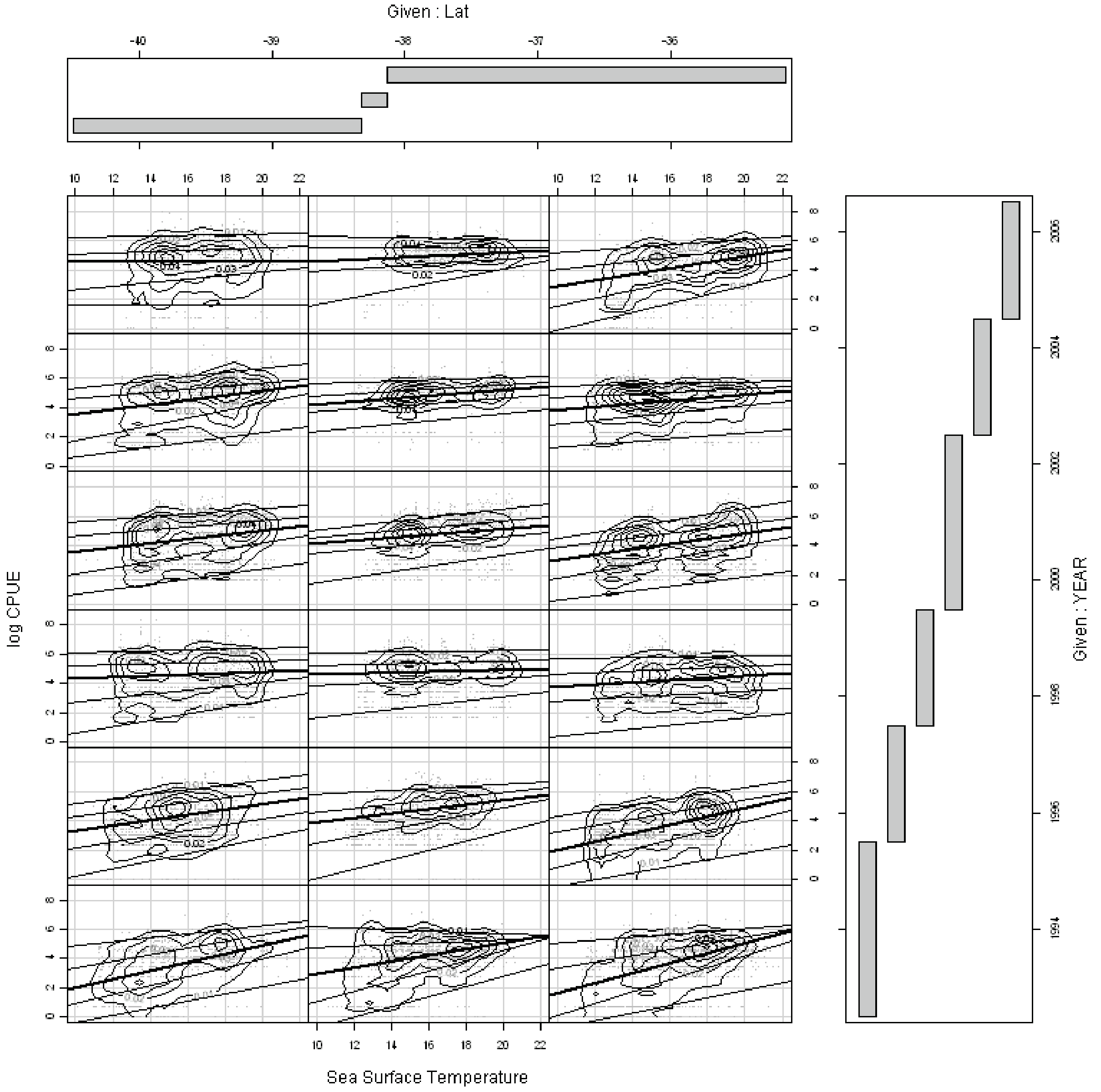

Figure 143. Tiger flathead (Danish seine) vs SST by latitude and year: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by latitude) and temporal variation (two or three year blocks) in the relationship between catch rate and environmental variables. The columns correspond to latitudes: the left column corresponds to southern latitudes (south of 38.333 degrees), and the right column to northern latitudes (north of 38.133 degrees), with the split in latitude to give an equal number of shots in each column. The rows correspond to two or three year time intervals (with the more recent years at the top).

Tiger flathead Danish seine - temperature-at-depth

This section shows the data for tiger flathead caught by the Danish seine fleet, showing any relationship between catch rate and temperature-at-depth. The correlation of catch rates of tiger flathead caught by the Danish seine fleet with temperature-at-depth was 0.021, which is a very low correlation, suggesting no relationship between catch rate and temperature-at-depth. The combined data (all years, all seasons and all areas) is shown in Figure 144, where all shots are included in a single plot. Figure 145 shows the same data broken down by zone and month, and suggests that there may be some interaction between season and zone, in any relationship between catch rate and temperature-at-depth.

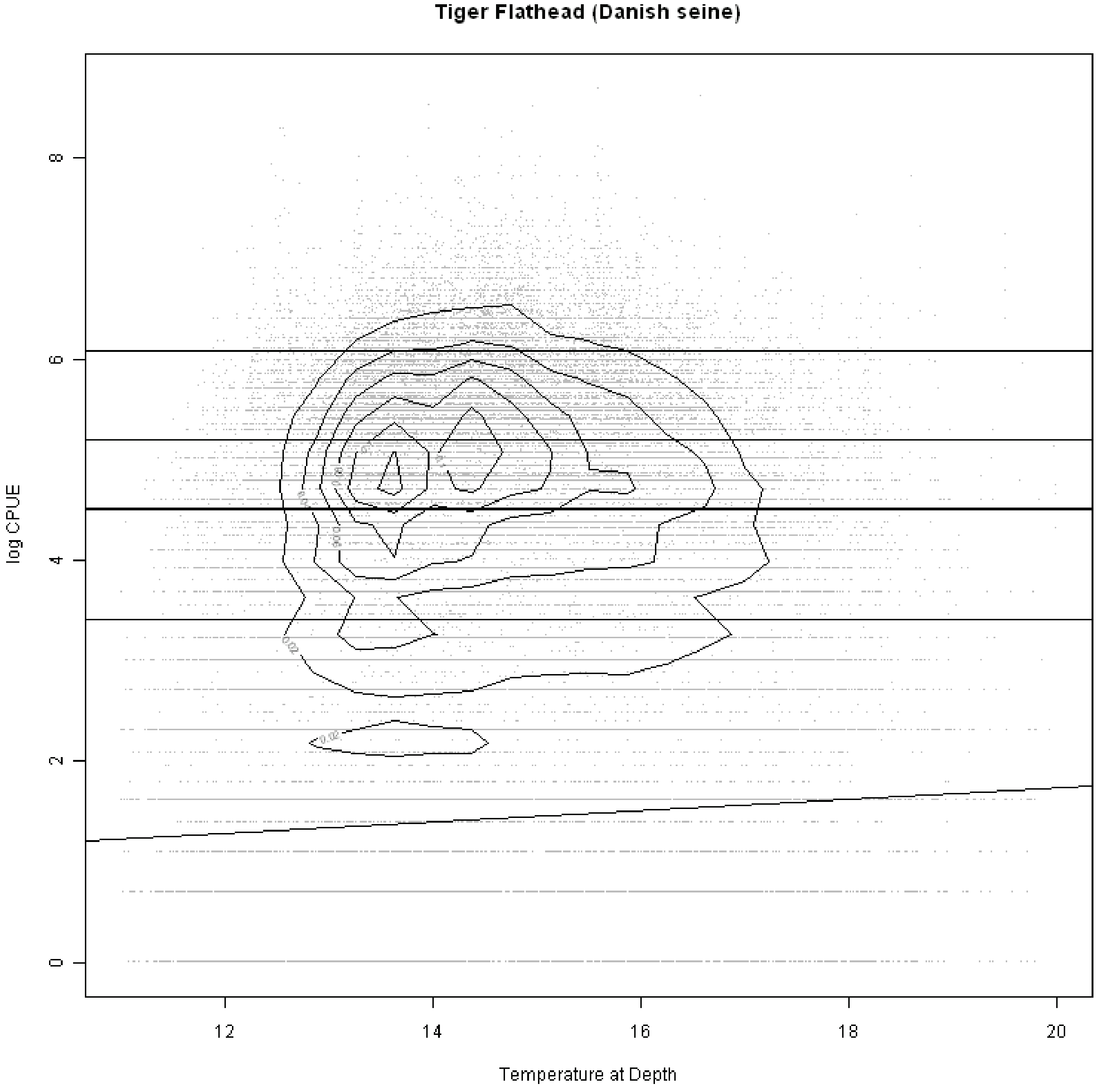

Figure 144. Tiger flathead (Danish seine) vs temperature-at-depth: log catch rate plotted against environmental variables.

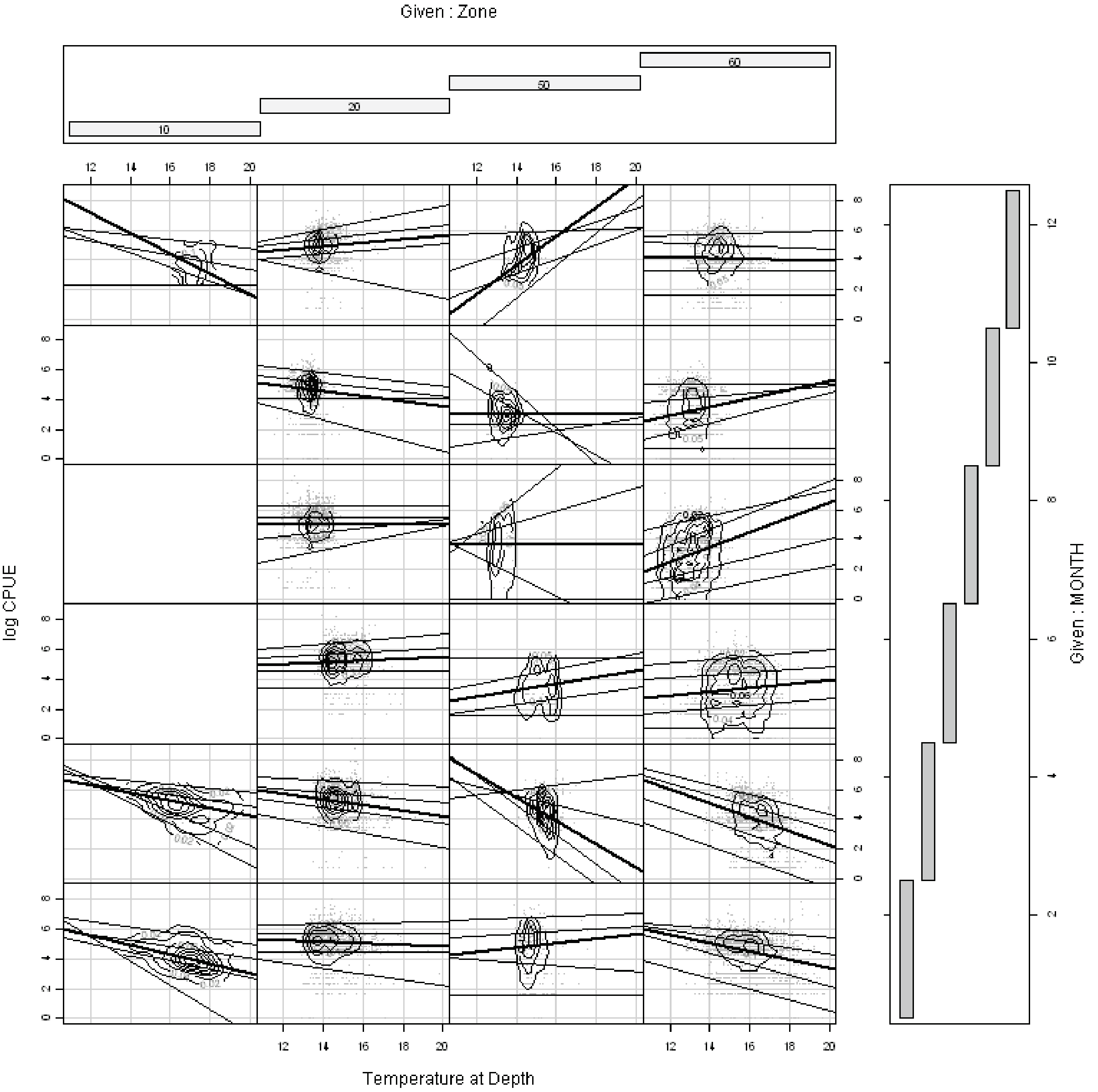

Figure 145. Tiger flathead (Danish seine) vs temperature-at-depth by zone and month: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the correlation between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Tiger flathead Danish seine - magnetic anomaly

This section presents the data for tiger flathead caught by the Danish seine fleet, showing the relationship between catch rate and magnetic anomaly. The correlation of catch rates of tiger flathead caught by the Danish seine fleet with magnetic anomaly was -0.173 and was the second highest correlation with an environmental variable for tiger flathead caught by the Danish seine fleet. The combined data (all years, all seasons and all areas) is shown in Figure 146. There appears to be a slight decrease in catch rate associated with an increase in magnetic anomaly for the lower catch rates. The slightly steeper slope for the 5% quantile regression line suggests that the response to magnetic anomaly is greater when the catch rates are low. Plots broken into zone (Figure 147) and latitude (Figure 148) suggest that there is some variation in any relationship between catch rate and magnetic anomaly as latitude and zone change. Magnetic anomaly has no temporal component so differences with temporal variables are not meaningful.

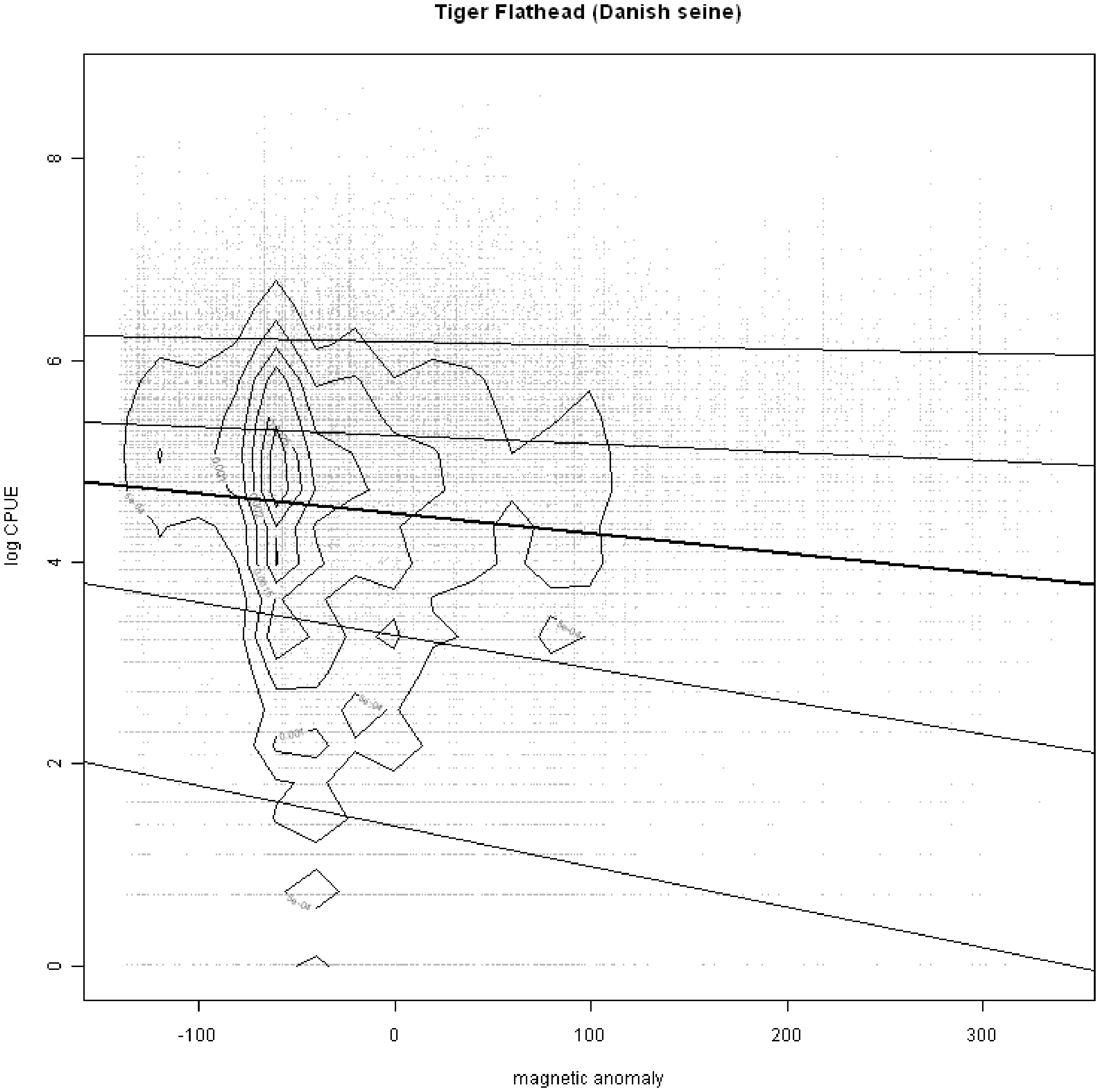

Figure 146. Tiger flathead (Danish seine) vs magnetic anomaly: log catch rate plotted against environmental variables.

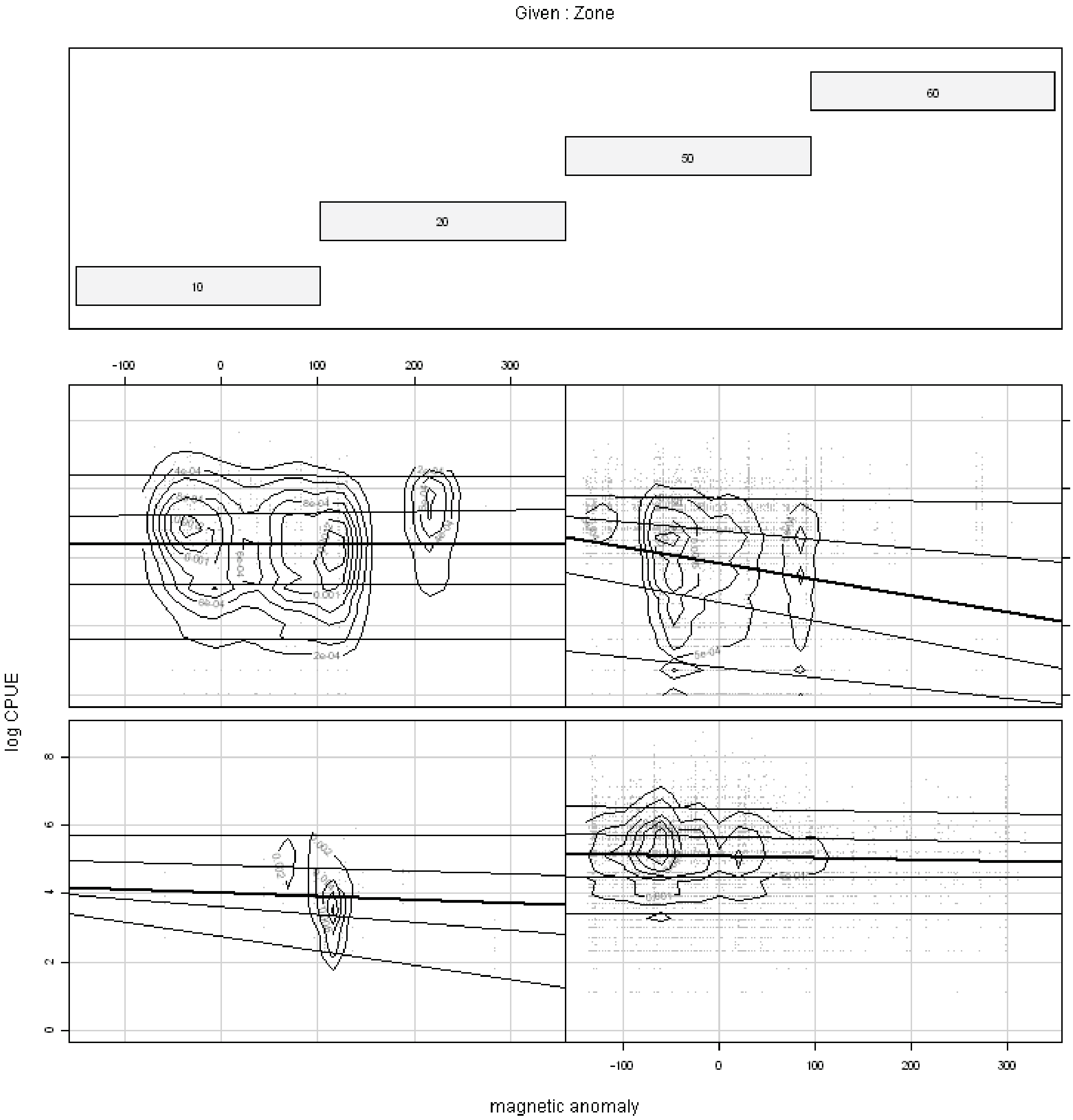

Figure 147. Tiger flathead (Danish seine) vs magnetic anomaly by zone: log catch rate plotted against environmental variables. This plot shows the spatial variation (by zone) in the relationship between catch rate and environmental variables. The lower left corner corresponds to zone 10 (around 1000 records), lower right is zone 20 (more than 50,000 records), top left is zone 50 (less than 5,000 records) and the top right is zone 60 (more than 75,000 records). Zone 10 has too few records to draw any sensible conclusion.

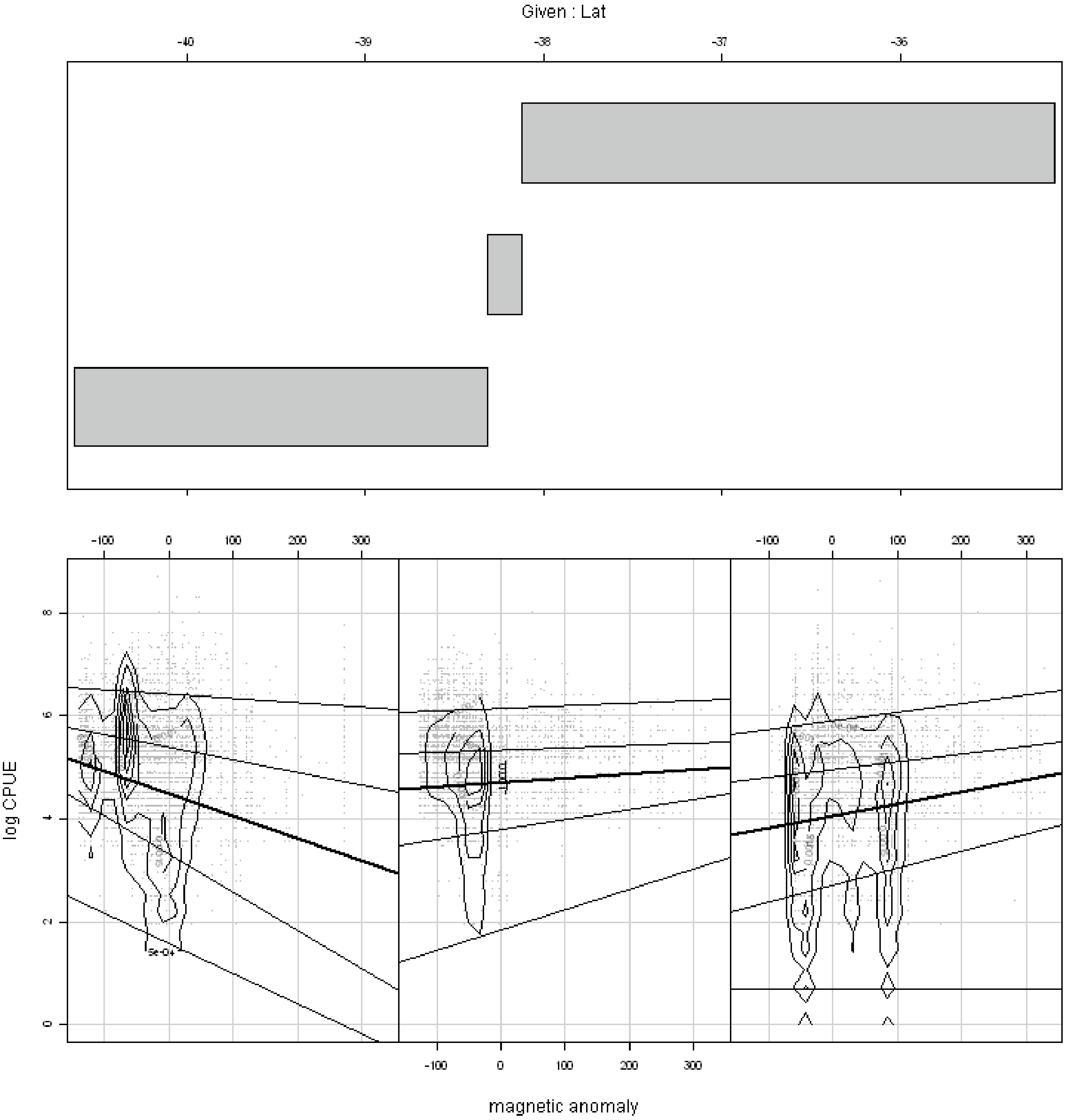

Figure 148. Tiger flathead (Danish seine) vs magnetic anomaly by latitude: log catch rate plotted against environmental variables. This plot shows the spatial variation (by latitude) in the relationship between catch rate and environmental variables. The left panel corresponds to southern latitudes (south of 38.317 degrees), and the right panel to northern latitudes (north of 38.125 degrees), with the split in latitude to give an equal number of shots in each panel.

Tiger flathead otter trawl - SST

This section shows the relationship between catch rate and SST data for tiger flathead caught by the otter trawl fleet, showing the. The correlation of catch rates of tiger flathead caught by the otter trawl fleet with SST is -0.040 which is very low, suggesting no relationship between catch rate and SST. The plot of these data show little of no trend (Figure 149). Separated by zone and month, there appears to be some interaction between season and zone, in any relationship between catch rate and SST (Figure 150).

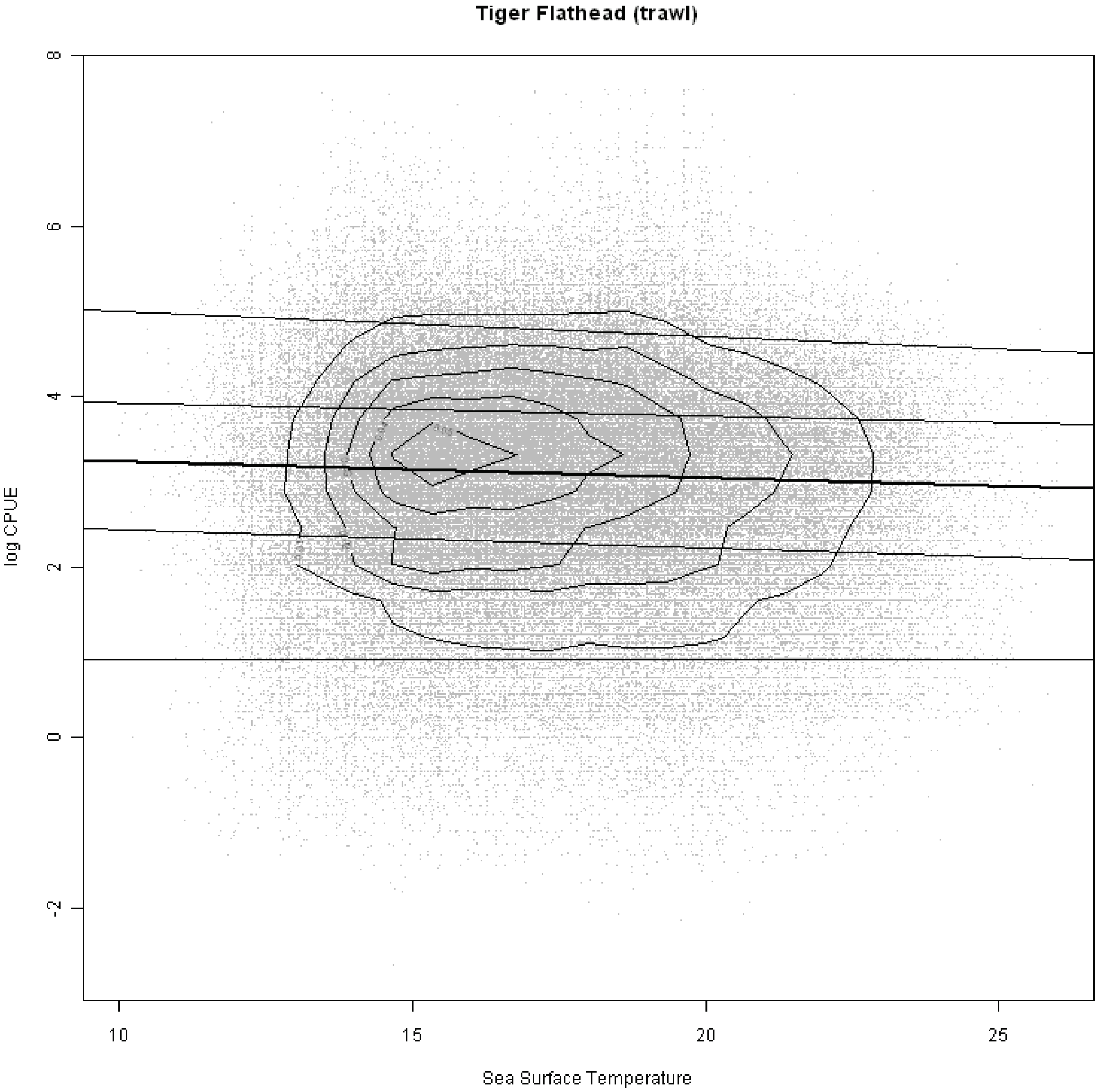

Figure 149. Tiger flathead (otter trawl) vs SST: log catch rate plotted against environmental variables.

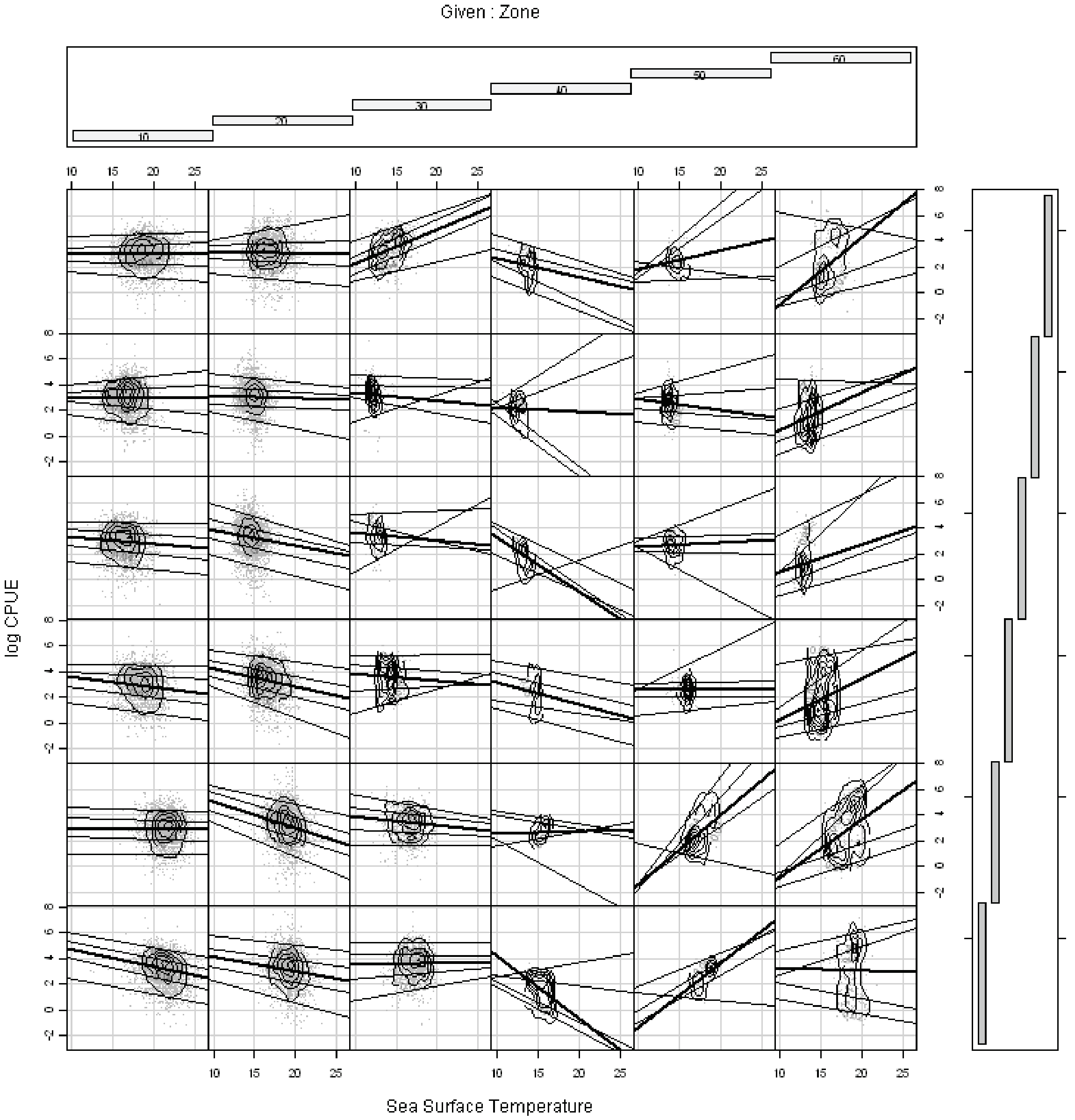

Figure 150. Tiger flathead (otter trawl) vs SST by zone and month: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Tiger flathead otter trawl - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for tiger flathead caught by the otter trawl fleet. The correlation of catch rates of tiger flathead caught by the Danish seine fleet with temperature-at-depth is 0.009 which is very low, suggesting no relationship between catch rate and temperature-at-depth. This is supported by a plot of the data (Figure 151), however, there may be some interaction between season and zone (Figure 152).

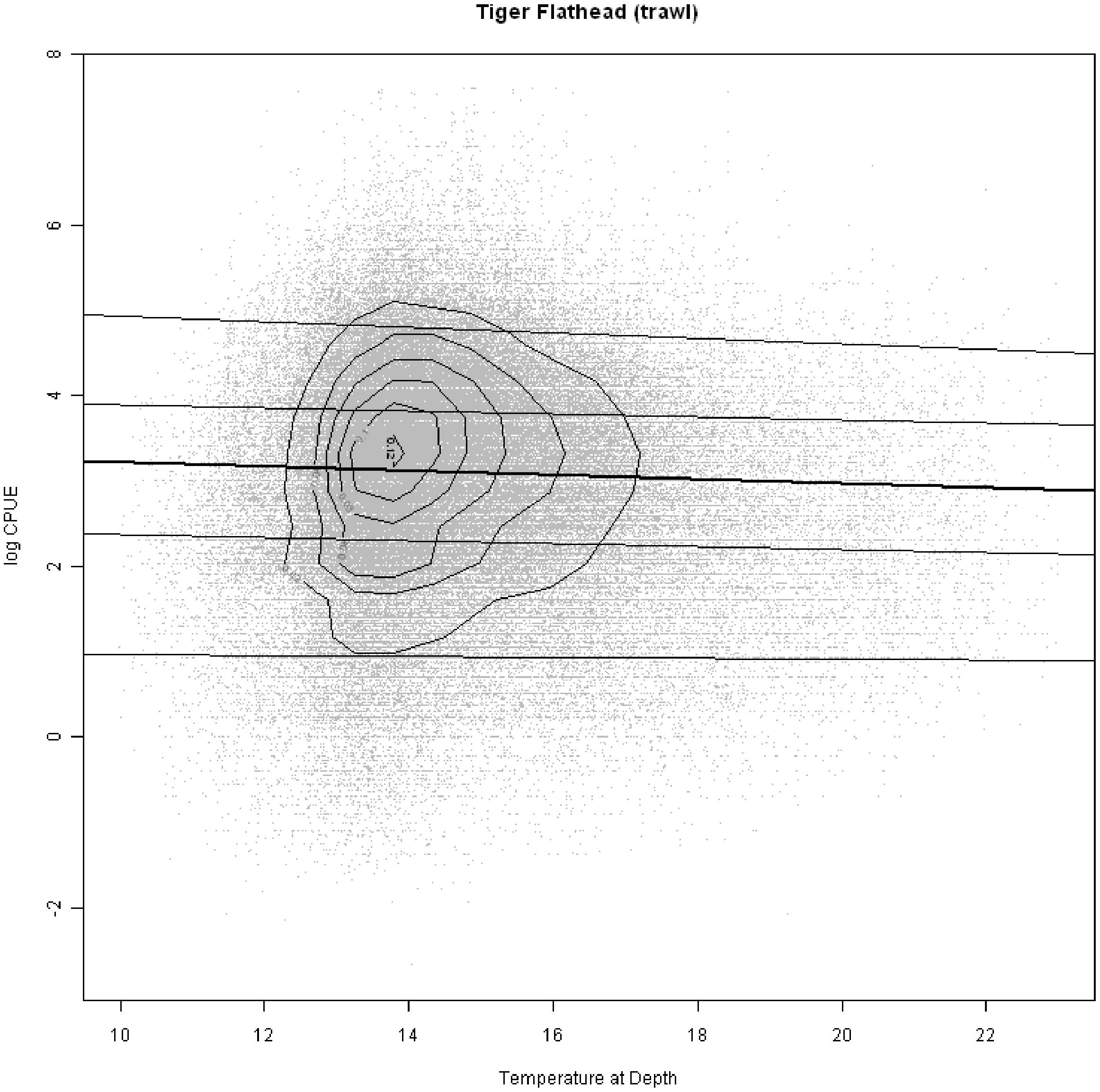

Figure 151. Tiger flathead (otter trawl) vs temperature-at-depth: log catch rate plotted against environmental variables.

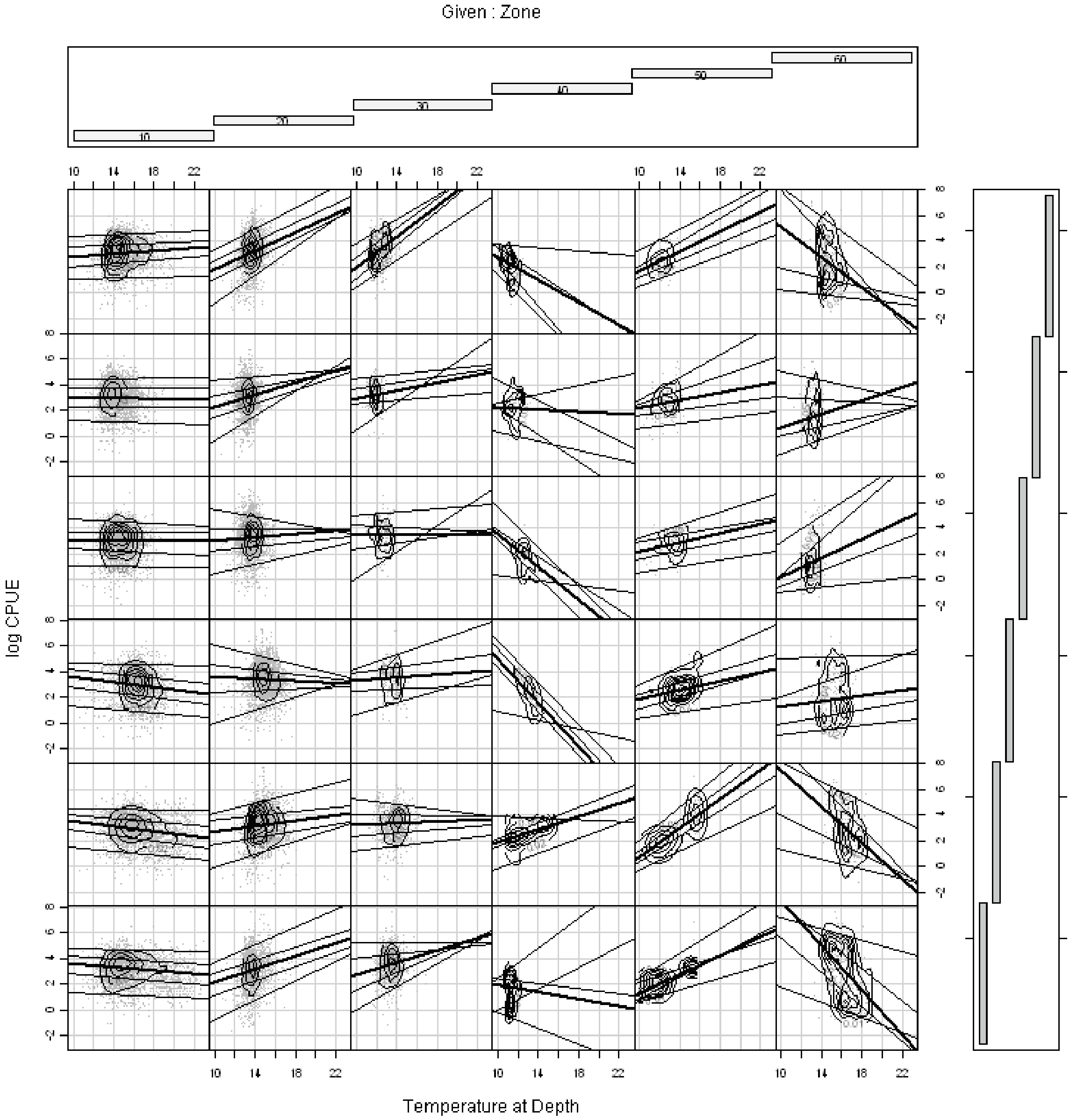

Figure 152. Tiger flathead (otter trawl) vs temperature-at-depth by zone and month: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Tiger flathead otter trawl - magnetic anomaly

This section shows the relationship between catch rate and magnetic anomaly data for tiger flathead caught by the otter trawl fleet. The correlation of catch rates of tiger flathead caught by the otter trawl fleet with magnetic anomaly is -0.111 and is the highest correlation with an environmental variable for tiger flathead caught by the otter trawl fleet. A plot of the combined data (all years, all seasons and all areas) is shown in Figure 153, and shows the negative relationship, particularly at high catch rates. Plots of the data separated by zone suggest that there is some variation in response of catch rate to magnetic anomaly between the different zones (Figure 154). It appears that magnetic anomaly has very little relationship with catch rate in zone 10, but there is a stronger effect in both zones 20 and 30, but with opposite effects.

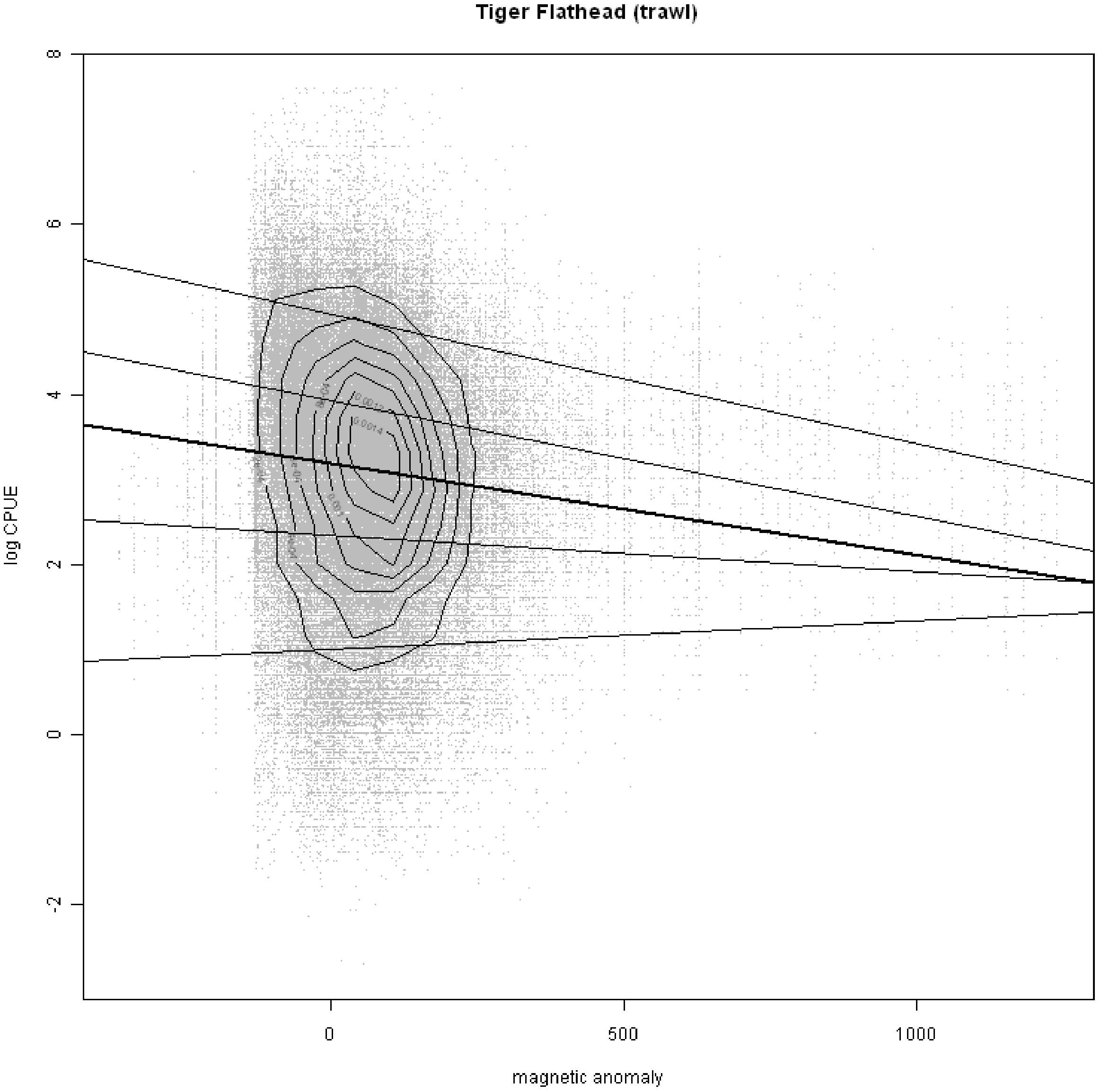

Figure 153. Tiger flathead (otter trawl) vs magnetic anomaly: log catch rate plotted against environmental variables.

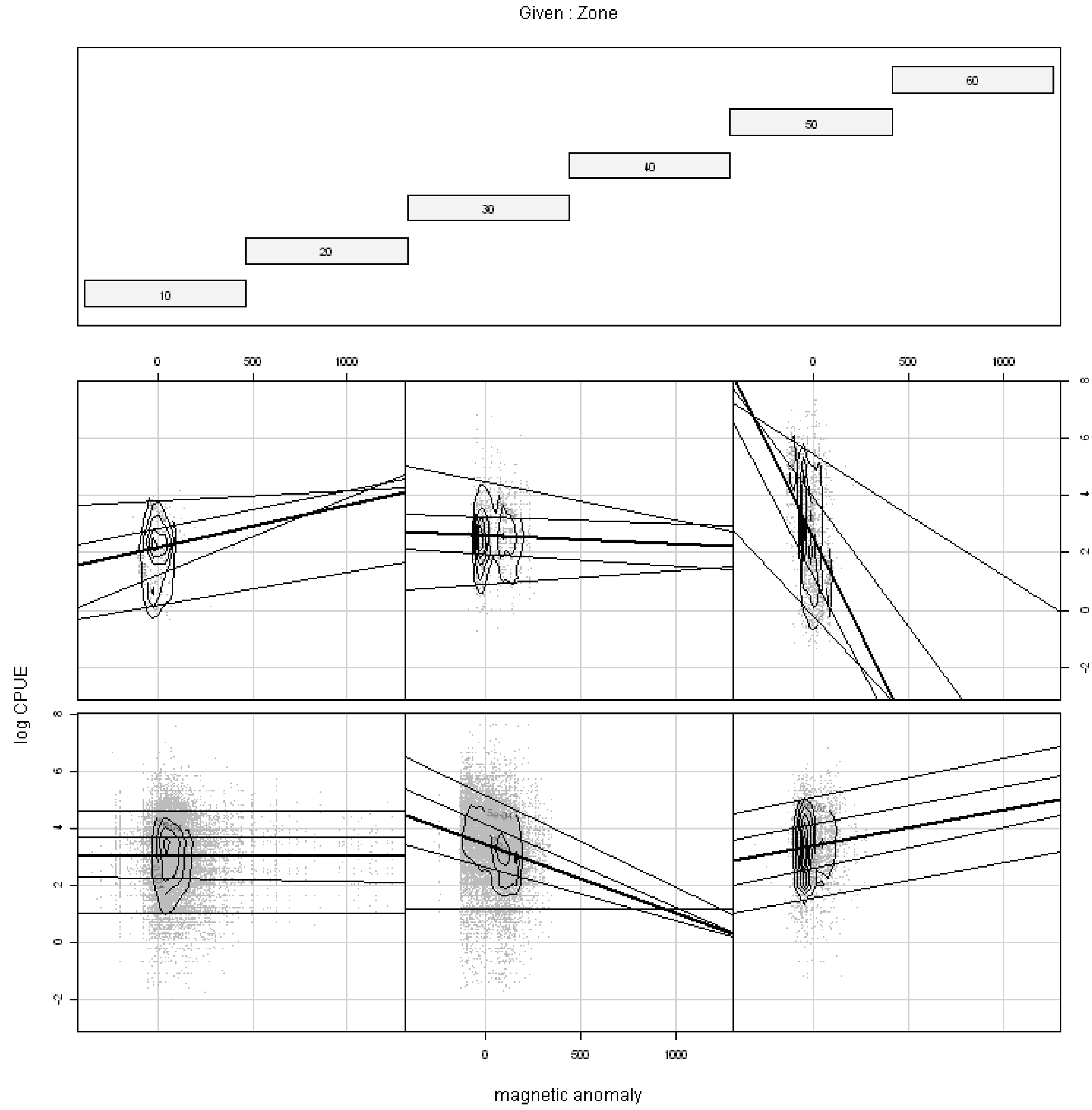

Figure 154. Tiger flathead (otter trawl) vs magnetic anomaly by zone: log catch rate plotted against environmental variables. This plot shows the spatial variation (by zone) in the relationship between catch rate and environmental variables. The lower left corner corresponds to zone 10 (around 100,000 records), lower middle is zone 20 (around 100,000 records), lower right is zone 30 (around 15,000 records), top left is zone 40 (around 1,000 records), middle left is zone 50 (around 5,000 records) and the top right is zone 60 (around 9,000 records).

Blue grenadier spawning SST

This section shows the relationship between catch rate and SST data for the blue grenadier spawning fishery. The correlation of catch rates of tiger blue grenadier spawning fishery with SST is 0.045 which is very low, suggesting no relationship between catch rate and SST. The combined data (all years, all seasons and all areas) is shown in Figure 155 and supports the low correlation showing no apparent relationship between catch rate and SST. A plot of the data separated by month and year suggests that there may be some interaction between year and month in any relationship between catch rate and SST.

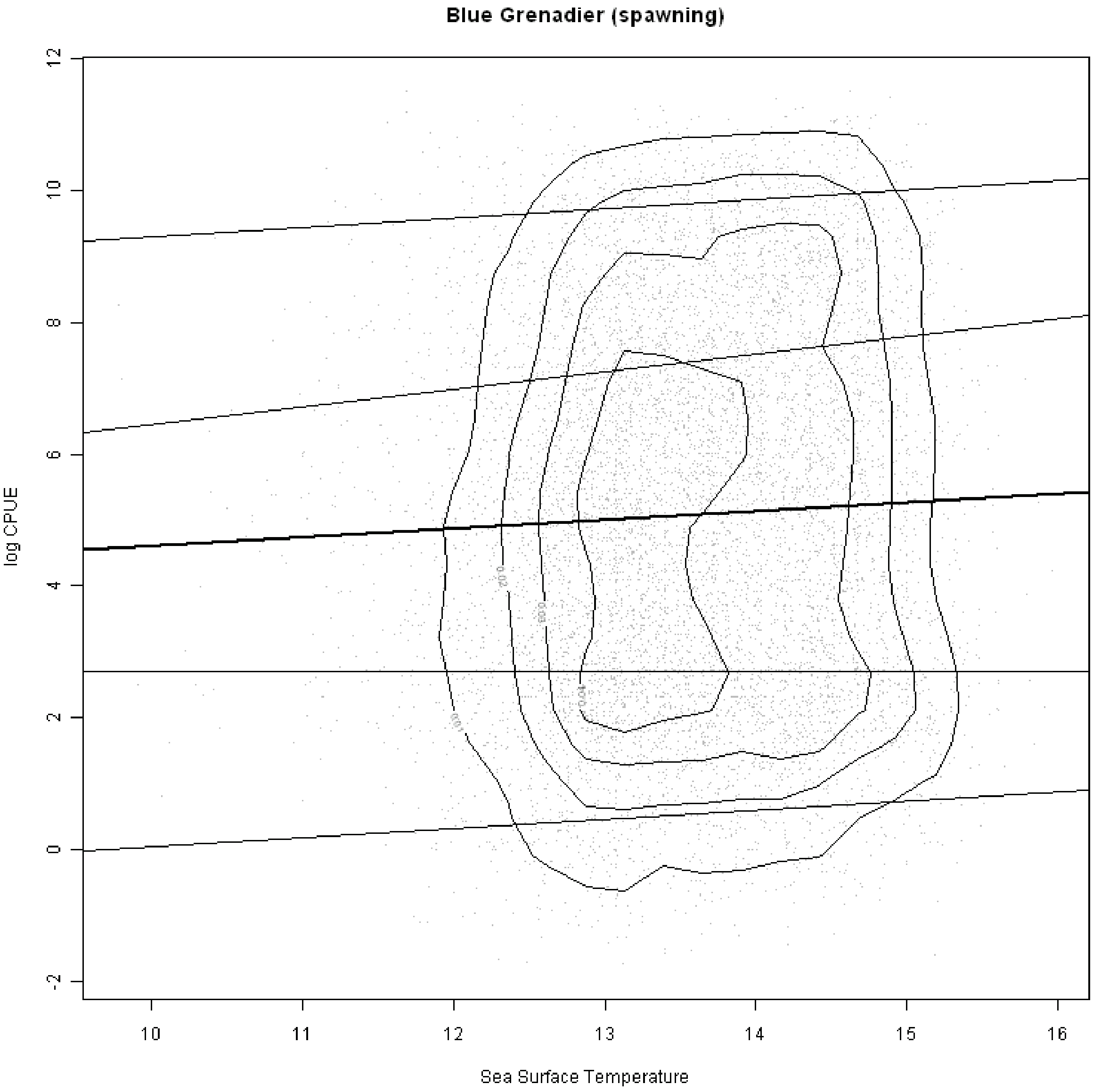

Figure 155. Blue grenadier (spawning) vs SST: log catch rate plotted against environmental variables.

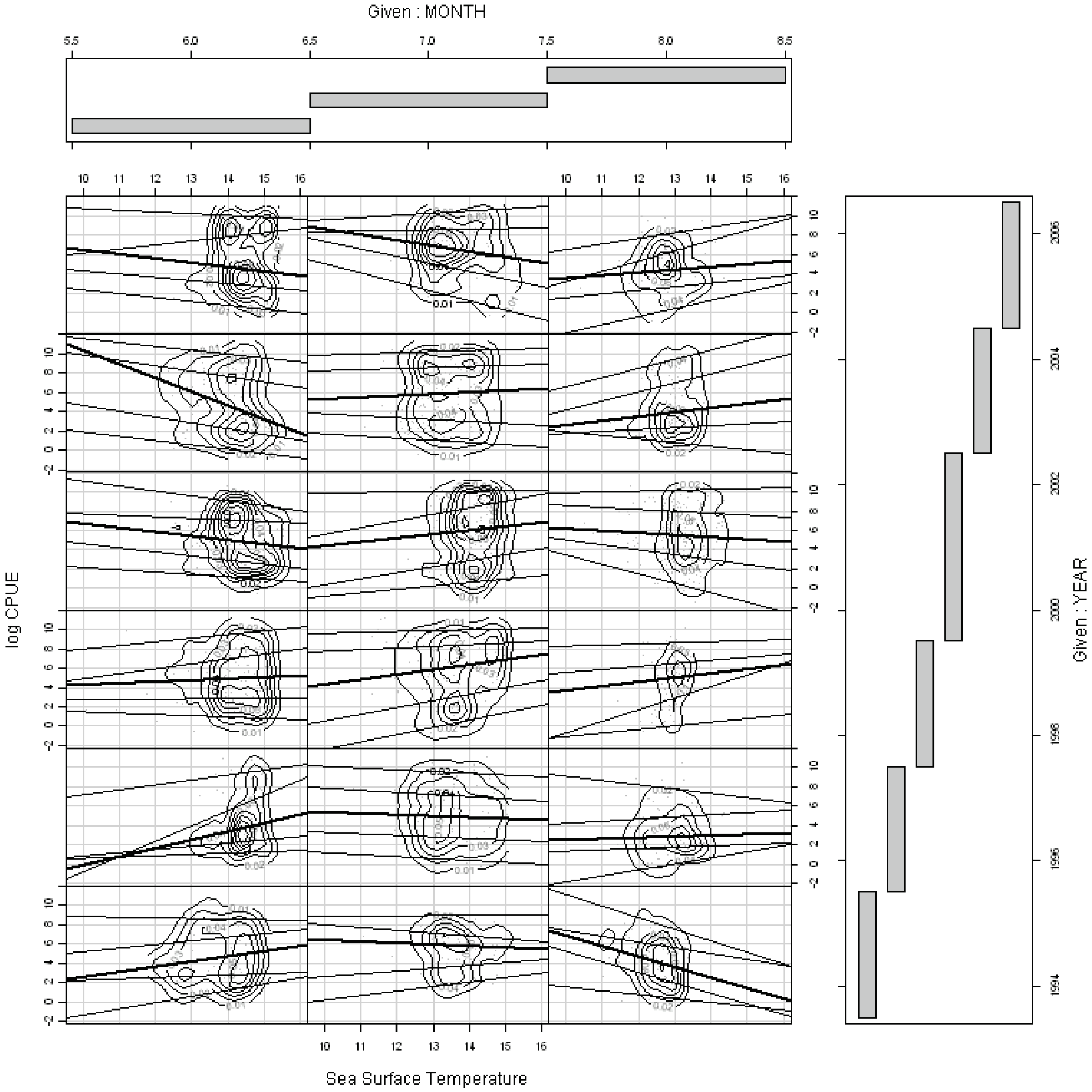

Figure 156. Blue grenadier (spawning) vs SST by month and year: log catch rate plotted against environmental variables. This plot shows the temporal variation in the relationship between catch rate and environmental variables. The rows correspond to two or three year time intervals (with the more recent years at the top) and the columns to the months June July and August.

Blue grenadier spawning - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for blue grenadier spawning fishery. The correlation of catch rates of blue grenadier spawning fishery with temperature-at-depth is 0.486 which is the largest correlation between catch rate and any environmental parameter for any of the cases examined here. A plot of the combined data (Figure 157) supports this high positive correlation. Separated by month and year, this relationship appears to hold true in all cases examined, with only little variation between months and years.

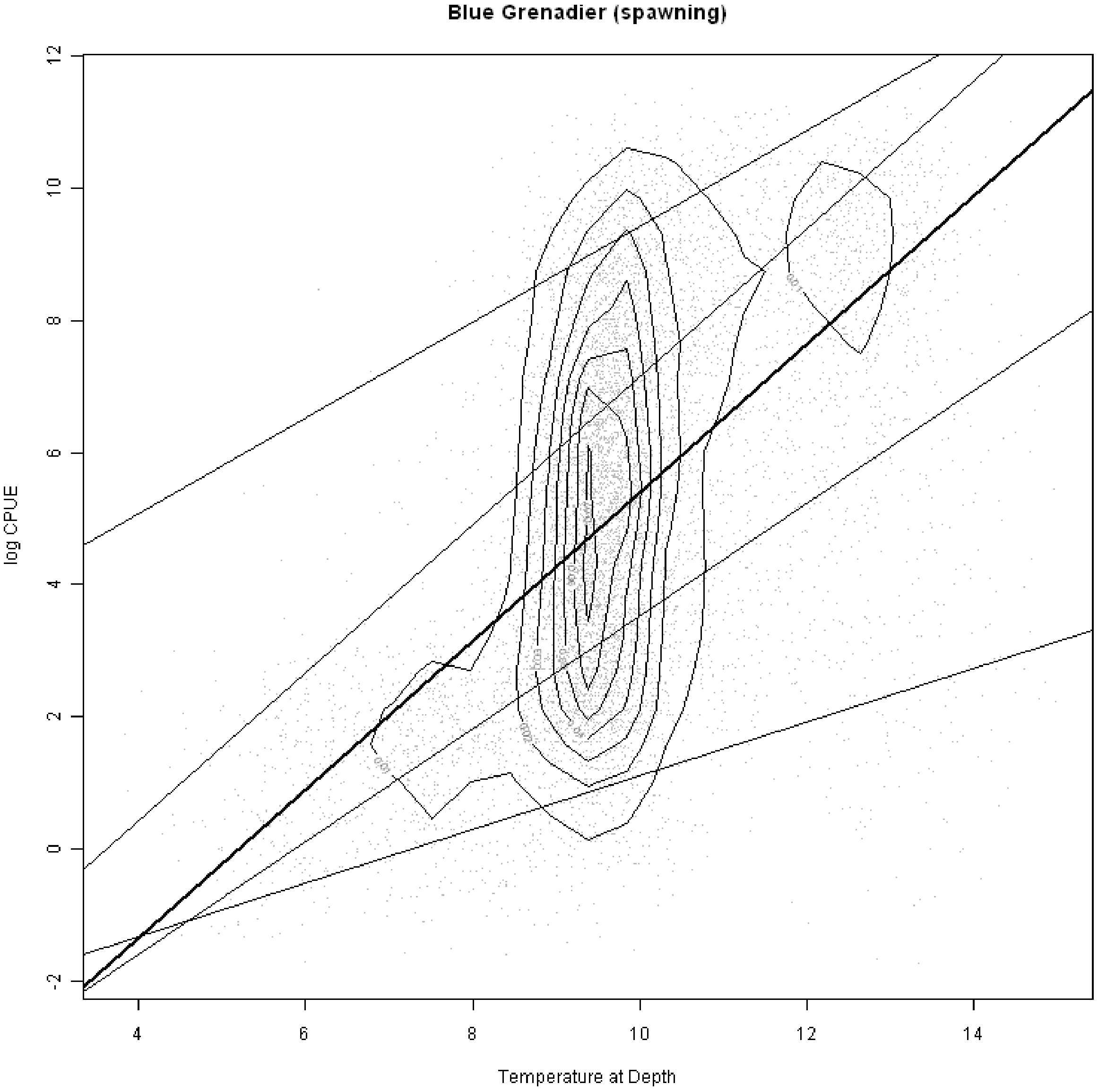

Figure 157. Blue grenadier (spawning) vs temperature-at-depth: log catch rate plotted against environmental variables.

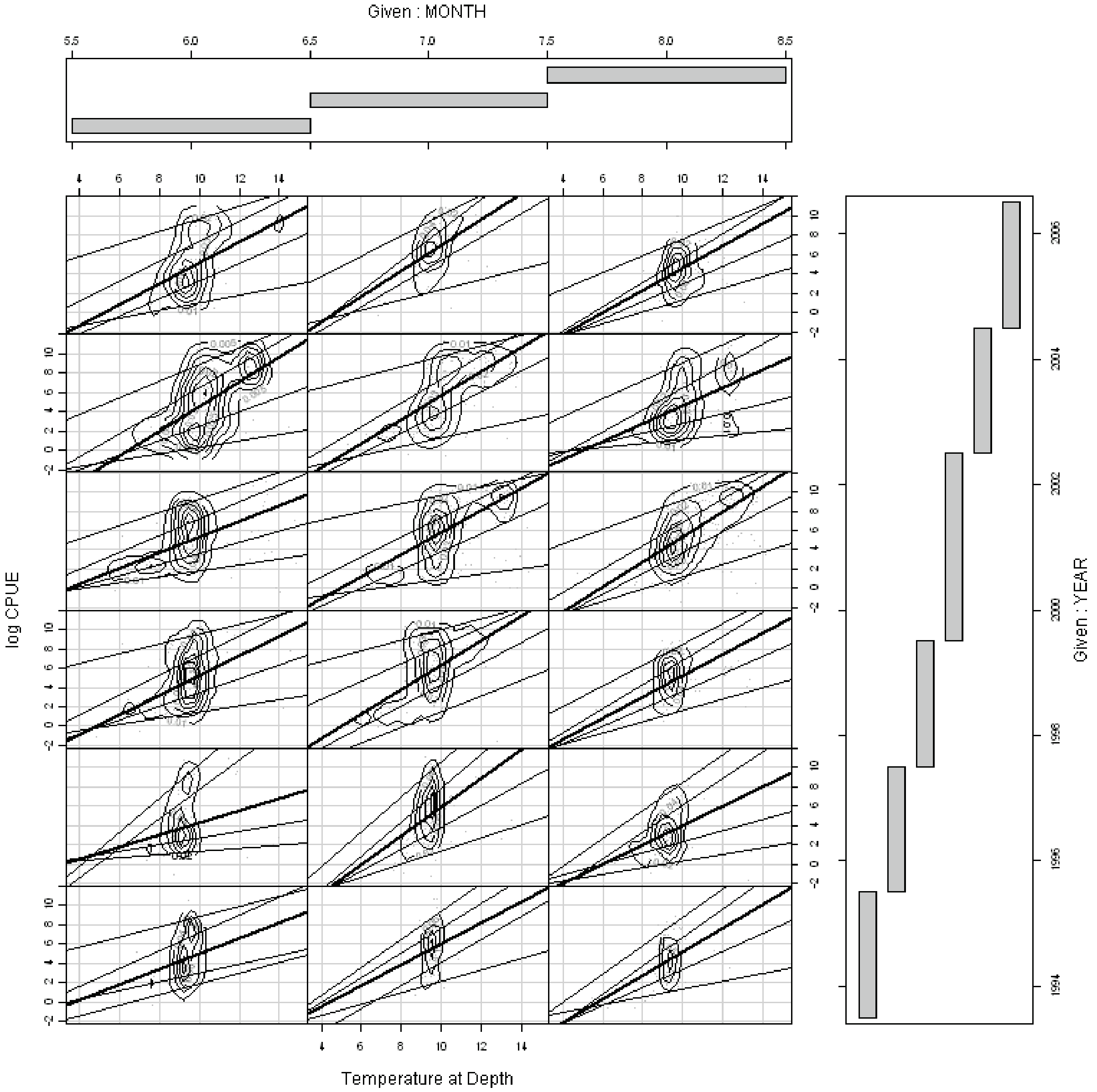

Figure 158. Blue grenadier (spawning) vs temperature-at-depth by month and year: log catch rate plotted against environmental variables. This plot shows the temporal variation in the relationship between catch rate and environmental variables. The rows correspond to two or three year time intervals (with the more recent years at the top) and the columns to the months June July and August respectively.

Blue grenadier spawning - mixed layer depth

This section shows the relationship between catch rate and mixed layer depth data for the blue grenadier spawning fishery. The correlation of catch rates of the blue grenadier spawning fishery with mixed layer depth was -0.137 which is low, suggesting no relationship between catch rate and SST. The plot of all records combined shows this weak negative correlation (Figure 159). There appears to be variation in any relationship with month (Figure 160), year (Figure 161) and an interaction of the two temporal scales (Figure 162).

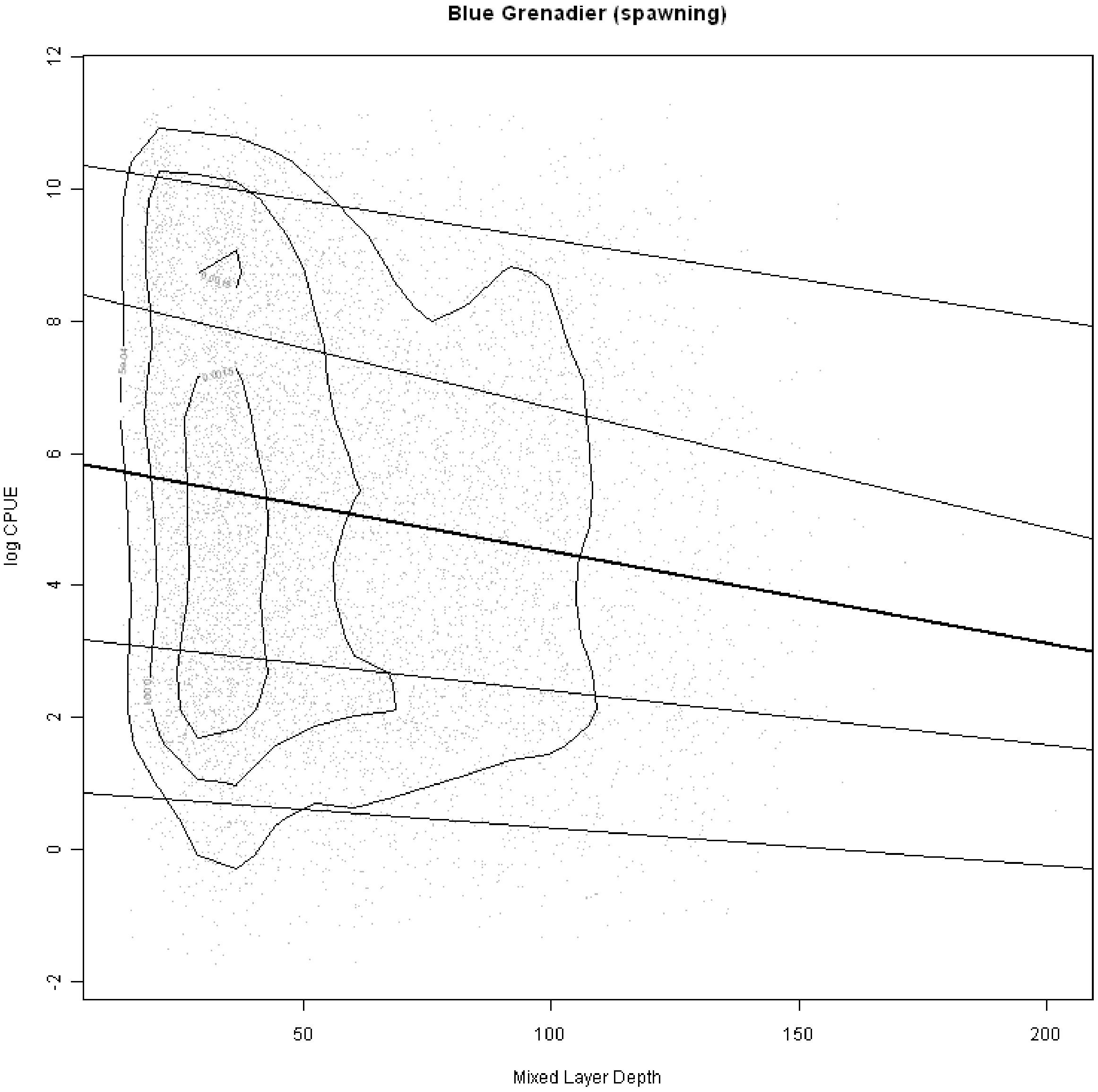

Figure 159. Blue grenadier (spawning) vs mixed layer depth: log catch rate plotted against environmental variables.

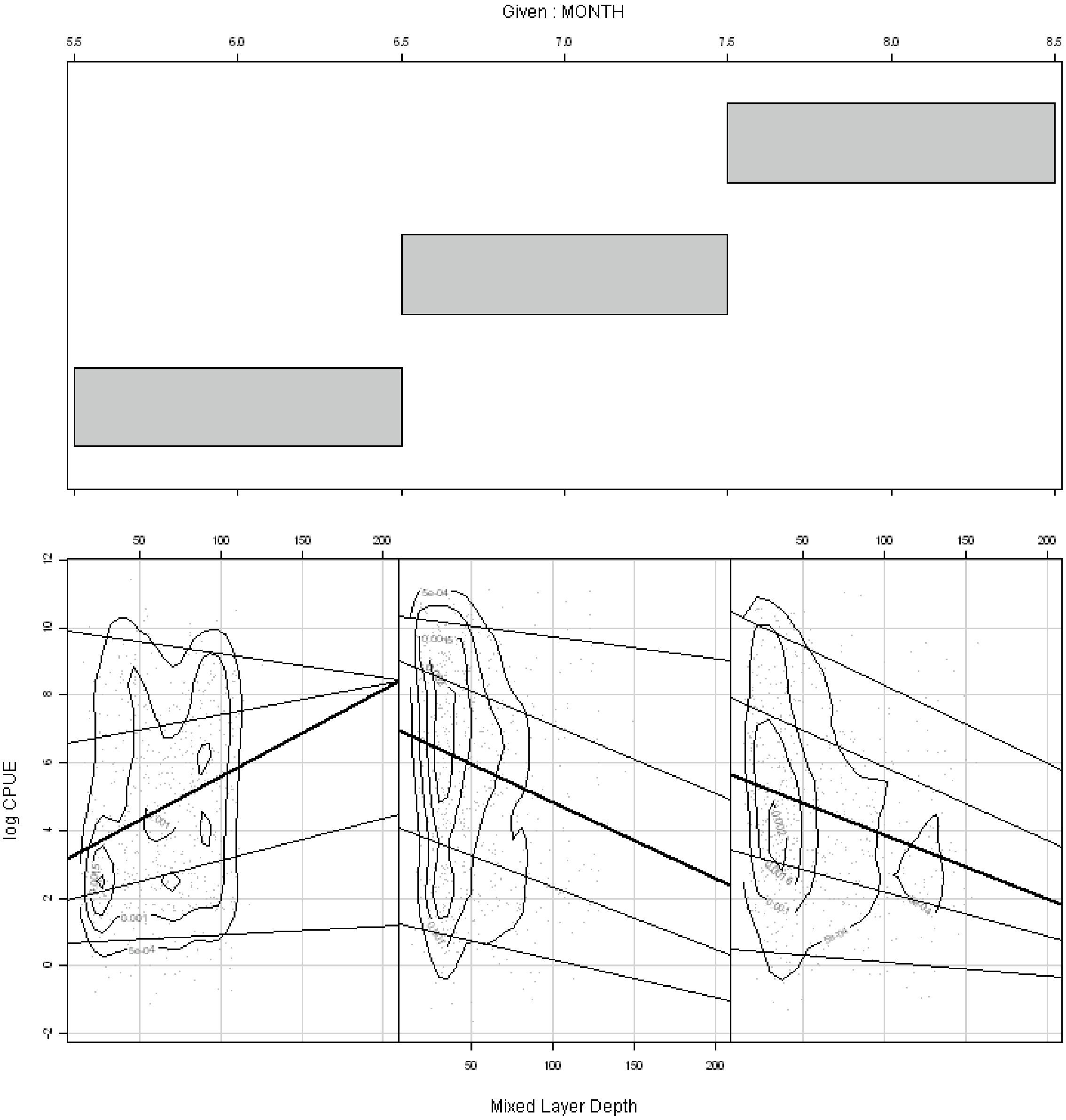

Figure 160. Blue grenadier (spawning) vs mixed layer depth by month: log catch rate plotted against environmental variables. This plot shows the seasonal variation in the relationship between catch rate and environmental variables. This plot shows catch rates for June (left), July (middle) and August (right).

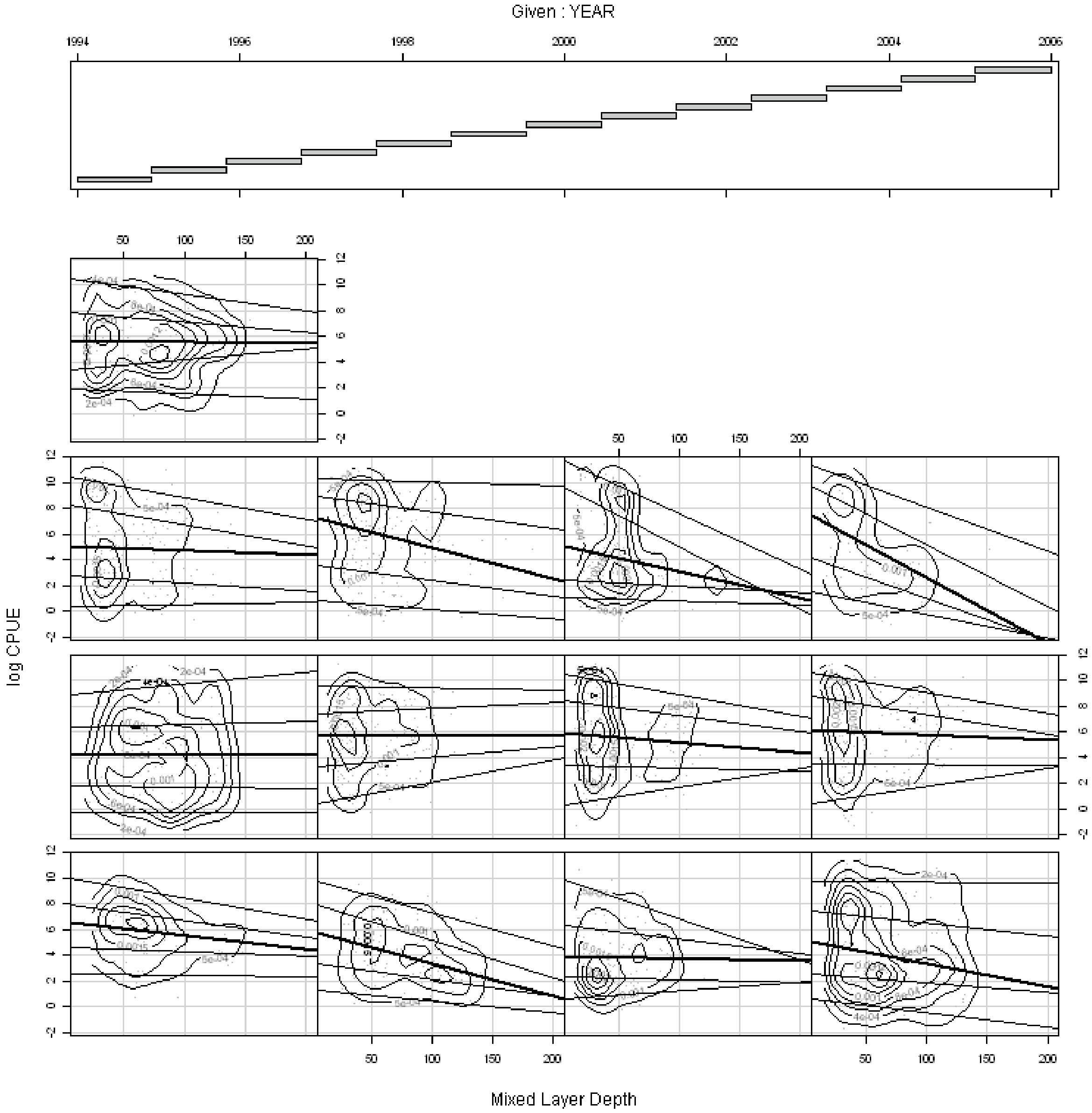

Figure 161. Blue grenadier (spawning) vs mixed layer depth by year: log catch rate plotted against environmental variables. This plot shows the annual variation in the relationship between catch rate and environmental variables. The lower left corner corresponds to 1994, with 1995 to the immediate right and then progressing left to right across each row with the box on the top row corresponding to 2006.

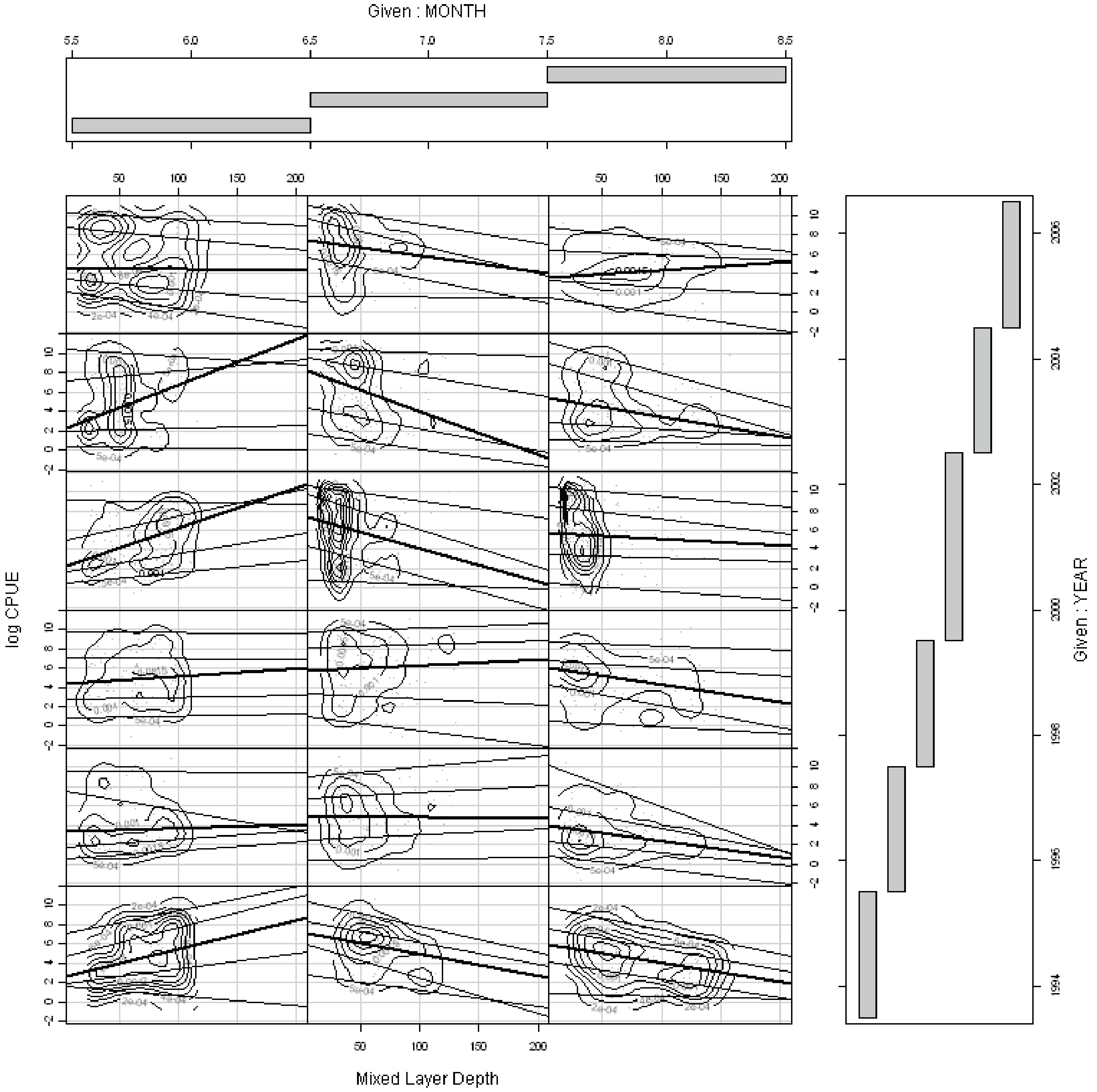

Figure 162. Blue grenadier (spawning) vs mixed layer depth by month and year: log catch rate plotted against environmental variables. This plot shows the temporal variation in the relationship between catch rate and environmental variables. The rows correspond to two or three year time intervals (with the more recent years at the top) and the columns to the months June July and August.

Blue grenadier non-spawning - SST

This section shows the relationship between catch rate and SST data for the blue grenadier non-spawning fishery. The correlation of catch rates of blue grenadier caught by the non-spawning fishery with temperature-at-depth is -0.013 which is very low, suggesting no relationship between catch rate and SST (Figure 163). Separating the data by zone and month (Figure 164) revealed only limited interaction between zone and month in any relationship between catch rate and SST, especially for those zones with the majority of records (zones 20, 40 and 50).

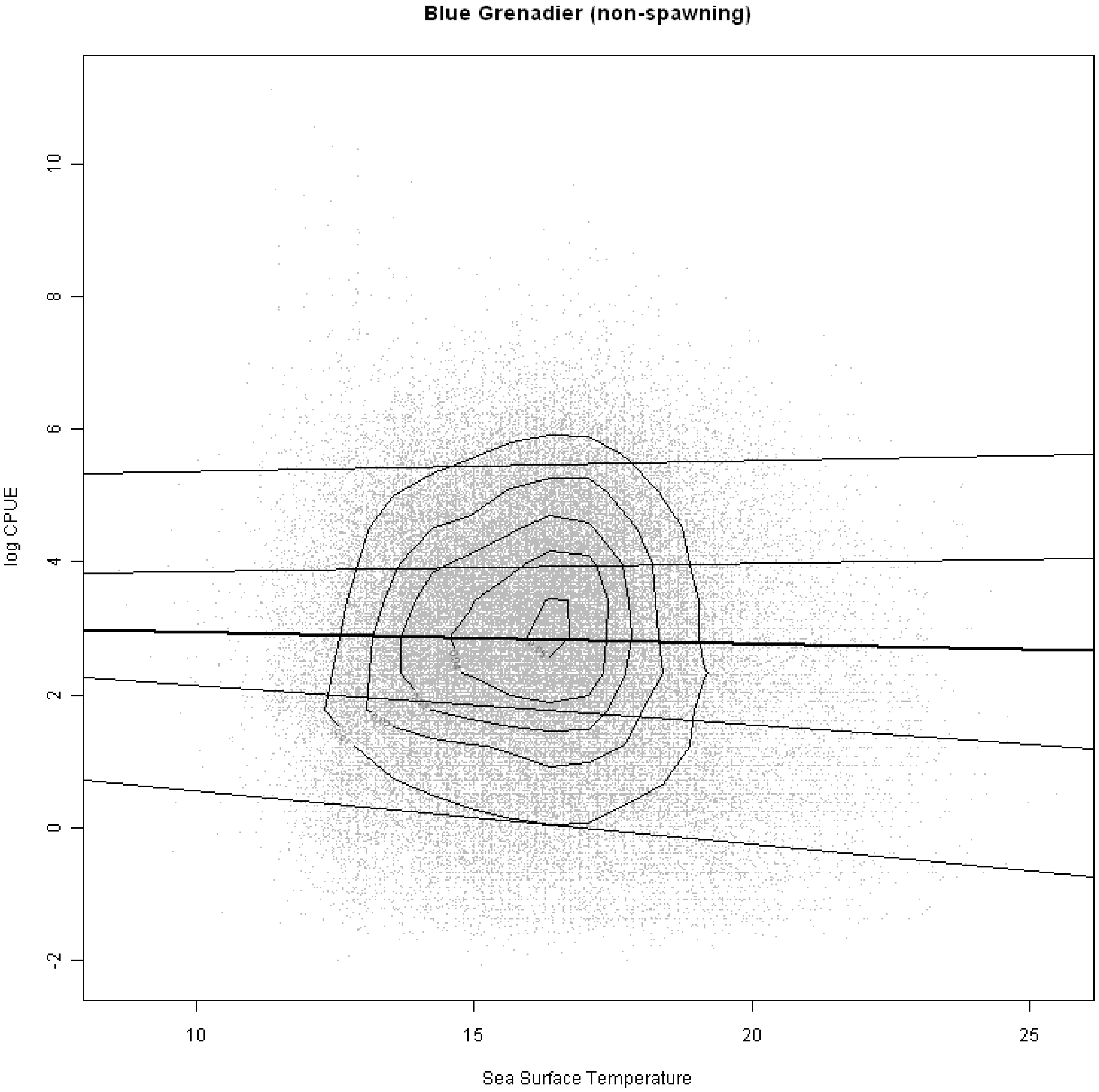

Figure 163. Blue grenadier (non-spawning) vs SST: log catch rate plotted against environmental variables.

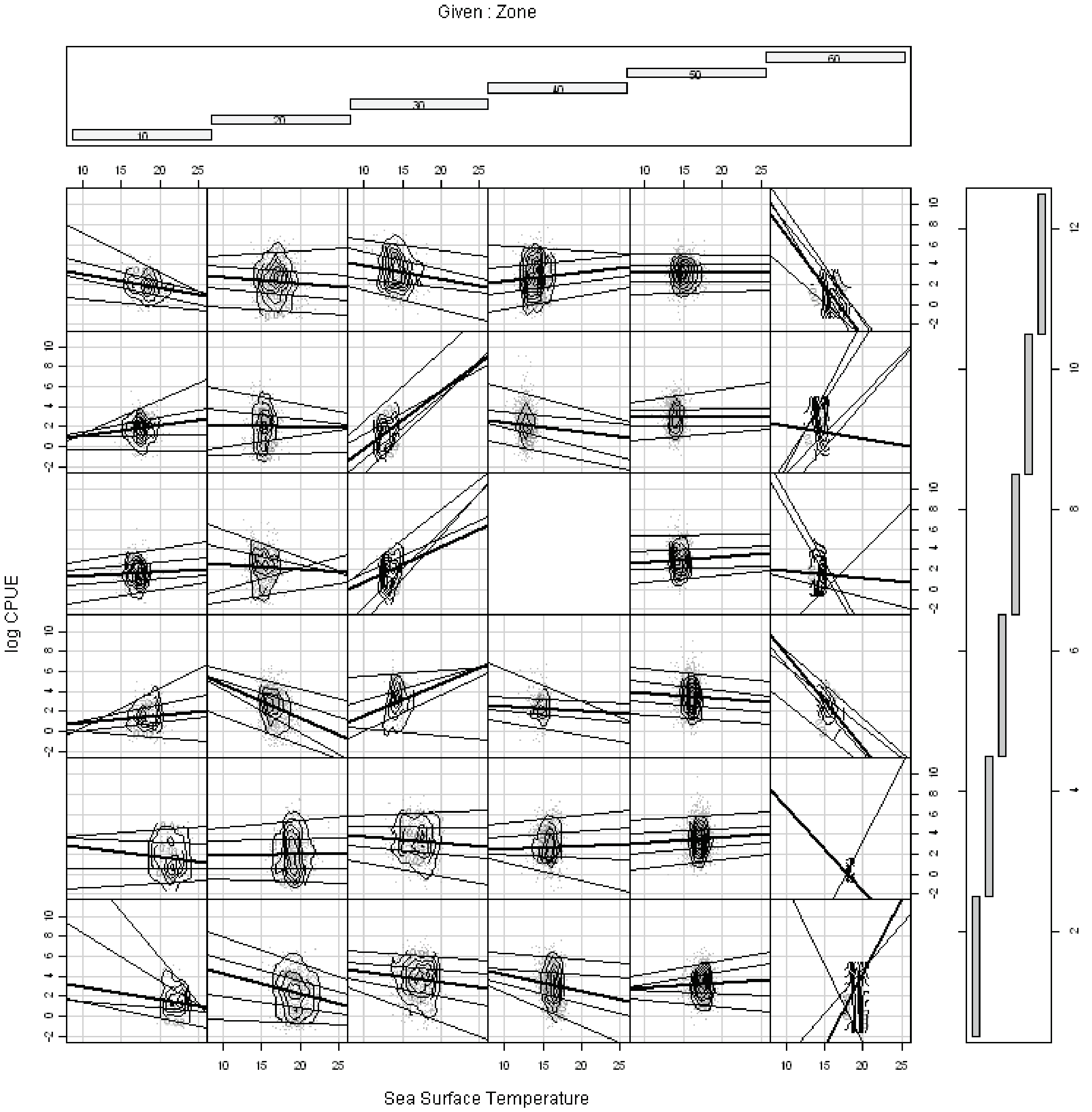

Figure 164. Blue grenadier (non-spawning) vs SST by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Blue grenadier non-spawning - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for the blue grenadier non-spawning fishery. The correlation of catch rates of blue grenadier caught by the non-spawning fishery with temperature-at-depth is -0.065 which is very low, suggesting no relationship between catch rate and temperature-at-depth (Figure 165). When catch rates are separated by zone and month (Figure 166), limited interaction was observed in any relationship between catch rate and temperature-at-depth.

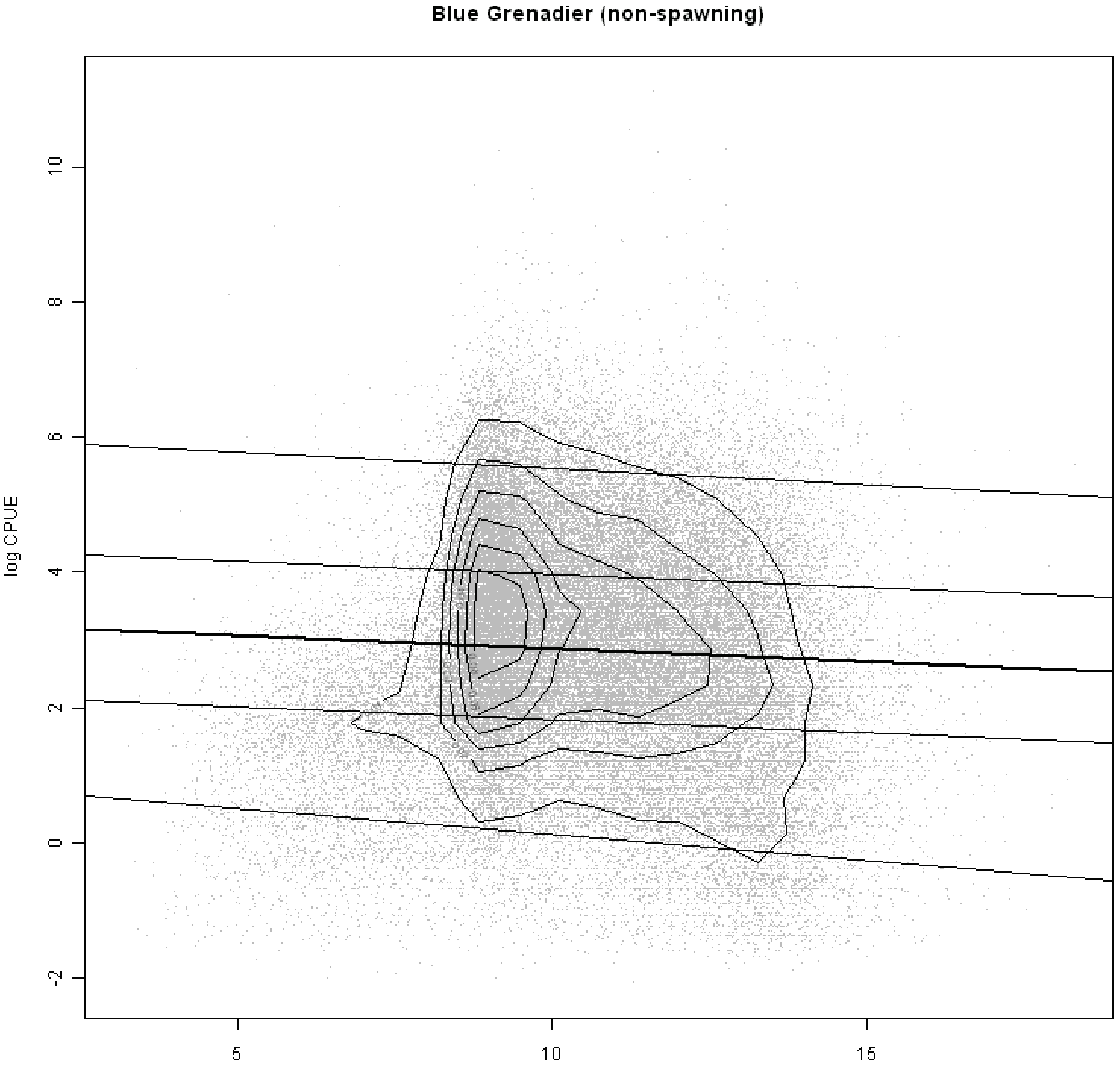

Figure 165. Blue grenadier (non-spawning) vs temperature-at-depth: log catch rate plotted against environmental variables.

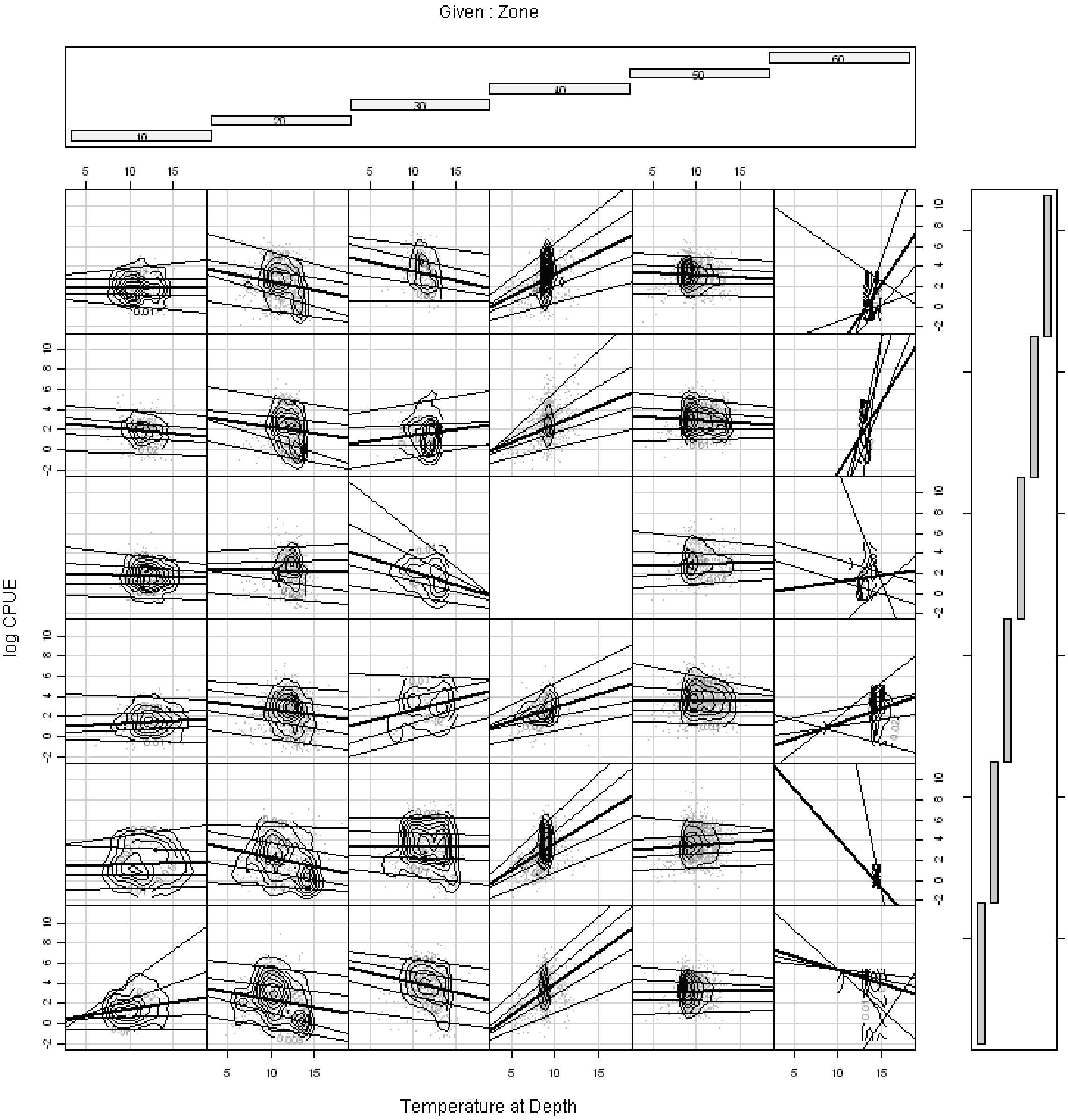

Figure 166. Blue grenadier (non-spawning) vs temperature-at-depth by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Blue grenadier non-spawning - chlorophyll A

This section shows the relationship between catch rate and chlorophyll A data for the blue grenadier non-spawning fishery. The correlation of catch rates of blue grenadier caught by the non-spawning fishery with chlorophyll A was -0.140 which was the highest correlation with catch rate and an environmental variable for the blue grenadier non-spawning fishery. However this correlation is still low, suggesting no relationship between catch rate and chlorophyll A, which is supported by the plot of the data (Figure 167). When catch rates are separated by month and zone, some interaction between year and month was observed (Figure 168), with considerable variation between months and zones.

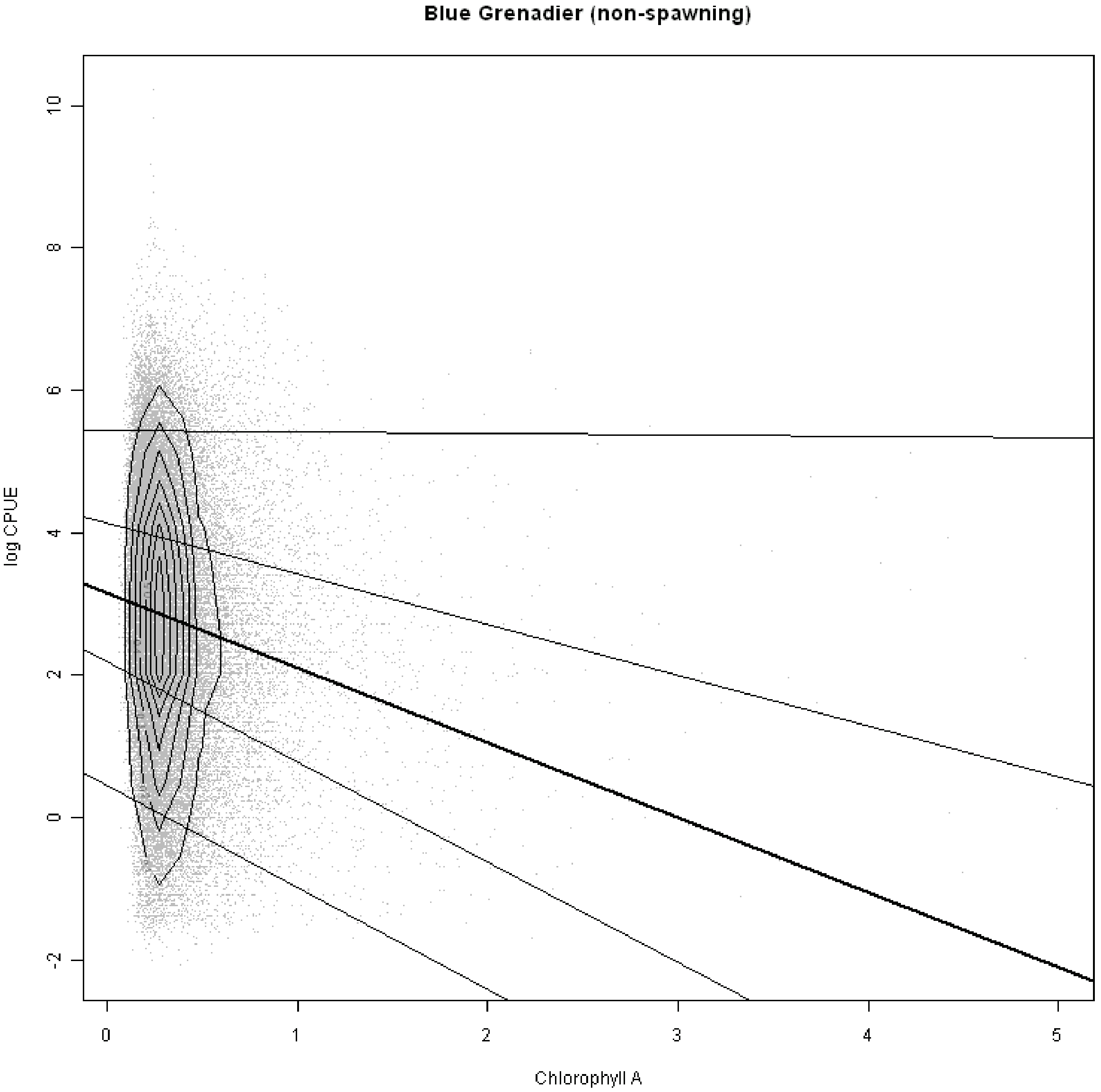

Figure 167. Blue grenadier (non-spawning) vs chlorophyll A: log catch rate plotted against environmental variables.

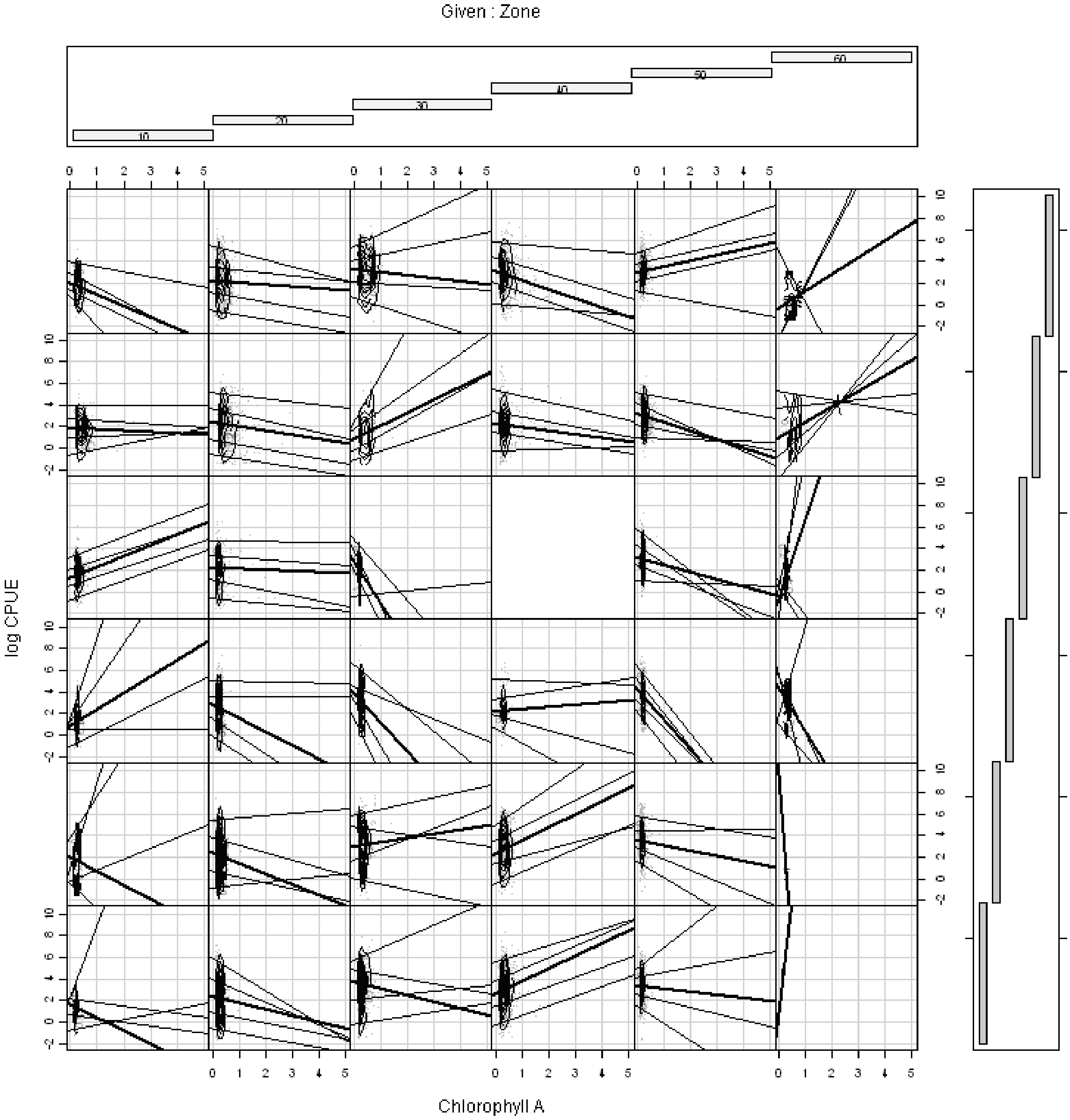

Figure 168. Blue grenadier (non-spawning) vs chlorophyll A by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Pink ling east - SST

This section shows the relationship between catch rate and SST data for pink ling (east). The correlation of catch rates of pink ling (east) with SST is 0.005 which is very low, suggesting no relationship between catch rate and SST. This is supported by a plot of the data (Figure 169). When catch rates are separated by month and zone some interaction was observed in any relationship between catch rate and SST (Figure 170).

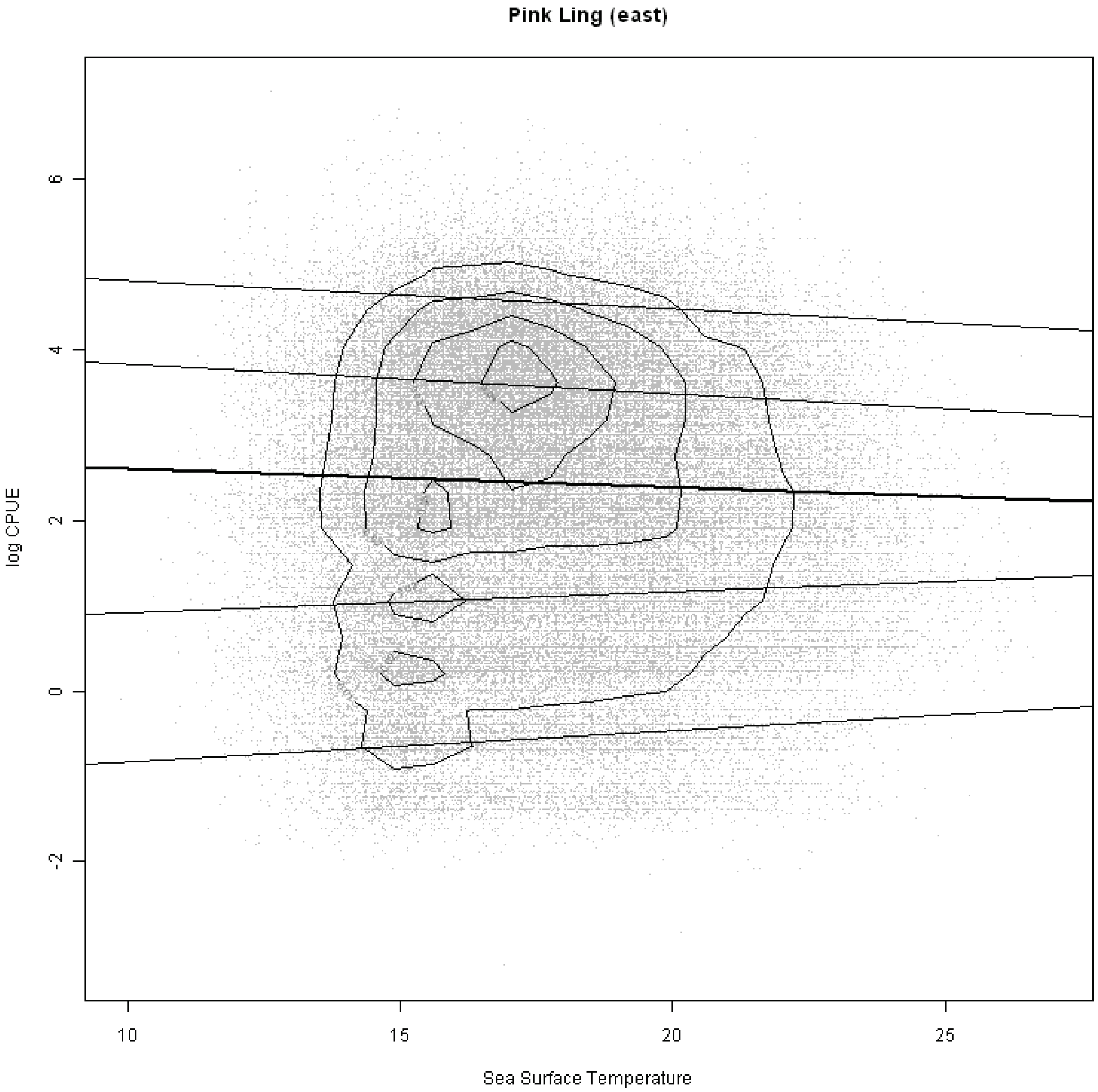

Figure 169. Pink ling (east) vs SST: log catch rate plotted against environmental variables.

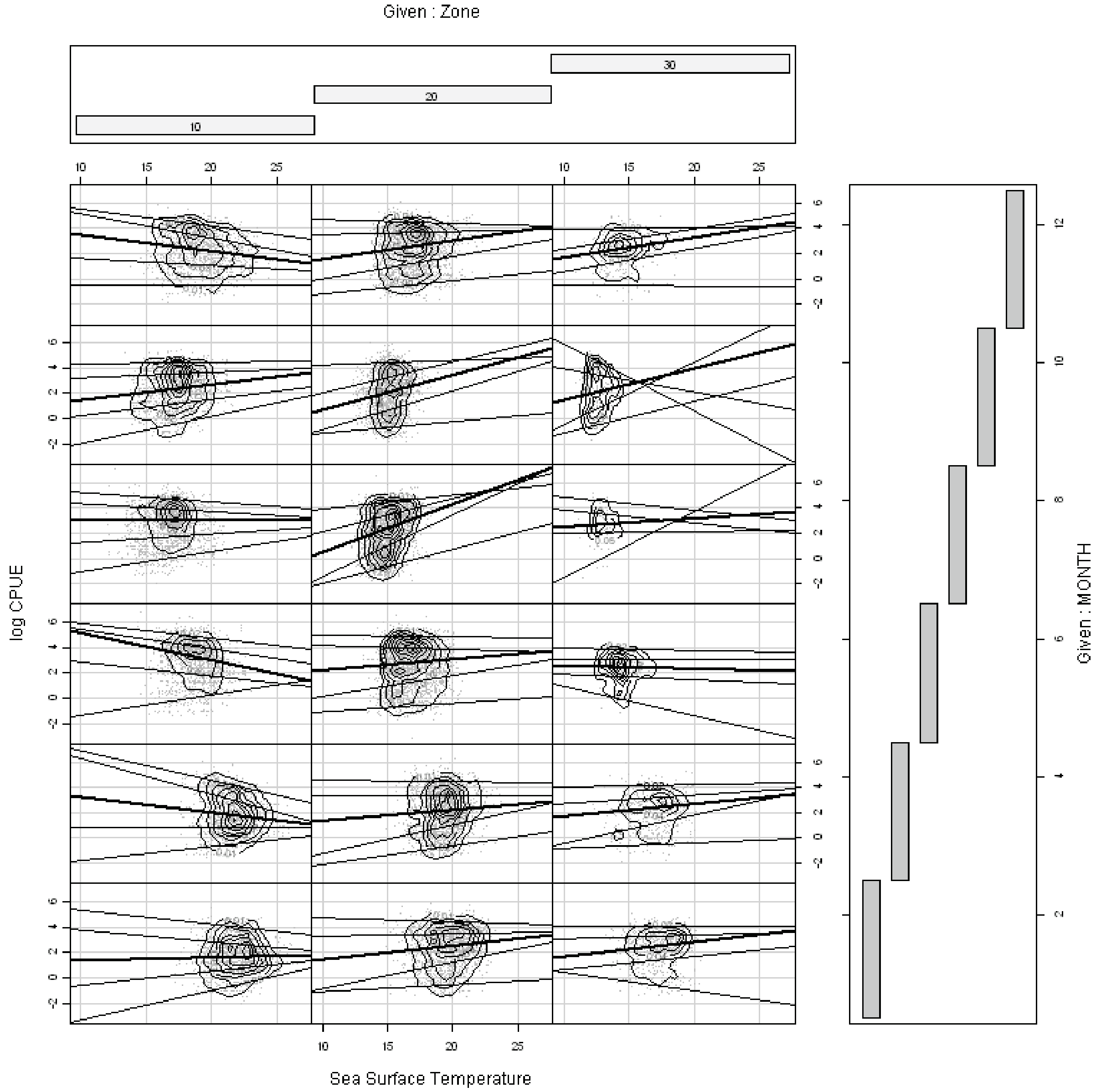

Figure 170. Pink ling (east) vs SST by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Pink ling east - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for pink ling (east). The correlation of catch rates of pink ling (east) with temperature-at-depth was -0.385 which was the second largest correlation between catch rate and any environmental parameter for any of the cases examined here. The plot of the data shows this correlation, and suggests that it is not so strong for high catch rates (Figure 171). When catch rates are separated by zone and month, there appears to be some interaction in any relationship between catch rate and temperature-at-depth (Figure 172).

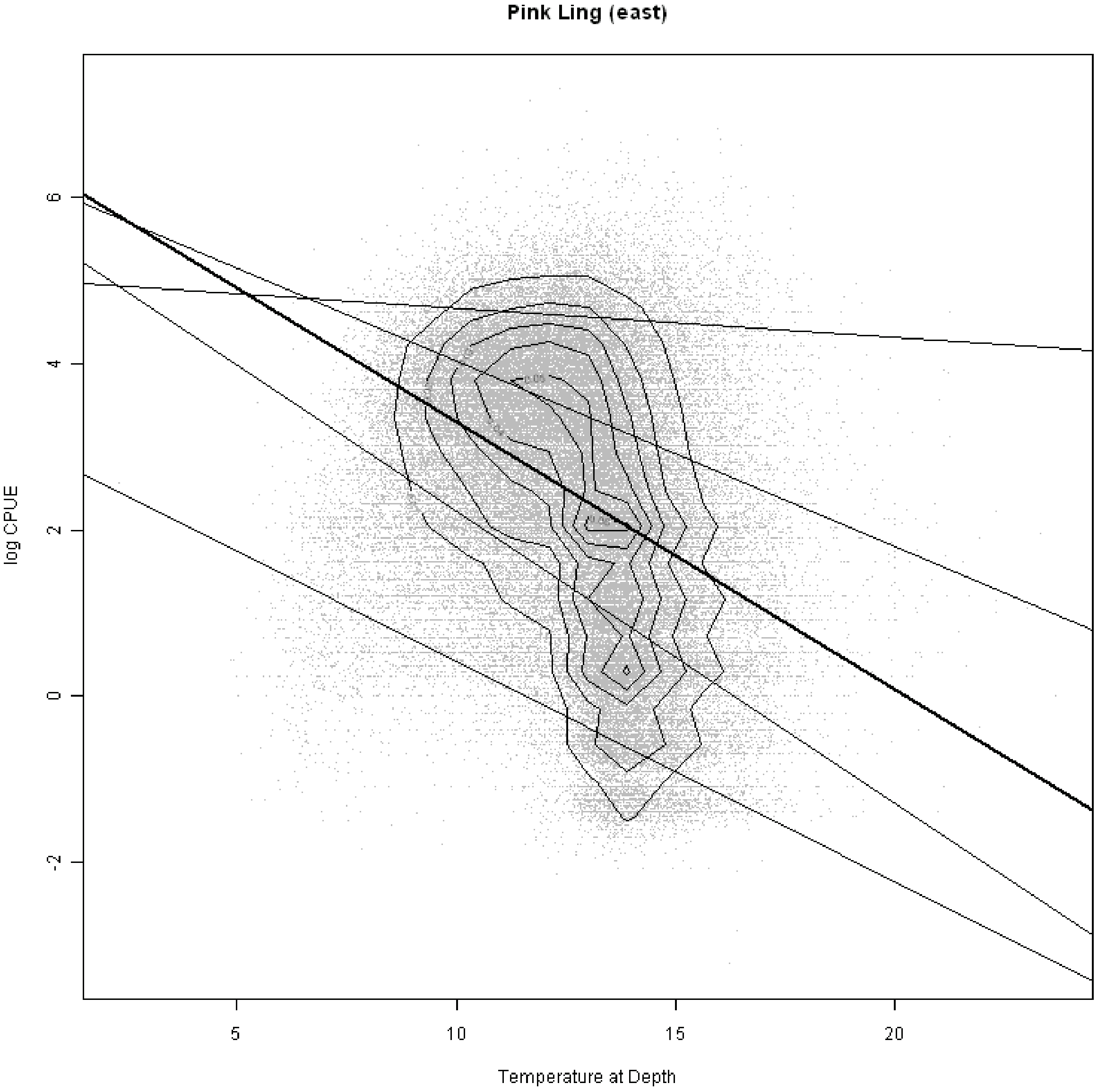

Figure 171. Pink ling (east) vs temperature-at-depth: log catch rate plotted against environmental variables.

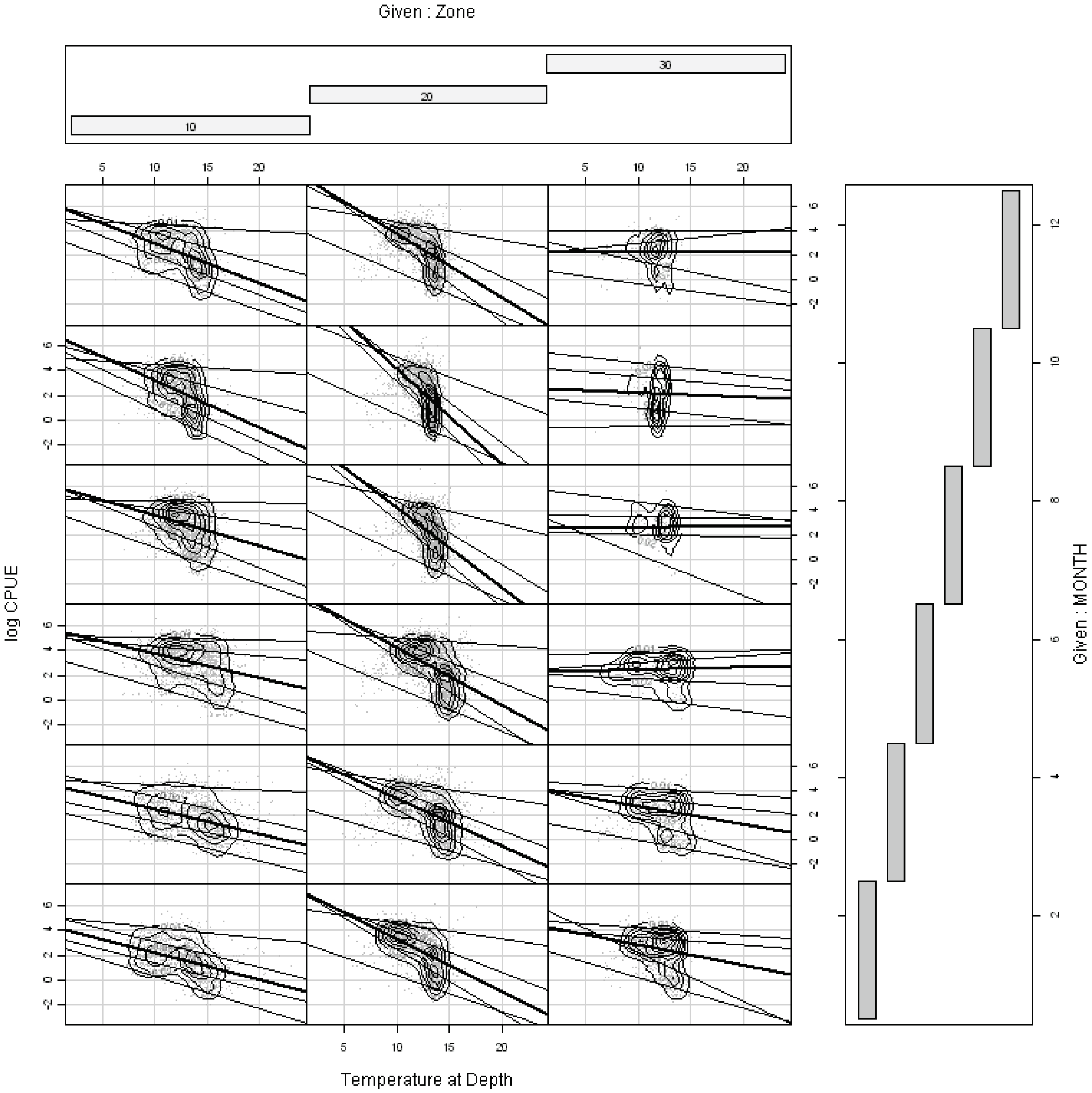

Figure 172. Pink ling (east) vs temperature-at-depth by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Pink ling east - chlorophyll A

This section shows the relationship between catch rate and chlorophyll A data for pink ling (east). The correlation of catch rates of pink ling (east) with chlorophyll A was -0.131 which is low, suggesting no relationship between catch rate and chlorophyll A. A plot of the data suggests that there is a weak negative relationship (Figure 173). When catch rates are separated by month and zone for pink ling (east), some interaction was observed between year and month (Figure 174).

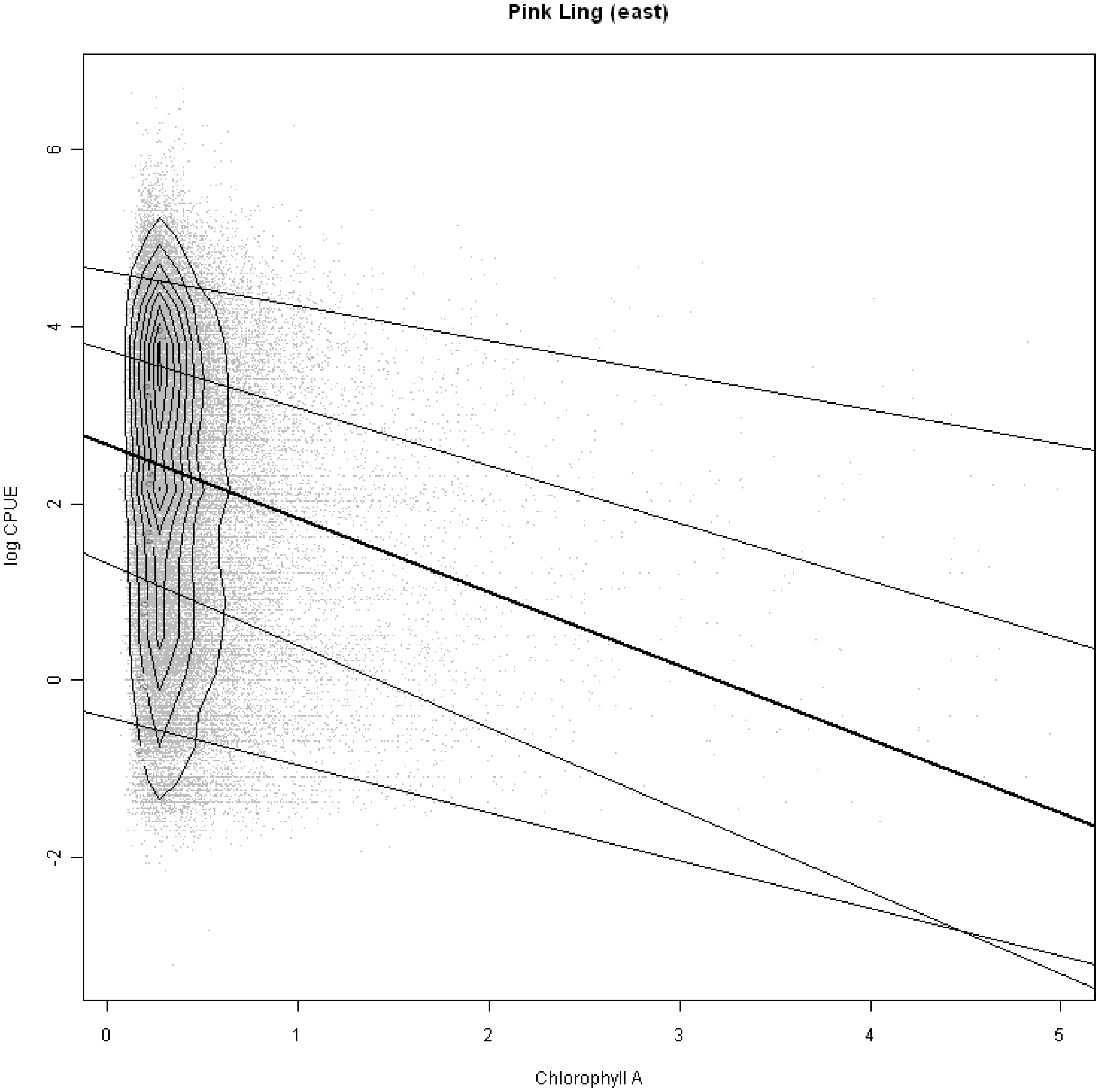

Figure 173. Pink ling (east) vs chlorophyll A: log catch rate plotted against environmental variables.

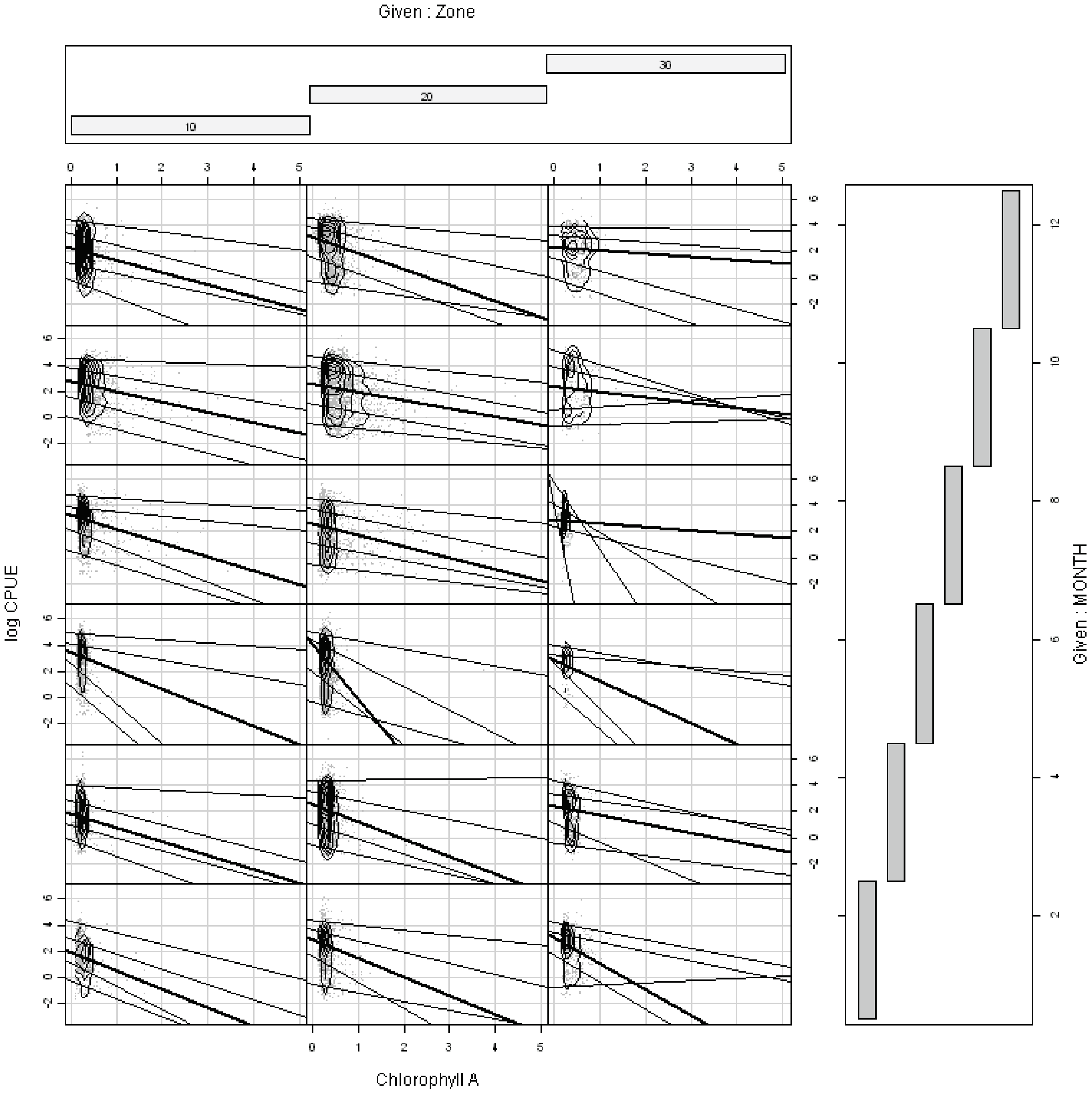

Figure 174. Pink ling (east) vs chlorophyll A by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Pink ling west - SST

This section shows the relationship between catch rate and SST data for pink ling (west). The correlation of catch rates of pink ling (west) with SST is -0.21. In contrast, this correlation coefficient is quite different in sign and magnitude to the correlation coefficient for pink ling (east), however, both correlations are low, suggesting no relationship between catch rate and SST. A plot of the data shows the weak negative correlation (Figure 175). When catch rates are separated by month and zone for pink ling (west), some interaction between zone and month was observed in any relationship between catch rate and SST.

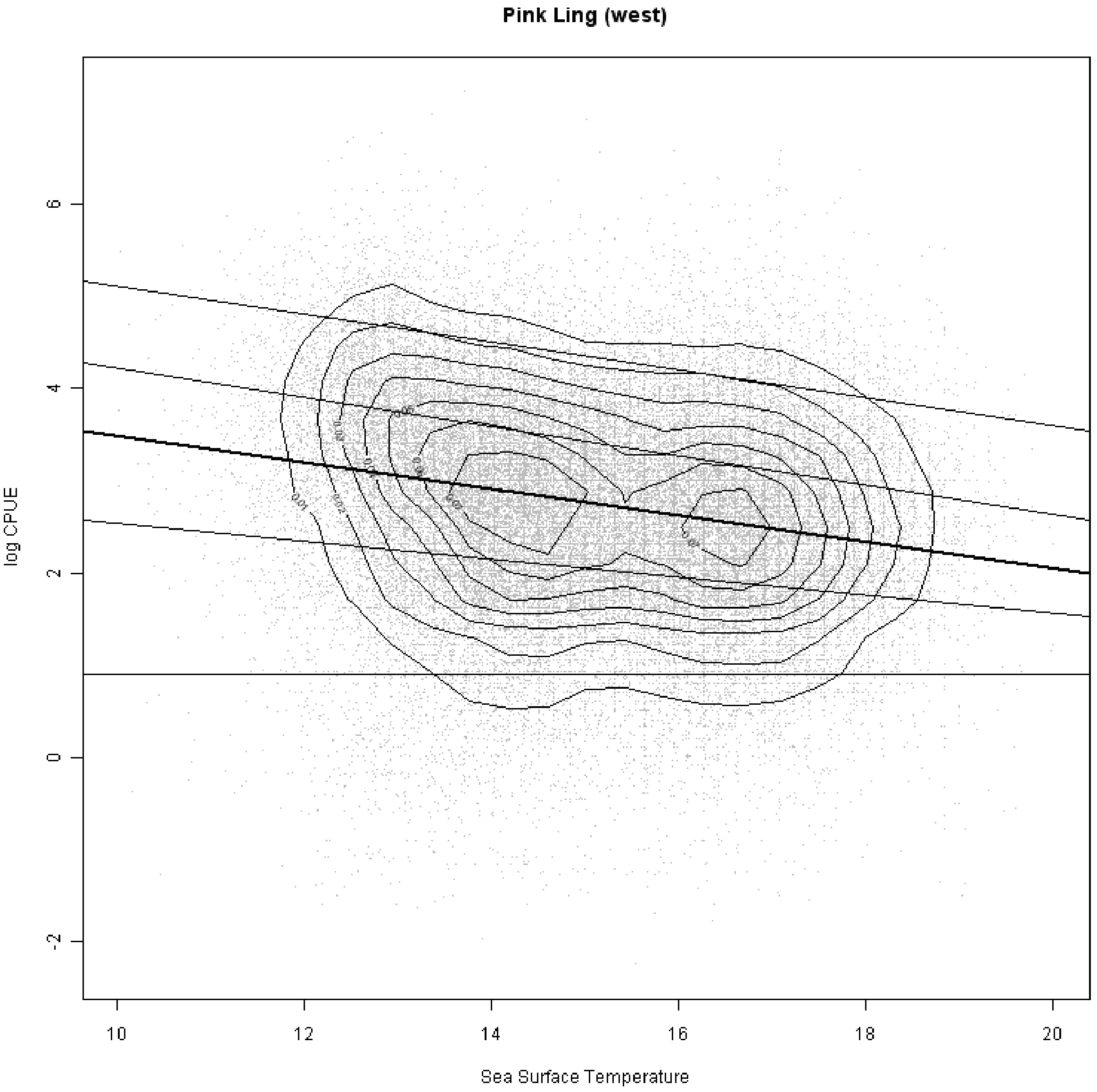

Figure 175. Pink ling (west) vs SST: log catch rate plotted against environmental variables.

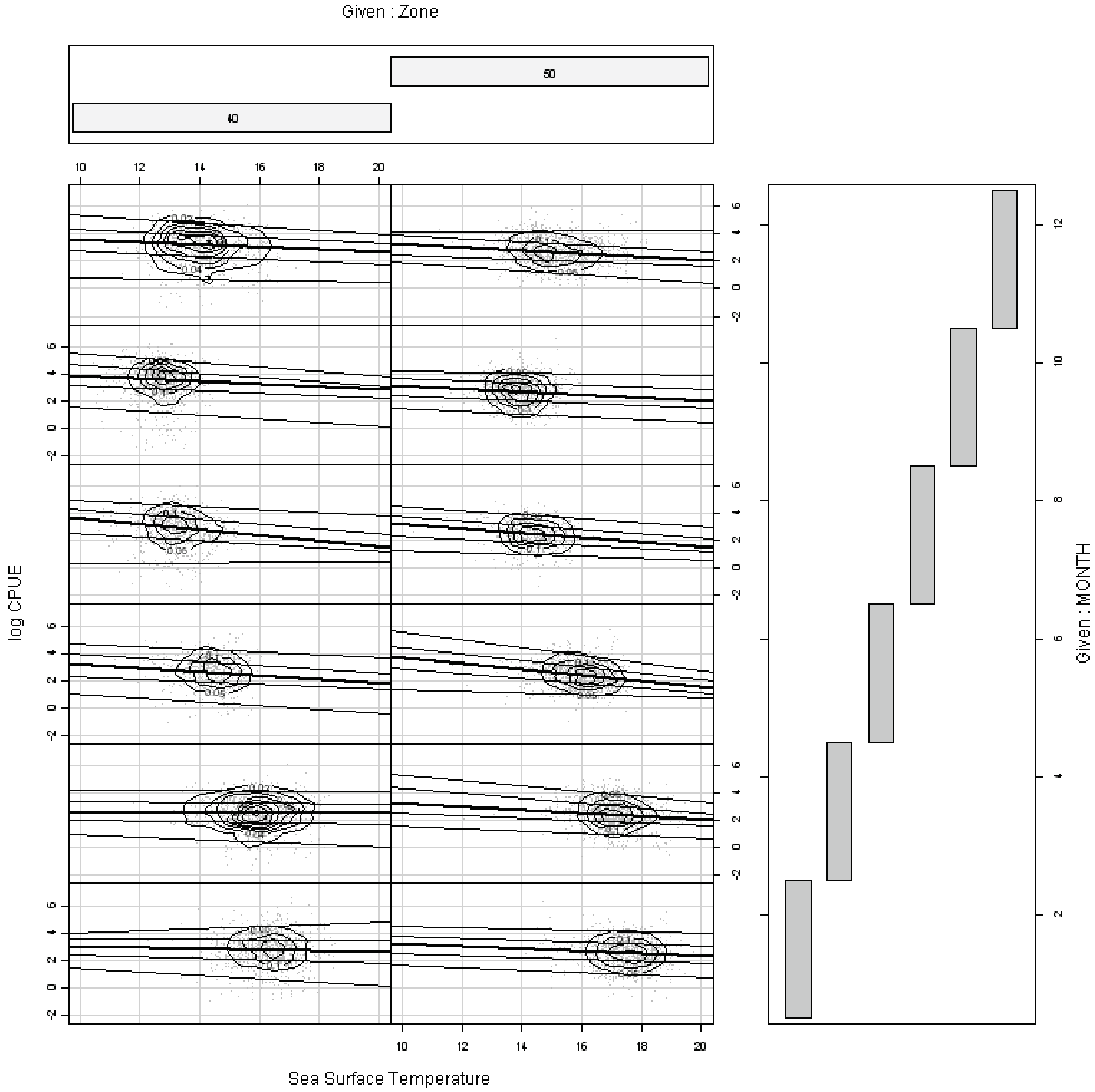

Figure 176. Pink ling (west) vs SST by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Pink ling west - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for pink ling (west). The correlation of catch rates of pink ling (west) with temperature-at-depth is -0.05 which is small, and again contrasts with the correlation coefficient for pink ling (east). This correlation coefficient is very low, suggesting no relationship between catch rate and temperature-at-depth. This is supported by a plot of the data (Figure 177). When catch rates are separated by month and zone, some interaction between zone and month was observed in any relationship between catch rate and temperature-at-depth (Figure 178).

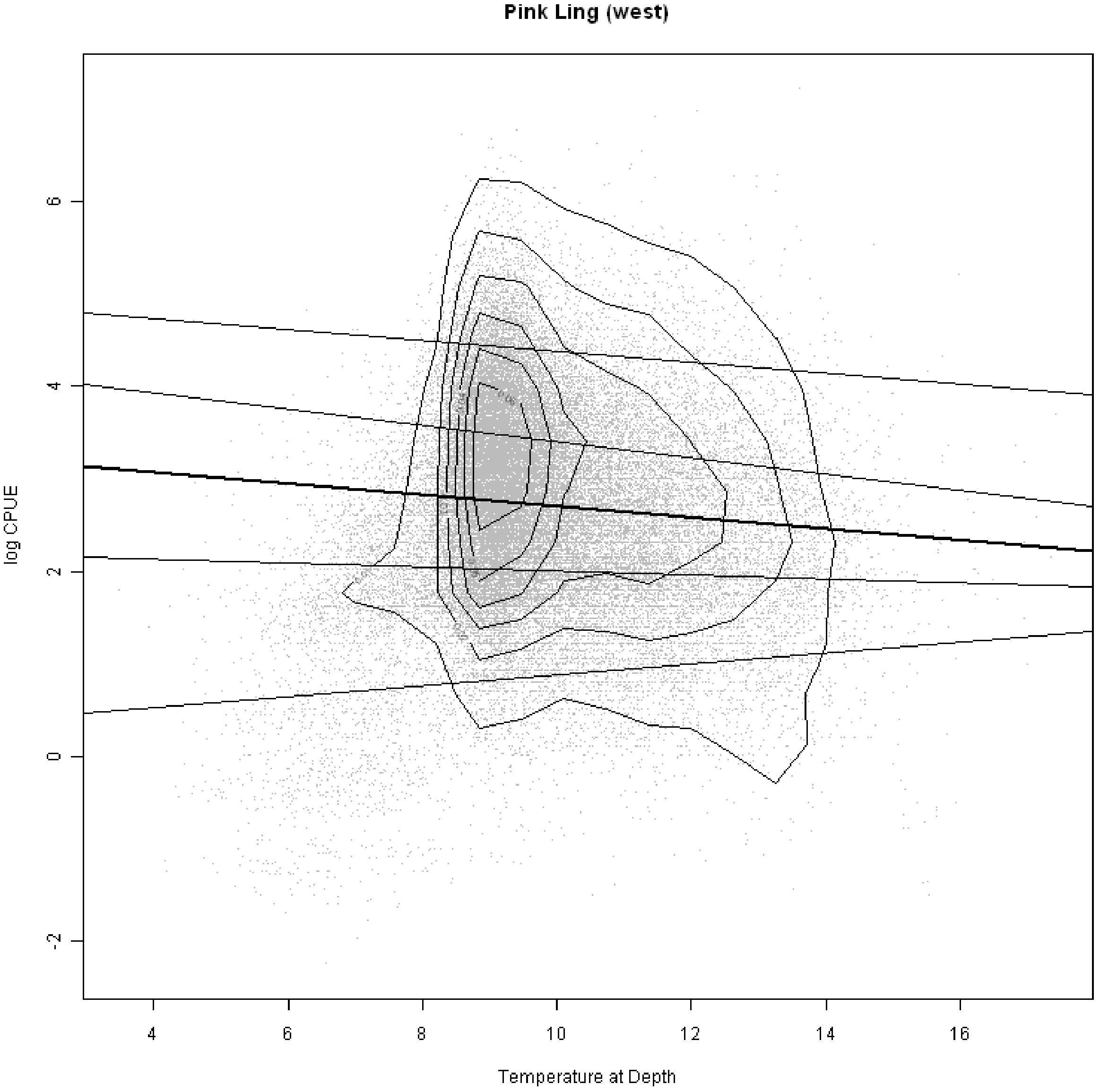

Figure 177. Pink ling (west) vs temperature-at-depth: log catch rate plotted against environmental variables.

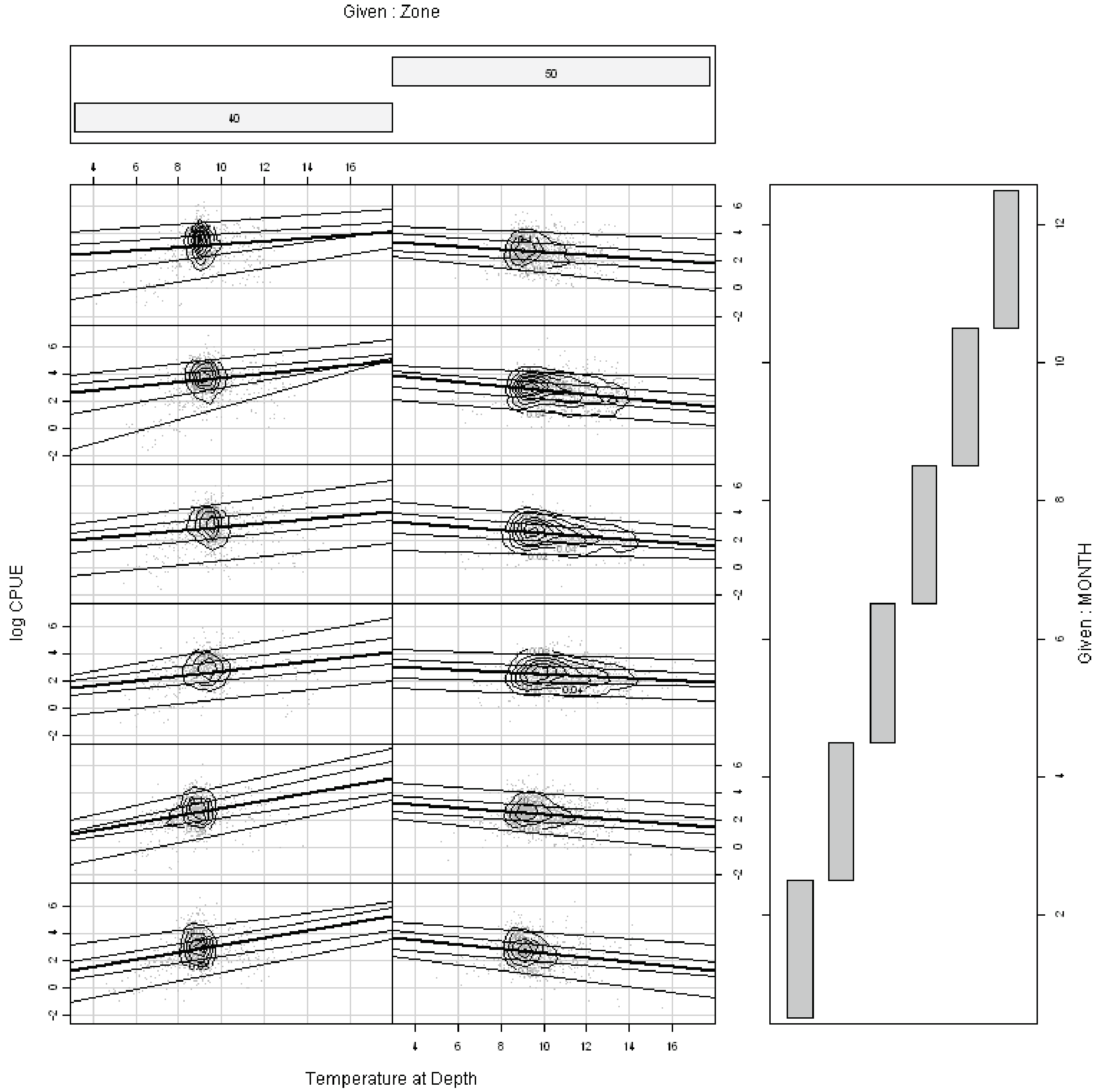

Figure 178. Pink ling (east) vs temperature-at-depth by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Pink ling west - chlorophyll A

This section shows the relationship between catch rate and chlorophyll A data for pink ling (west). The correlation of catch rates of pink ling (west) with chlorophyll A was 0.148, which was of similar magnitude to the correlation coefficient for pink ling (east) but of opposite direction. Both correlations are low, suggesting no relationship between catch rate and chlorophyll A. A plot of the data shows that any relationship is particularly low at low catch rates (Figure 179). When catch rates are separated by month and zone some interaction appear month and zone in any relationship between catch rate and chlorophyll A (Figure 180).

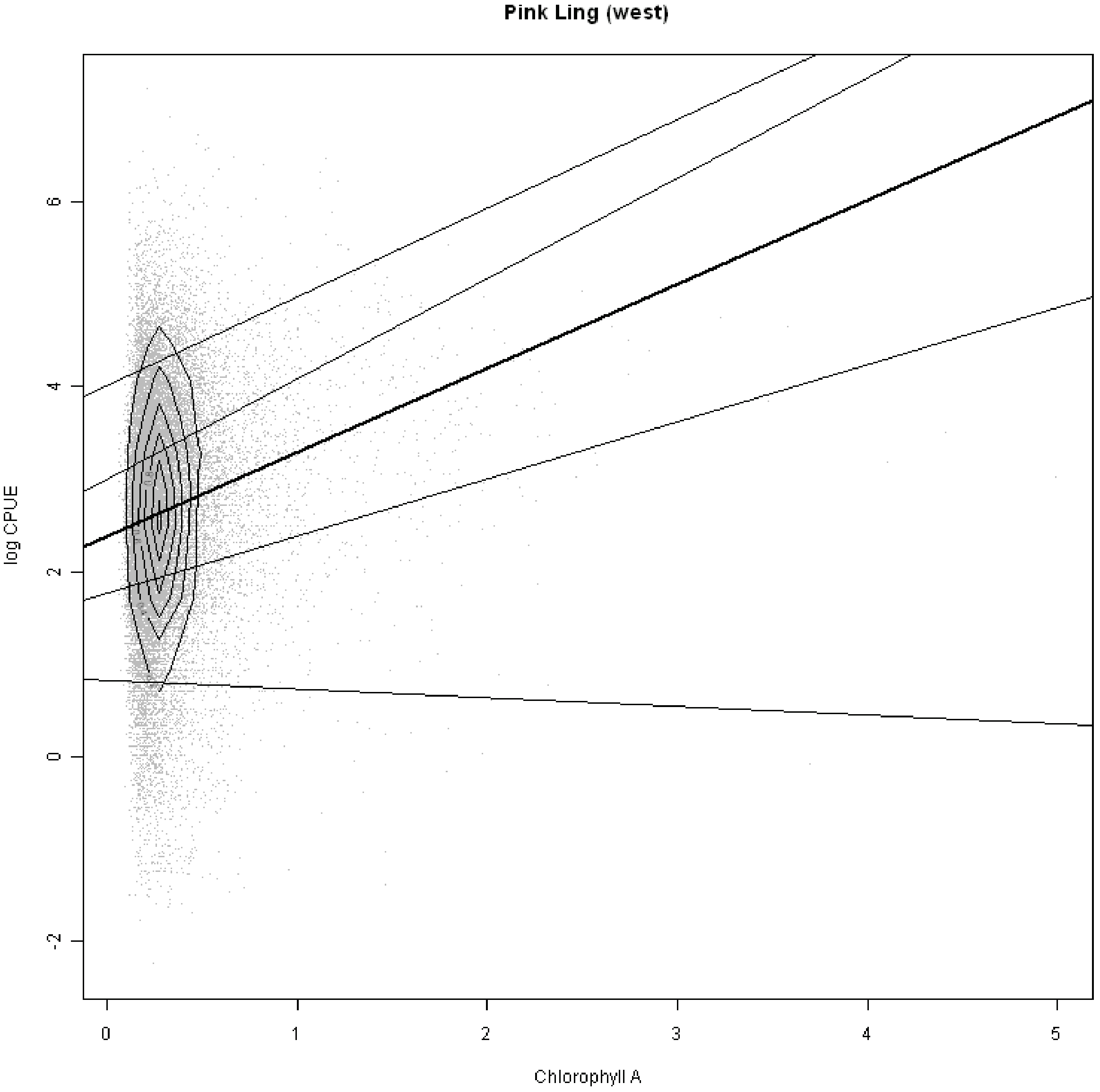

Figure 179. Pink ling (west) vs chlorophyll A: log catch rate plotted against environmental variables.

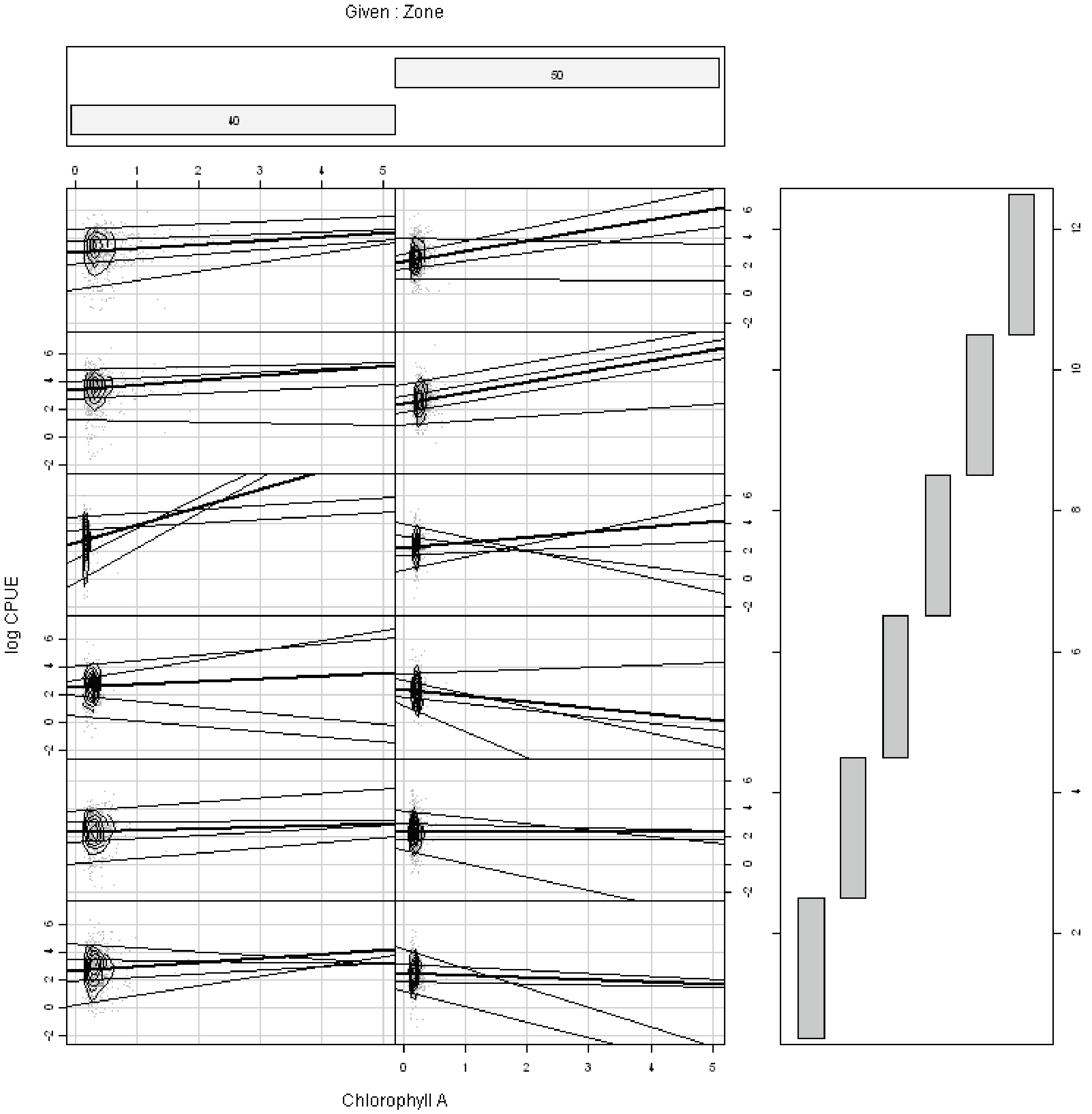

Figure 180. Pink ling (west) vs chlorophyll A by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Redfish - SST

This section shows the relationship between catch rate and SST data for redfish. The correlation of catch rates of redfish with SST was 0.163 which is low, suggesting no relationship between catch rate and SST (Figure 181). When catch rates are separated by month and there appears to be some interaction between zone and month in any relationship between catch rate and SST (Figure 182).

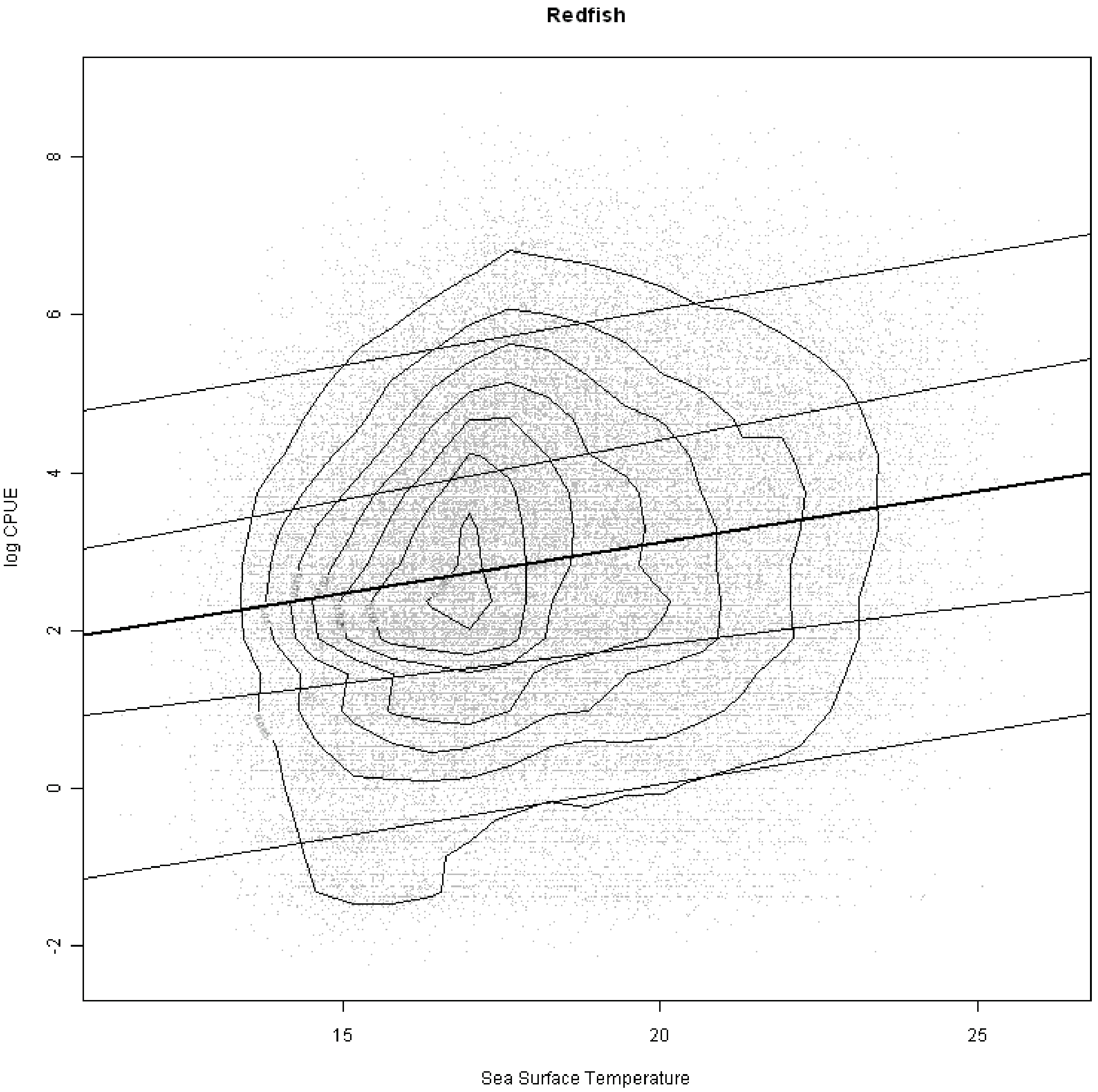

Figure 181. Redfish vs SST: log catch rate plotted against environmental variables.

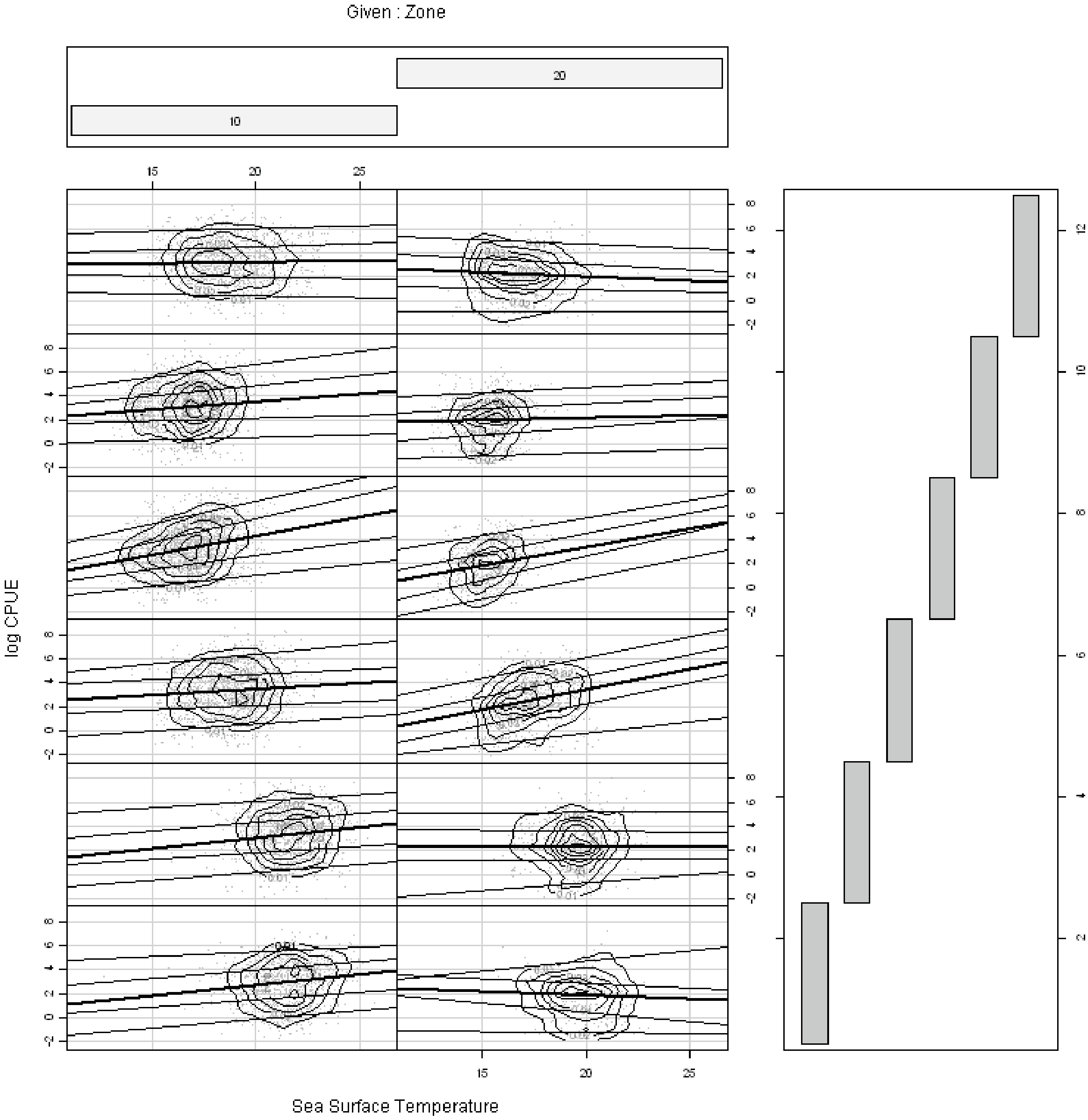

Figure 182. Redfish vs SST by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Redfish - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for redfish. The correlation of catch rates of redfish with temperature-at-depth is 0.083 which is very low, suggesting no relationship between catch rate and temperature-at-depth (Figure 183). When catch rates are separated by month and zone, there appears to be some interaction between zone and month in any relationship between catch rate and temperature-at-depth (Figure 184).

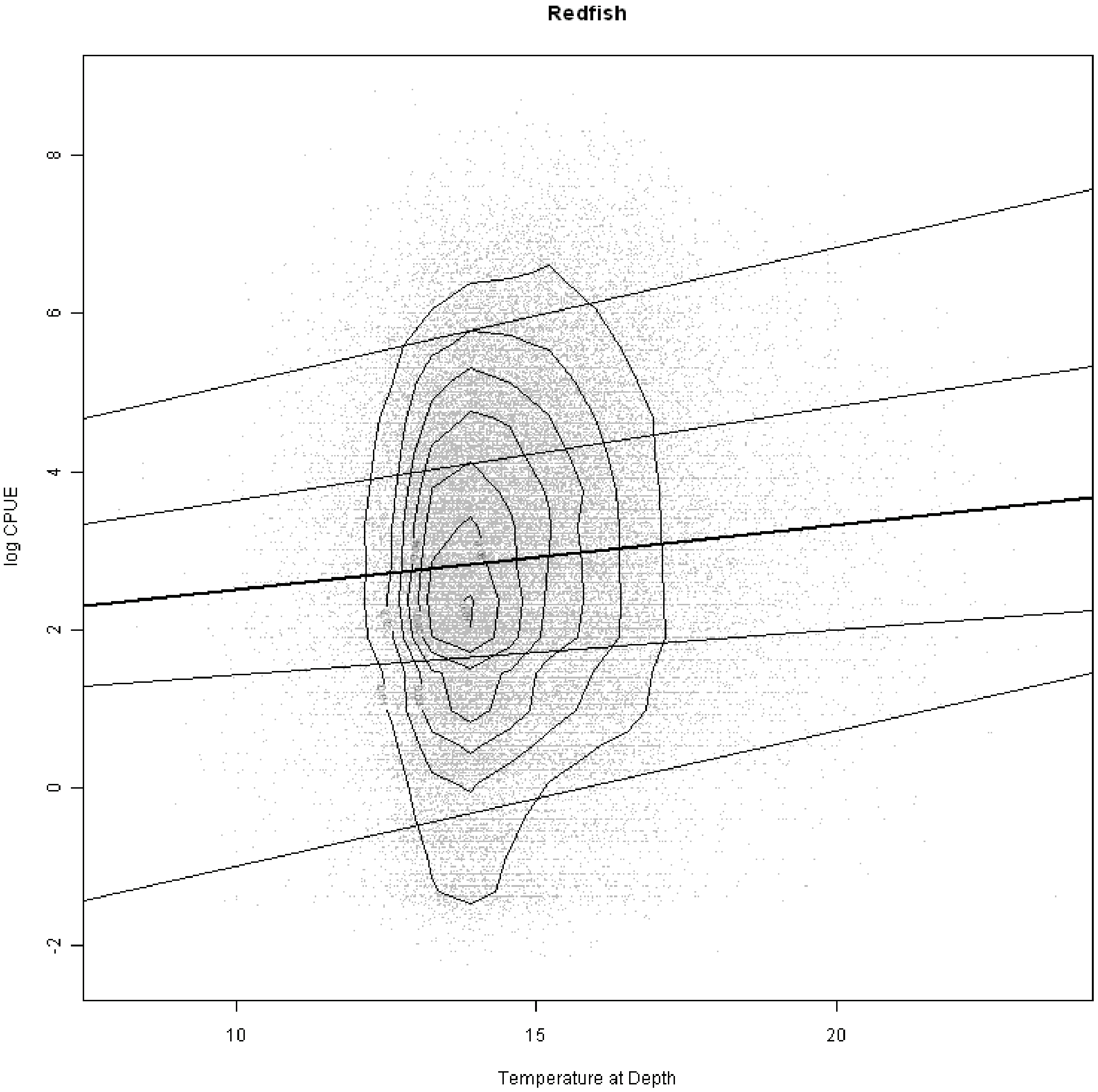

Figure 183. Redfish vs temperature-at-depth: log catch rate plotted against environmental variables.

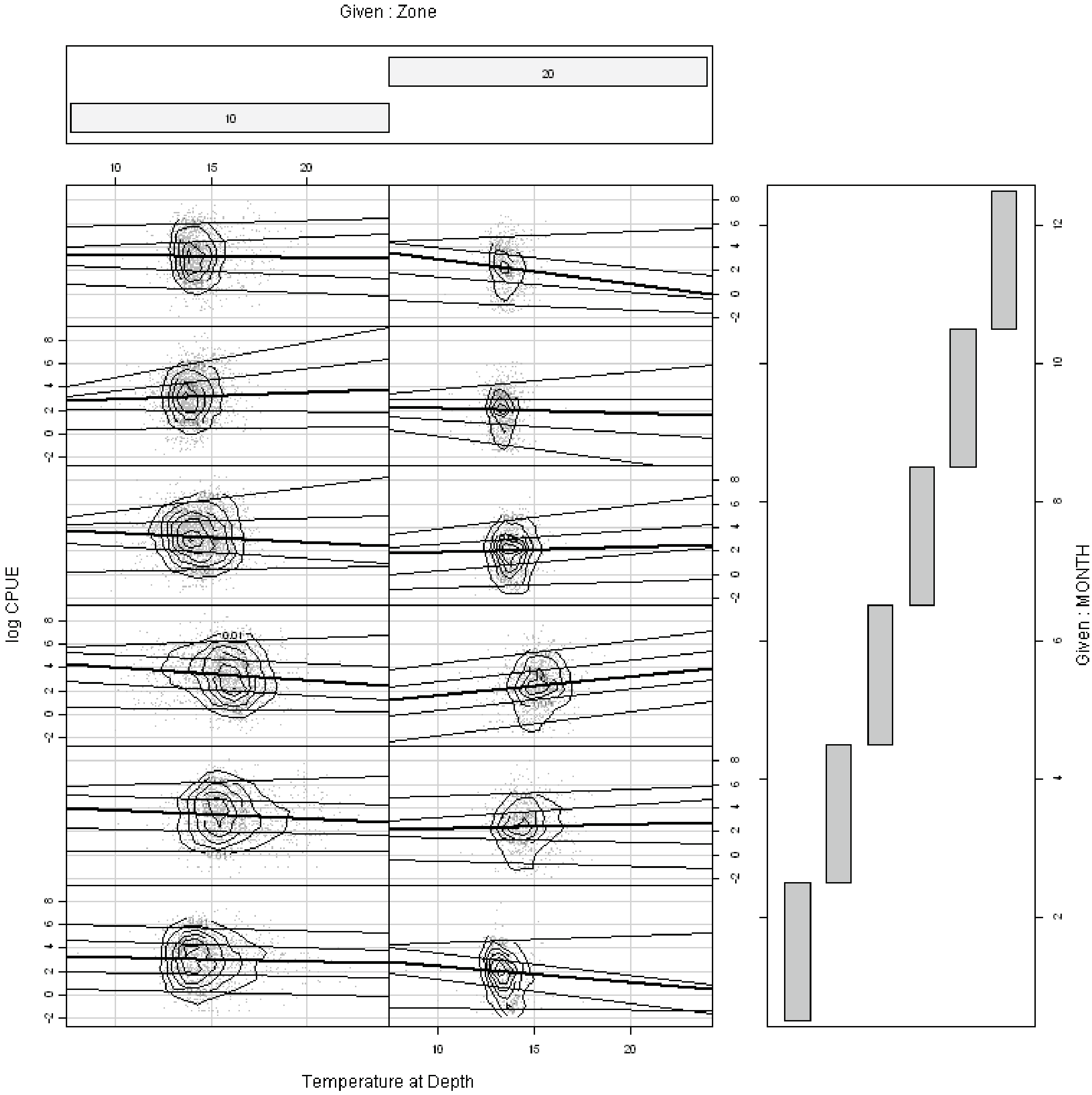

Figure 184. Redfish vs temperature-at-depth by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Redfish - chlorophyll A

This section shows the relationship between catch rate and chlorophyll A data for redfish. The correlation of catch rates of redfish with chlorophyll A was -0.178 which is low, suggesting no relationship between catch rate and chlorophyll A (Figure 185). When catch rates are separated by month and zone appeared to be some interaction between year and month in any relationship between catch rate and chlorophyll A (Figure 186).

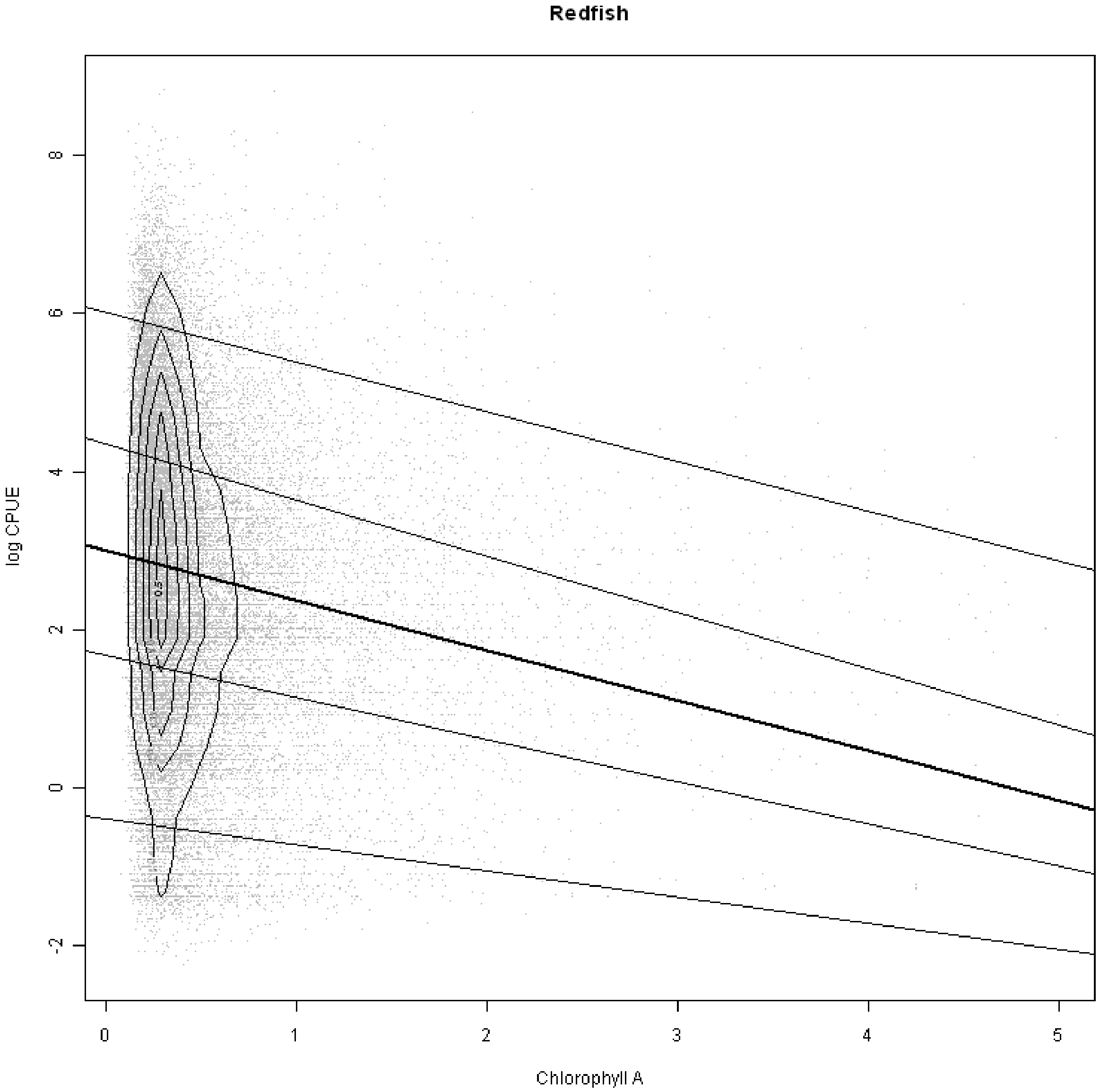

Figure 185. Redfish vs chlorophyll A: log catch rate plotted against environmental variables.

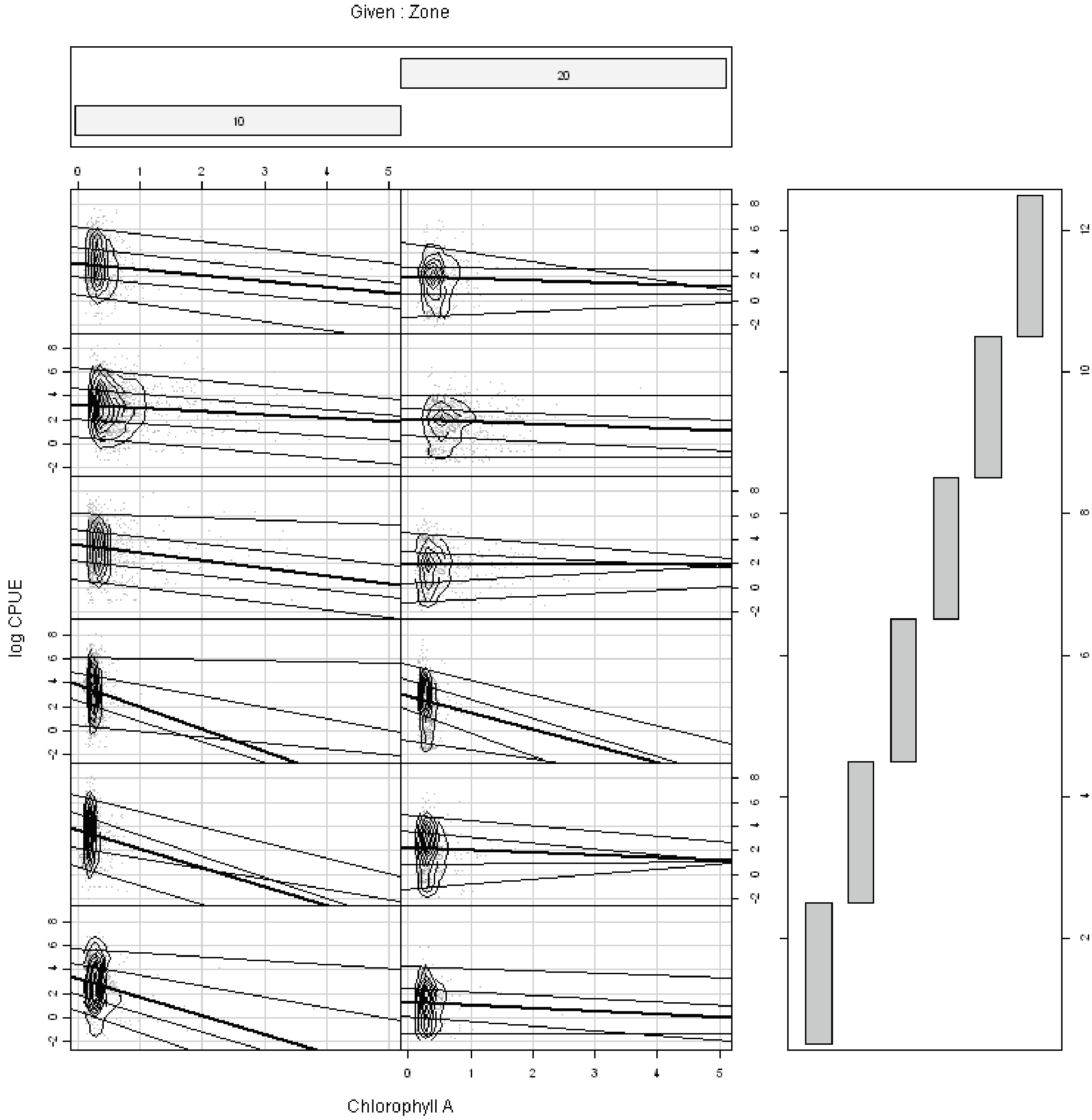

Figure 186. Redfish vs chlorophyll A by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Bight redfish - SST

This section shows the relationship between catch rate and SST data for Bight redfish. The correlation of catch rates of Bight redfish with SST was 0.273 which is low, suggesting limited relationship between catch rate and SST. The positive relationship can be seen in Figure 187. When data was separated into longitude and month (Figure 188) and month and year (Figure 189), interactions between factors were observed.

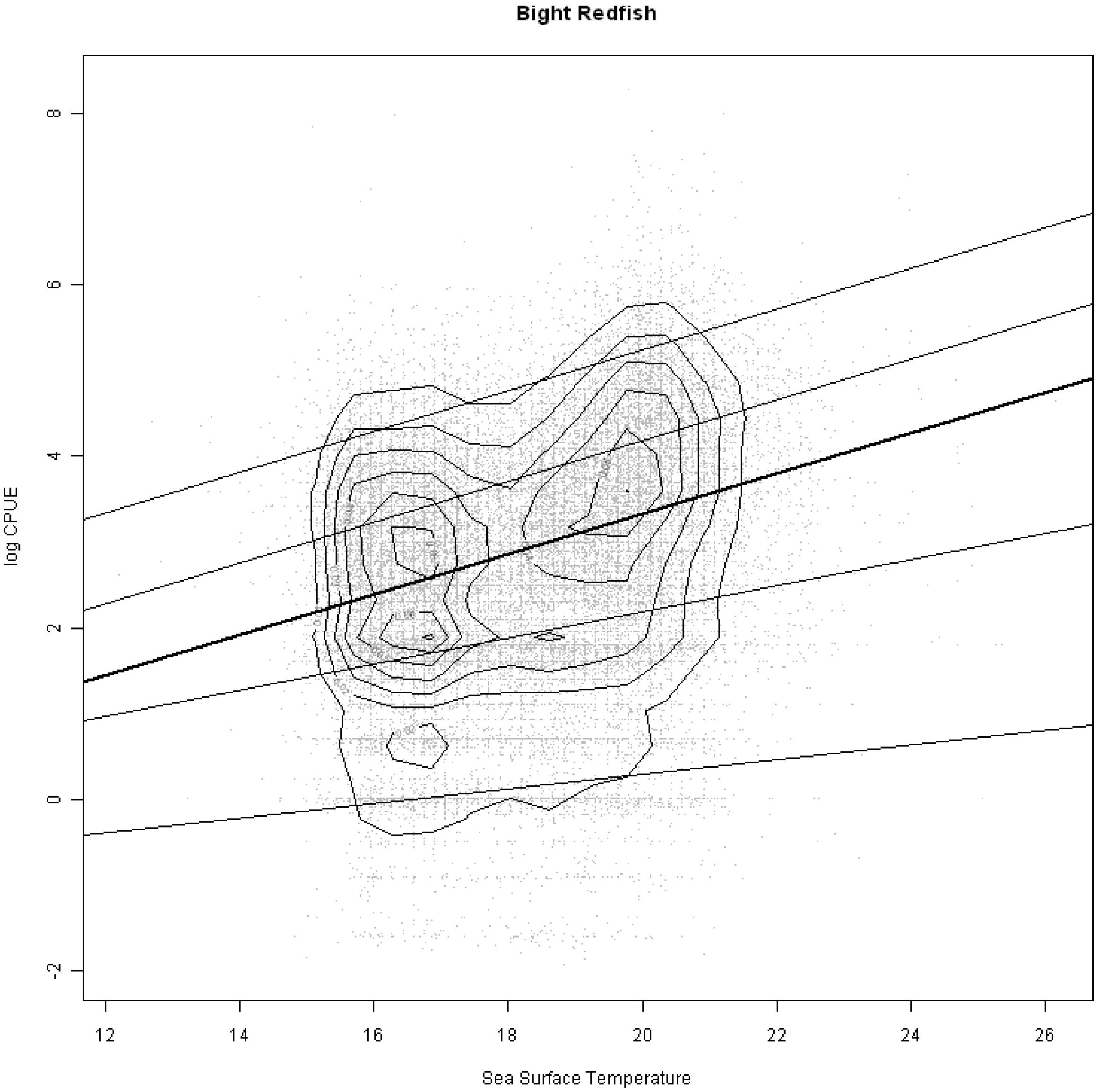

Figure 187. Bight redfish vs SST: log catch rate plotted against environmental variables.

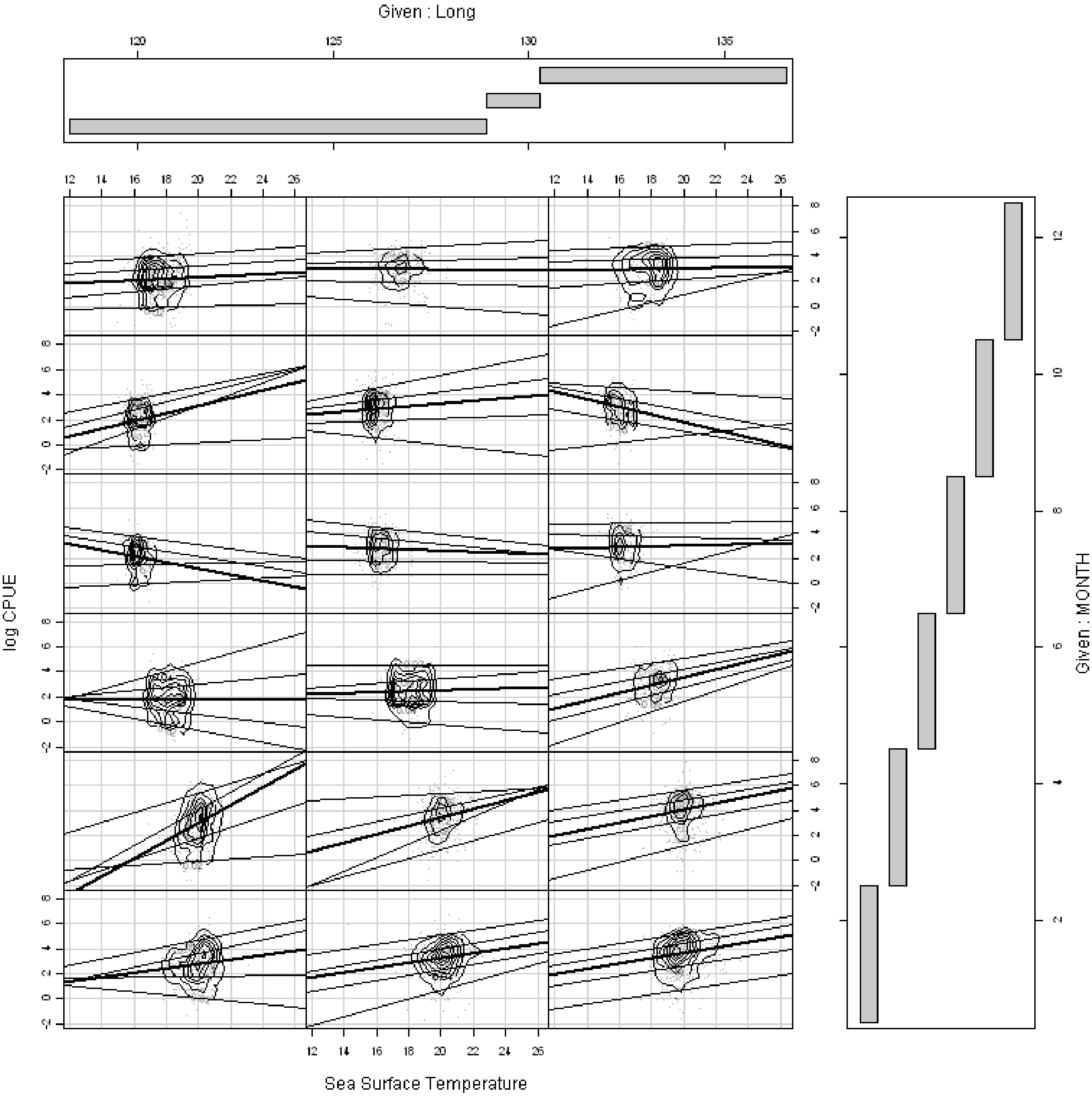

Figure 188. Bight redfish vs SST by month and longitude: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (measured by longitude in this case) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to longitudinal bands (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

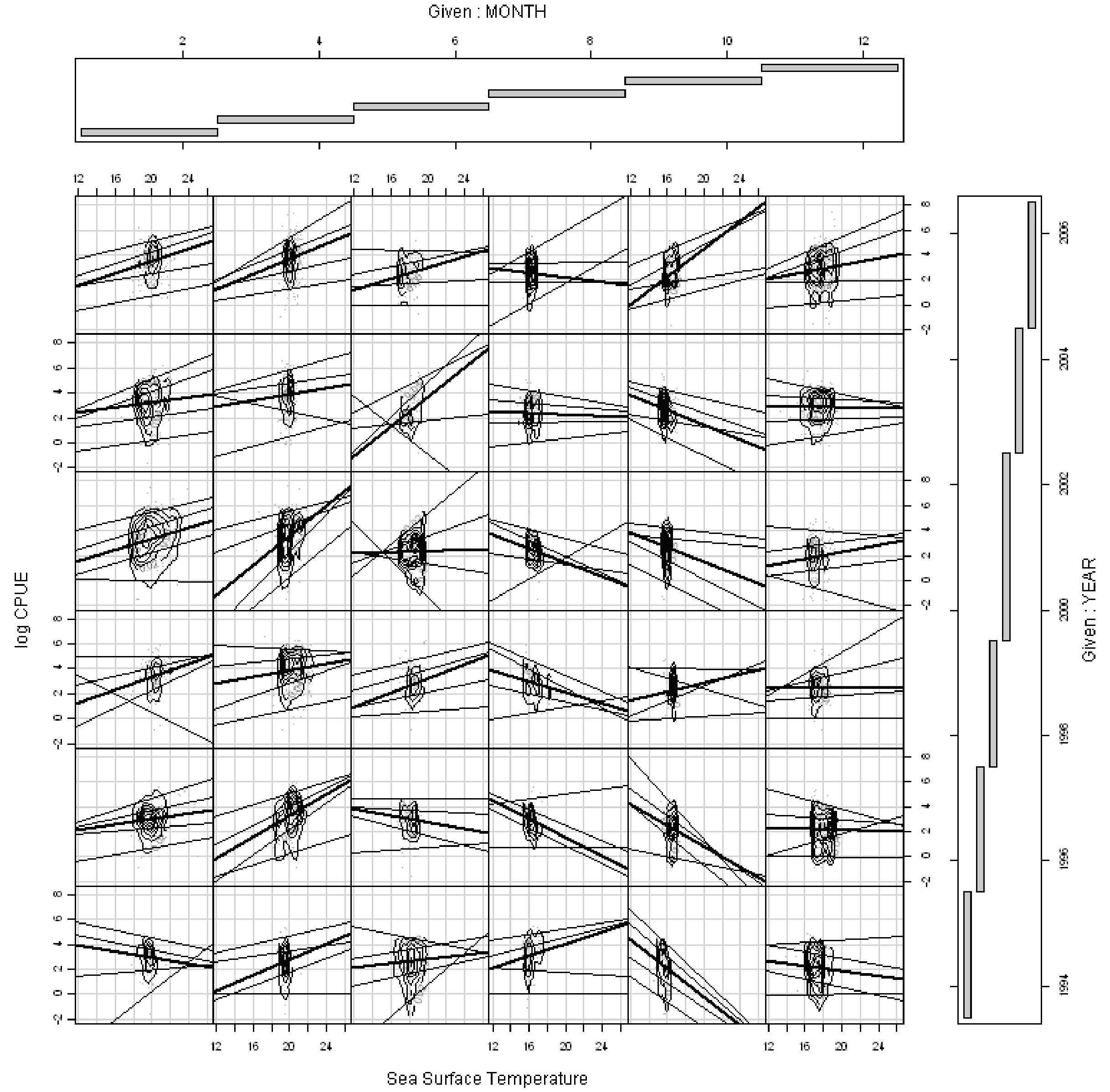

Figure 189. Bight redfish vs SST by month and year: log catch rate plotted against environmental variables. This plot simultaneously shows the temporal variation on a seasonal and a yearly scale (two month blocks and 2 or three year intervals) in the relationship between catch rate and environmental variables. The columns correspond to two month time intervals (Jan/Feb at the left and Nov/Dec at the right) with the rows corresponding to two or three year time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Bight redfish - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for Bight redfish. The correlation of catch rates of redfish with temperature-at-depth was -0.044 which was very low, suggesting no relationship between catch rate and temperature-at-depth (Figure 190). When catch rates are separated by month and longitude, there is evidence of some interaction between longitude and month in any relationship between catch rate and temperature-at-depth (Figure 191).

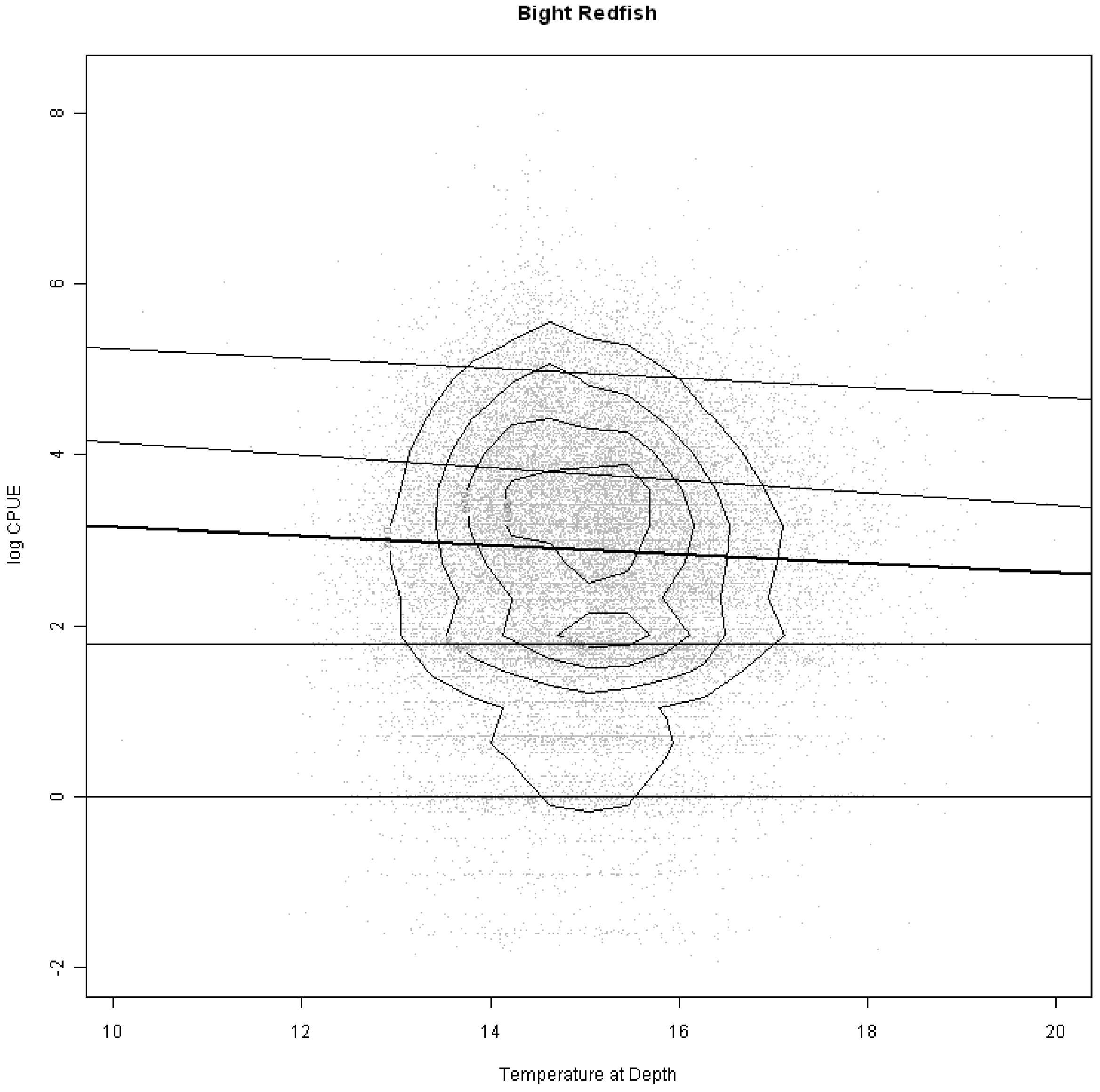

Figure 190. Bight redfish vs temperature-at-depth: log catch rate plotted against environmental variables.

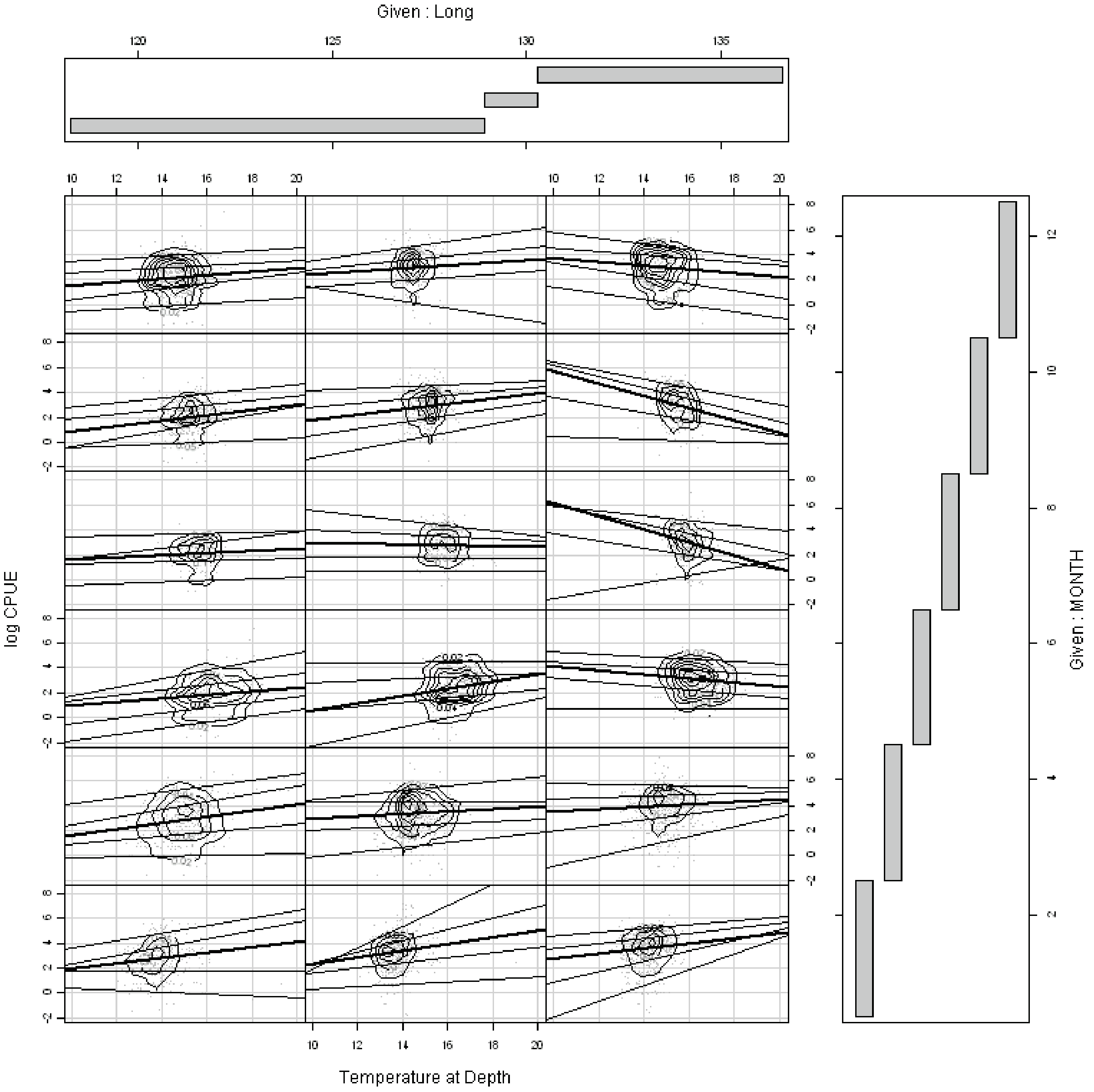

Figure 191. Bight redfish vs temperature-at-depth by month and longitude: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (measured by longitude) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to longitudinal bands (moving to the east from left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Bight redfish - chlorophyll A

This section shows the relationship between catch rate and chlorophyll A data for Bight redfish. The correlation of catch rates with chlorophyll A was -0.144 which is low, suggesting no relationship (Figure 192). Separating the data by month and longitude shows that there may be some interaction between year and month in any relationship between catch rate and chlorophyll A (Figure 193).

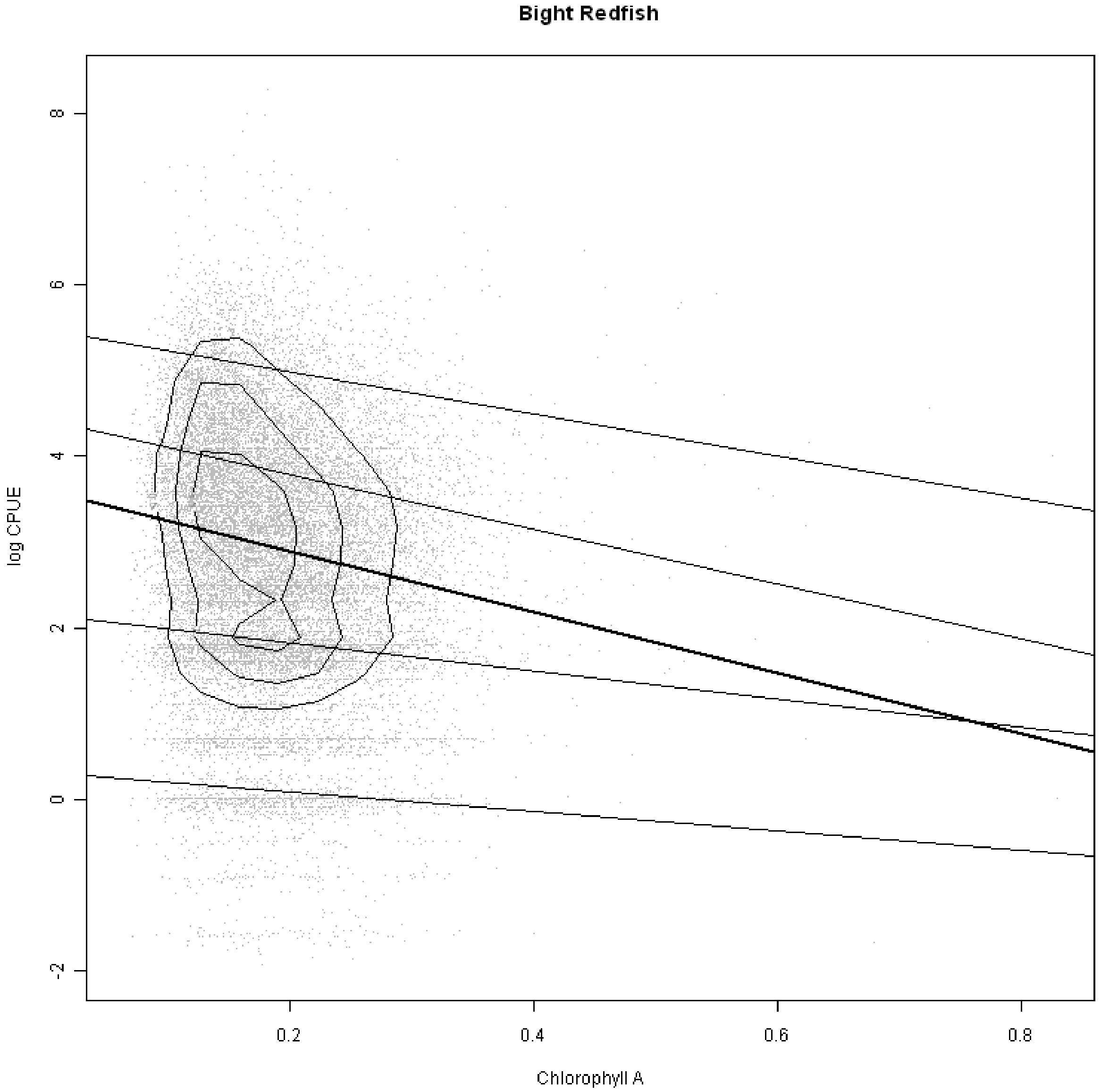

Figure 192. Bight redfish vs chlorophyll A: log catch rate plotted against environmental variables.

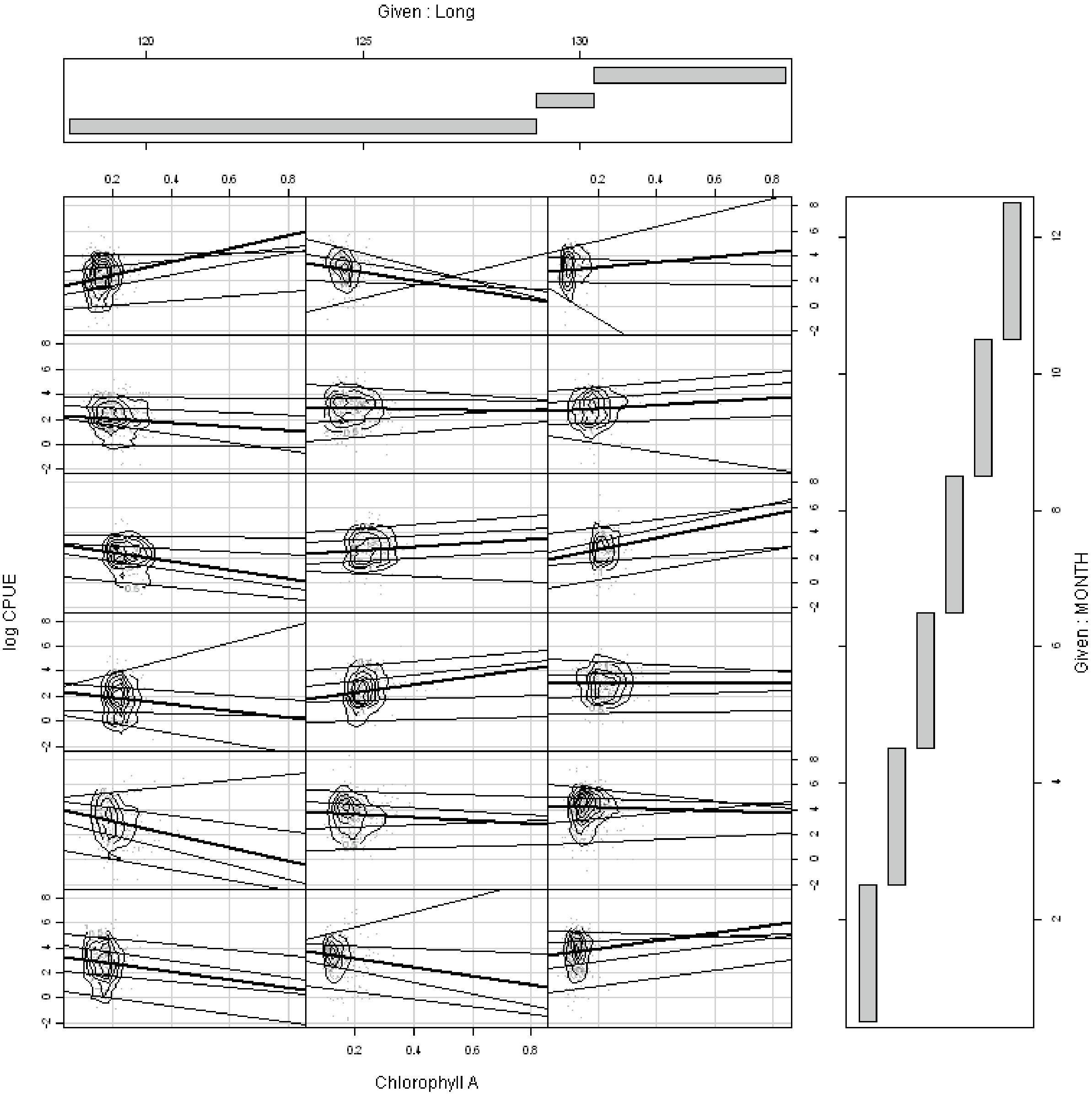

Figure 193. Redfish vs chlorophyll A by month and longitude: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (measured by longitude) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to longitudinal bands (moving to the east from left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Silver warehou - SST

This section shows the relationship between catch rate and SST data for silver warehou. The correlation of catch rates of silver warehou with SST was -0.265 which is low, suggesting a limited relationship between catch rate and SST. The negative relationship can be seen in the plot of the data (Figure 194). When catch rates are separated by month and zone some interaction can be seen between zone and month in any relationship between catch rate and SST.

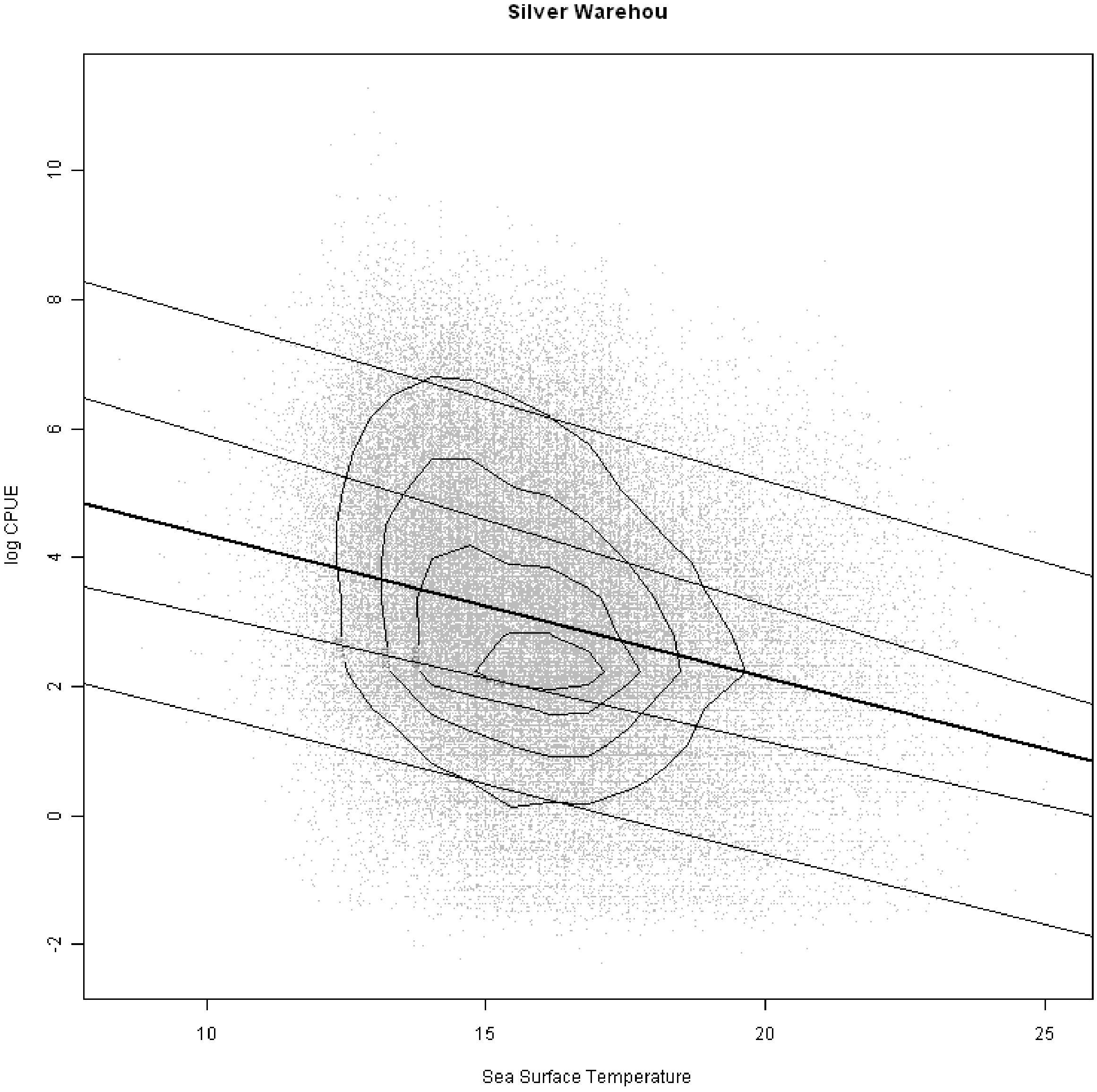

Figure 194. Silver warehou vs SST: log catch rate plotted against environmental variables.

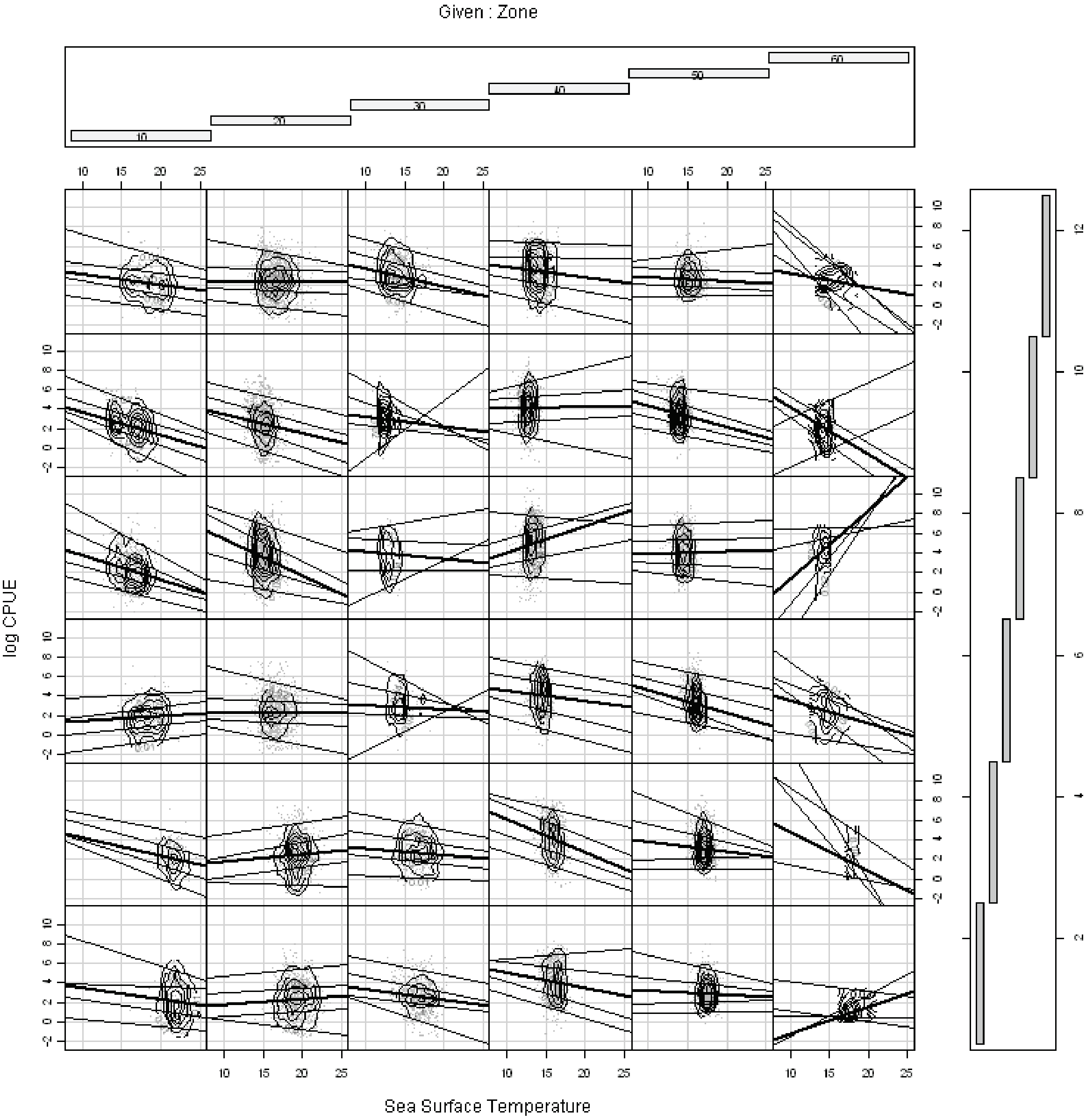

Figure 195. Silver warehou vs SST by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Silver warehou - temperature-at-depth

This section shows the relationship between catch rate and temperature-at-depth data for silver warehou. The correlation of catch rates of silver warehou with temperature-at-depth was -0.166 which is low, suggesting no relationship between catch rate and temperature-at-depth (Figure 196). When catch rates are separated by month and zone, there appears to be some interaction between zone and month in any relationship between catch rate and temperature-at-depth (Figure 197).

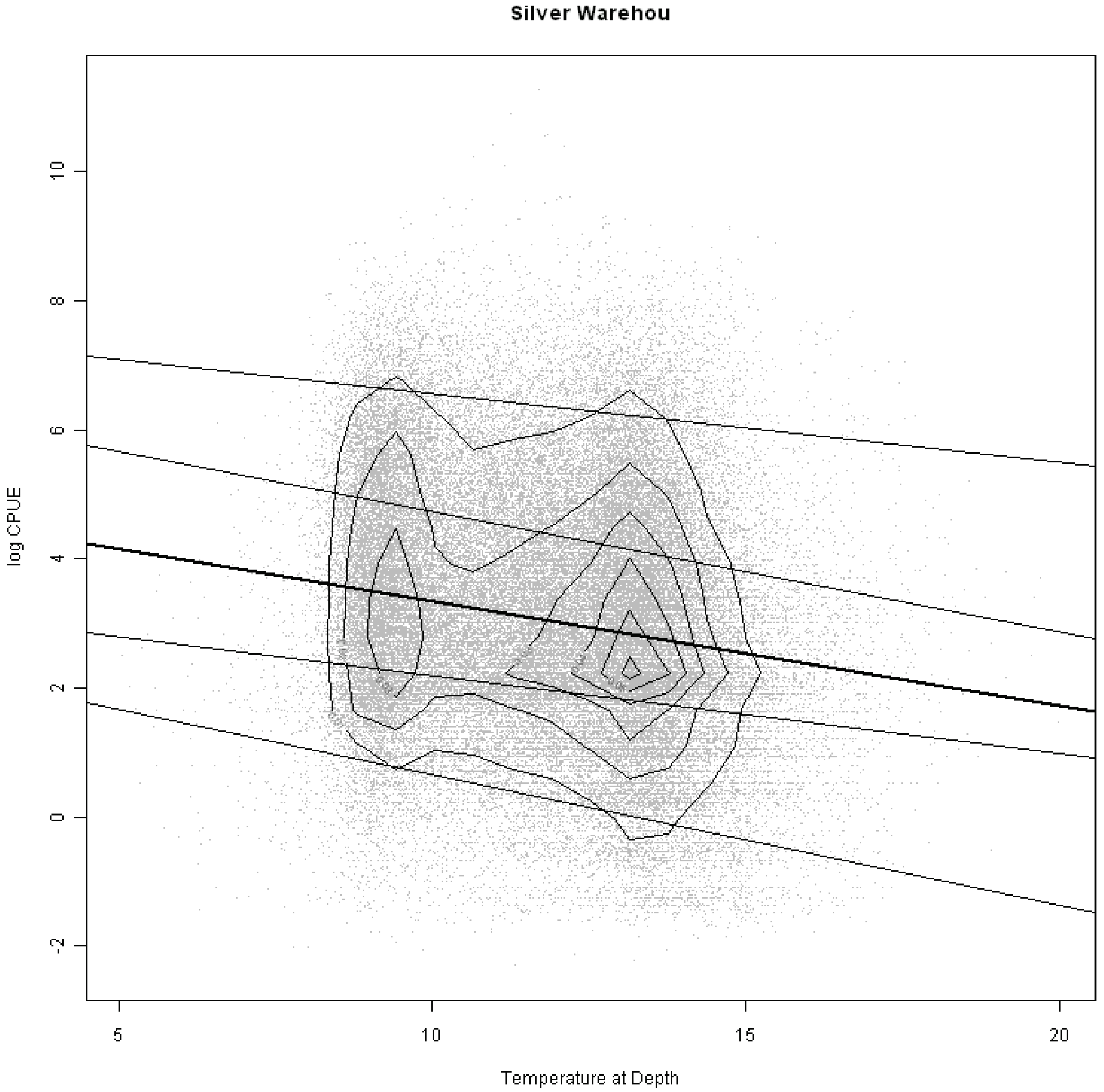

Figure 196. Silver warehou vs temperature-at-depth: log catch rate plotted against environmental variables.

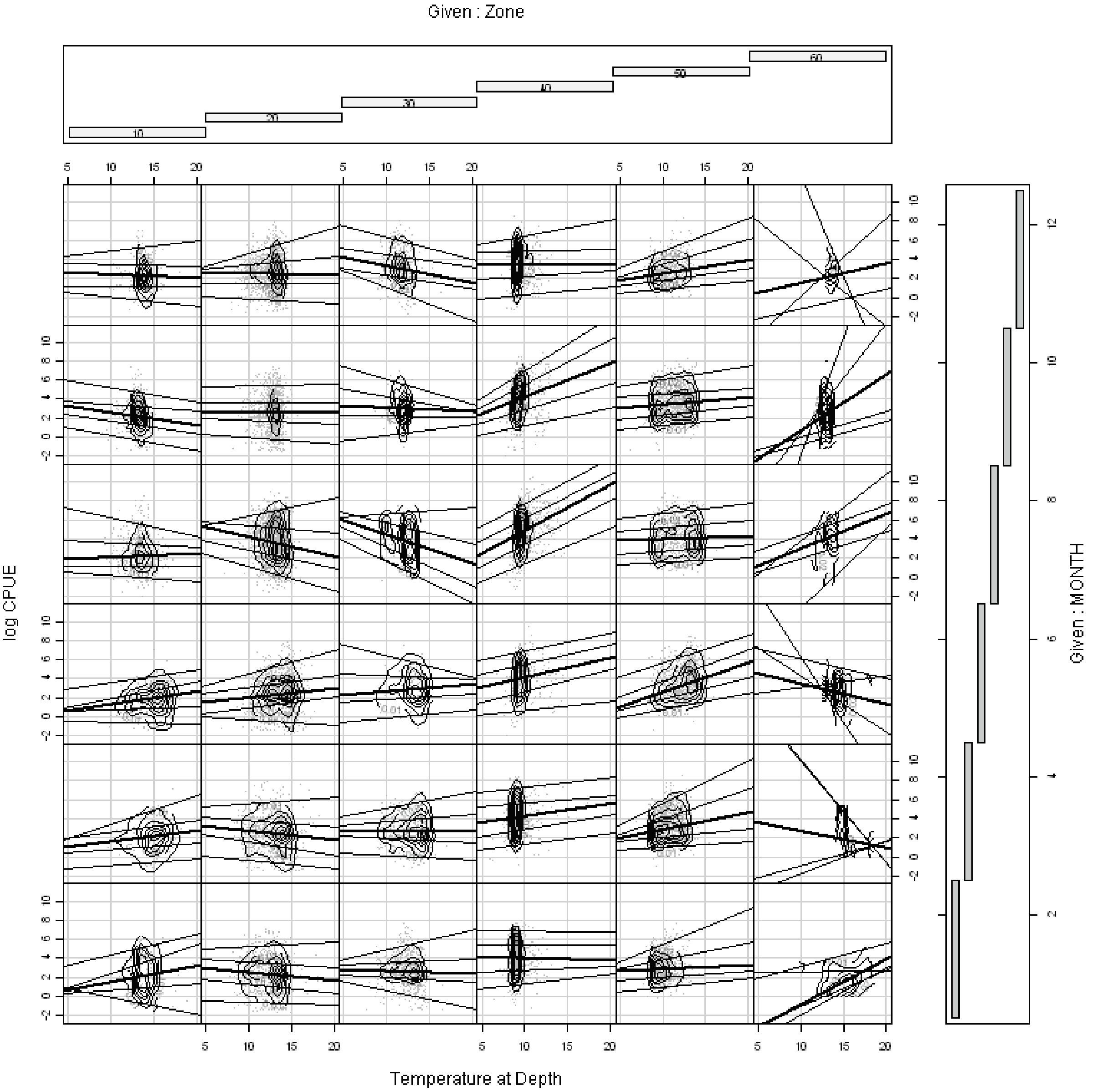

Figure 197. Silver warehou vs temperature-at-depth by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).

Silver warehou - wind speed

This section shows the relationship between catch rate and wind speed data for silver warehou. The correlation of catch rates of silver warehou with wind speed was 0.191 which is low, suggesting no relationship between catch rate and wind speed (Figure 198). When catch rates are separated by month and zone, some interaction between year and month is apparent in any relationship between catch rate and wind speed (Figure 199).

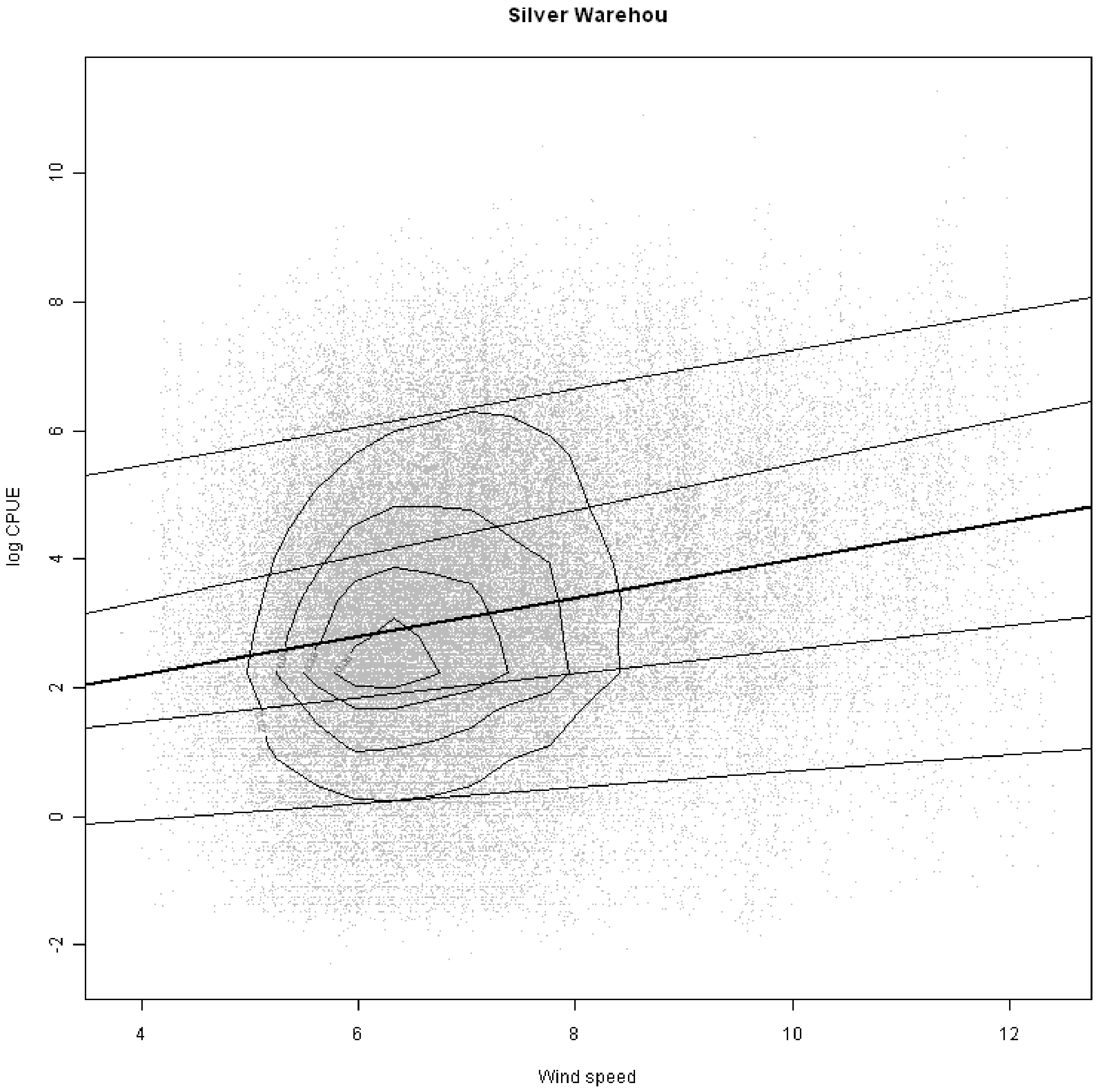

Figure 198. Silver warehou vs wind speed: log catch rate plotted against environmental variables.

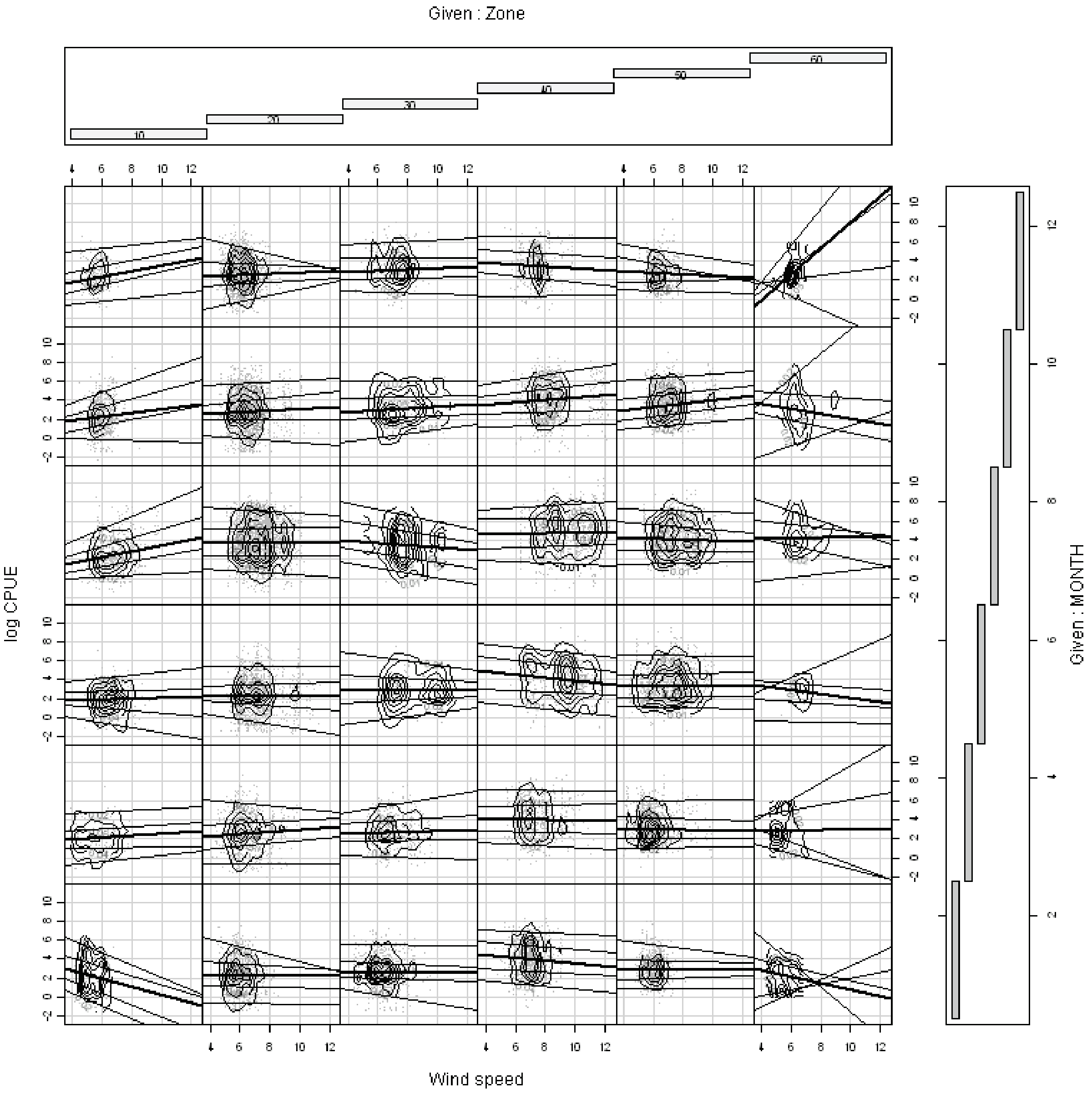

Figure 199. Silver warehou vs wind speed by month and zone: log catch rate plotted against environmental variables. This plot simultaneously shows the spatial variation (by zone) and temporal variation (two month blocks) in the relationship between catch rate and environmental variables. The columns correspond to zones (increasing left to right) with the rows corresponding to two month time intervals (Jan/Feb at the bottom and Nov/Dec at the top).