FINAL REPORT (DEVELOPMENT AWARD)

AWARD CODE and TITLE:

2008/314.15 2009 FRDC International travel bursary - John Keane

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HOST ORGANISATION: University of Tasmania

DATE: 27/08/14

ACTIVITY UNDERTAKEN

Attend the 33rd annual larval fish conference in Portland, USA, which was held in cooperation with the annual meeting of the American Society of Ichthyologists and Herpetologists, and to meet with Professor David Checkely from SCRIPPS Institute of Oceanography as well as Tony Koslow from the National Oceanic and Atmospheric Administration (NOAA) to discuss the affect of climate change on small pelagic fishes.

OUTCOMES ACHIEVED TO DATE

The dynamics of larvae of small pelagic fish taxa common in shelf waters of south-eastern Australia were linked with oceanographic features associated with the seasonal East Australian Current (EAC) to define essential habitats and predict key spawning areas. Along-shelf distributions and abundances varied markedly with water mass structure, with peak abundances frequently occurring in the mixed water mass (MIX; located between the EAC and Tasman Sea (TAS) water masses) just south of the EAC deflection point where upwelling of nutrient-rich slope water was evident. Quotient analyses revealed notable similarities in temperature preferences among all taxa with a marked decline in abundances in waters <18°C, i.e. those immediately south of the MIX-TAS interface, suggesting that this temperature front may be a barrier to the southward dispersal of larvae. Results were discussed with key researchers from SCRIPPS and NOAA and presented at the 33rd annual international larval fish conference. Overall findings indicate larval distributions are determined by the strength and extent of the EAC, and suggest that variable hydrographic conditions play a key role in defining the timing and location of spawning of these small pelagic taxa.

Acknowledgments

I would like to thank the University of Tasmania for their assistance in facilitating this travel and development. Special thanks to Dr Ana Lara Lopez from SCRIPPS Institute of Oceanography for hosting me and Dr Tony Miskiewicz for introducing me to many of the profound researches presenting at the conference.

Background

Extensive plankton surveys were conducted off the eastern Australian coast between 2002-2004 as part of FRDC project 2002/061; Development and evaluation of egg-based stock assessment methods for blue mackerel *Scomber australasicus* in southern Australia. The opportunity existed to further examine data of other small pelagic species to develop theories and hypothesis regarding links between the early life history of small pelagic fishes and oceanographic processes, as well as predicting possible effects of imminent climate change within south-eastern Australia. To fully develop hypotheses on such linkages it was vital to obtain the latest information on large scale marine systems, ecological models and theories regarding transport, advection, dispersal and retention processes. An opportunity to gather such information existed with a workshop and conference dedicated to connectivity in marine fish populations in Portland, USA.

The 33rd annual larval fish conference of the Early Life History Section of the American Fisheries Society was held in conjunction with the Joint Meeting of Ichthyologists and Herpetologists (JMIH). The conference took place at the Hilton Portland & Executive Tower in Portland, Oregon, 22-27 July 2009. The 2009 JMIH also included the 25th annual meeting of the American Elasmobranch Society, the 52nd annual meeting of the Society for the Study of Amphibians and Reptiles, the 67th annual meeting of the Herpetologists' League, and the 89th annual meeting of the American Society of Ichthyologists and Herpetologists.

The larval fish conference and workshop was themed “Temperate-tropical differences in connectivity – real and perceived” and organized by Jeff Leis of the Australian Museum, as well as by Jenn Caselle and Bob Warner from the University of California, Santa Barbara. The purpose of workshop was to bring together larval biologists, fisheries biologists, oceanographers and other researchers working in temperate and tropical environments to explore what differences are real and which may stem from different approaches to working on connectivity.

Perspectives and goals differ amongst tropical and temperate workers, and this naturally leads to different research approaches. This can lead us to perceive greater differences amongst systems than may really exist. The organisers identified a number of contrasts between temperate and tropical fish populations and in how research has been conducted in these two realms. Topics relating to factors influencing connectivity addressed in the workshop included: larval biology, scale, species, MPAs, dispersal/retention vs food-related, productivity and variability, marine-freshwater interactivity, intermediate habitats and type of dispersal.

Need

Determining links between spawning dynamics, as well as the early life history, of small pelagic fishes and oceanographic processes off south-eastern Australia is needed to strengthen the understanding of stock structure, basic biology, and the impacts of various environmental influences on the target species in the Commonwealth Small Pelagic Fishery (SPF). Little information is known about bio-physical links in this region, despite studies worldwide showing that oceanographic processes play a critical role in determining recruitment success of small pelagics and influence population dynamics as a whole. Such information on spatio-temporal spawning dynamics becomes crucial when designing species specific surveys, such as those for biomass estimates from the daily egg production method (DEPM). Furthermore, global climate change models predict that a strengthening of the East Australian Current (EAC), the largest influence on marine ecosystems in south-eastern Australia, will result in the region being most vulnerable to climate change. As a result, it is essential to understand how EAC dynamics influence small-pelagic fish stocks before any predictions of the influence of climate change can be made.

Objectives

1. To determine links between larval dynamics of small pelagic fishes and oceanographic features off south-eastern Australia.

   Data analyses showed larvae of *Etrumeus teres*, *Sardinops sagax*, *Engraulis australis*, *Trachurus* spp., *Scomber australasicus* and *Emmilichthys nitidus* have clear links with the water mass structure off south-eastern Australia. Such results suggest that spawning of these taxa is closely linked to the extent, strength and timing of the seasonal EAC cycle. This knowledge can be further used in the design of future fisheries studies, such as DEPM surveys.

2. To source the latest knowledge on connectivity between the early life history of fish and oceanographic processes.

   Meetings were arranged with researchers at the NOAA's South Western Fisheries Science Centre (SWFSS) and SCRIPPS Institute of Oceanography in California to discuss bio-physical links between small pelagic fish larvae and oceanography. Furthermore, attendance at the 33rd annual larval fish conference and workshop in Portland, Oregon, revealed the latest research from around the globe.

3. To develop hypotheses regarding the influence of oceanic processes associated with the East Australian Current on the spawning dynamics and early life history stages of small pelagic fishes, and propose likely changes to the stock under imminent climate change predictions.

   Discussions with international experts from NOAA, SCRIPPS and the Larval Fish Conference allowed for comparisons between small pelagic fishes in the EAC and other major western boundary currents worldwide, as well as providing insights into potential effects of climate change on small pelagic fish stocks in the region.

Methods

Analysis of larval data on small pelagic fish species, namely *Etrumeus teres*, *Sardinops sagax*, *Engraulis australis*, *Trachurus* spp., *Scomber australasicus* and *E. nitidus* collected off the east coast of Australia in 2002-2004 during FRDC project 2002/061 (Ward and Rogers, 2007) was conducted to describe links between their distribution and water mass structure off eastern Australia. Survey details are documented in Ward and Rogers (2007) while methods for data analysis followed those described in Keane and Neira (2008), and Neira and Keane (2008). Following data analysis travel was conducted to the National Oceanic and Atmospheric Administration's (NOAA) South Western Fisheries Science Centre (SWFSS) and to SCRIPPS Institute of Oceanography in La Jolla, California to discuss findings with international experts in fisheries oceanography. Results, encompassing knowledge gained from the SWFSS/SCRIPPS visit, was then presented at the 33rd Annual larval fish conference of the Early Life History Section of the American Fisheries Society in Portland, Oregon (Appendix 1).

Results

Small pelagic fish larval habitat and the East Australian Current.

Three discrete water masses occurred within the study region, namely East Australian Current (EAC) to the north, Tasman Sea (TAS) to the south, and mixed (MIX), a composite mass containing EAC-TAS water. The EAC strongly influenced conditions, being both stronger and further advanced to the south in summer than in winter. Separation of the current from the coast generally occurred at major headlands. Distinct regions of upwelling were present at the EAC separation points in spring surveys. Water mass interfaces shifted seasonally and spatially depending on the EAC strength and extent. The MIX water mass was characterised by steep vertical temperature profiles resulting from the warmer EAC overlaying cooler TAS water. Overall results depict the highly variable nature of the EAC, and show that this western boundary current drives oceanographic processes along the south-eastern Australian shelf.

Etrumeus teres were predominately present within the EAC and MIX water masses and absent from TAS waters. Peak abundances occurred near the southern extent of the EAC, within 50 nm of the EAC-MIX interface, coinciding with areas of high temperature gradient and near the EAC separation point where coastal uplift of cooler waters was observed. Larval *E. teres* were caught within a broad range of temperatures between 17.0 and 24.3ºC, with all positive stations averaging 20.9°C. The occurrence of larvae at the minimum SST (17.0°C) corresponded with upwelling at the EAC separation point. The highest mean abundance of 79/10m^2 occurred in 20.0-20.5ºC water. Quotient analysis showed a temperature preference of 19.0-22.5ºC, although predominantly 19.0-21.0ºC, which encompasses water around the EAC-MIX interface. Highest mean larval abundances occurred in waters 100-120 m deep, with quotient analyses showing a preference to waters of 40-120 m deep, i.e. over the inner to mid-shelf region.

Sardinops sagax were most prevalent throughout EAC and MIX waters with highest abundances coincided with regions of upwelling relating to the EAC separation from the coast. Results parallel previous reports of peak spawning occurring off southern Qld/northern NSW in winter, followed by a marked shift in the spawning area to the south towards summer Larval *S. sagax* were caught in a broad range of temperatures between 15.5 and 24.3ºC, with positive stations averaging 20.4ºC. The highest mean abundance occurred in 19-19.5ºC water. Quotient analysis showed a temperature preference of 18.0-22.0ºC, although predominantly between 18.0-20.0ºC, which corresponds to the MIX water mass. Larvae were predominantly abundant over the inner and mid-self in waters of 20-160 m depth, with quotient analysis showing a preference of 20-120 m.

Engraulis australis were abundant in EAC and MIX waters and absent from TAS waters. The southernmost occurrence of larvae was 30ºS (northern NSW) in winter, 35ºS (southern NSW) in spring and 42ºS (Tasmania) in summer which mirrored the seasonal extension of the EAC down the coast. Larvae were caught in a broad range of temperatures between 16.8 and 23.6ºC, with an average of 20.8°C recorded from all positive stations. The highest mean abundance was in 18-18.5ºC, with abundances decreasing markedly with higher and lower temperatures. Quotient analysis shows temperature preference of larvae to be 18.0 - 20.0°C. Larvae of *E. australis* were caught at stations between the 17 and 1940 m depth contours. However, they were most prevalent over the inner to mid shelf with quotient analysis showing a preference over the 40-140 m depth contours.

Larvae of *E. nitidus* were caught solely within the TAS water mass in spring. Temperatures ranged between 14.7 and 17.1ºC, with an average of 15.9°C recorded from all positive stations. Quotient analysis shows temperature preference of *E. nitidus* larvae to be in waters <17ºC and at depths >80 m with the highest abundance occurring in waters of 250-500 m

Scomber australasicus larvae were most abundant in MIX waters, present in EAC waters and rare in TAS waters. Larvae were caught in temperatures between 16.8 and 22.5ºC, averaging 20.1°C from all positive stations. Quotient analysis showed a clear temperature preference of larvae between 18.5 and 20.5ºC which encompasses the MIX water mass plus EAC-MIX frontal waters. Larval were abundant over the shelf including the break, before numbers declined in offshore waters. Moreover, the highest mean abundance occurred between the 160 and 180 m depth contours, with quotient analysis showing a preference of larvae in waters of 40-250 m depth.

Larvae of *Trachurus spp.* were abundant in all water masses, with peak abundances occurring in close proximity to the EAC-MIX interface where upwelling was apparent. The widespread distribution of larval *Trachurus spp*. is a result of this taxon comprising two common but morphologically inseparable species, namely *T. novaezelandiae* and *T. declivis*. Adult *T. novaezelandiae* are more prominent in warmer EAC associated waters, while *T. declivis* is confined mostly to cooler TAS waters in south-eastern Australia and it is likely larval distributions will mirror this. Larval *Trachurus spp*. were caught in a broad range of temperatures (15.5 – 24.3), with an average of 20.3°C recorded from all positive stations. Quotient analysis shows temperature preference of *Trachurus spp*. larvae to be 18.5 - 21.5ºC, although predominantly between 18.5 and 20.0ºC (MIX waters). Quotient analysis shows preference of larvae to be primarily over the inner to mid-shelf in waters of 40-140 m depth.

Table 1. Summary of habitat characteristics of the dominant small pelagic taxa. Preferred surface temperature and bathymetric depth ranges are derived from quotient analyses (Quotient >1).

Taxa	Temperature(ºC)		Depth (m)		Predominant water mass
	Range	Quotient >1	Range	Quotient >1	
Etrumeus teres	17.0-24.3	19-22.5	26-848	40-120	EAC-MIX
Sardinops sagax	15.5-24.3	18-22	26-1200	20-120	EAC-MIX
Engraulis australis	16.8-23.6	18-20	17-1940	40-120	MIX
Trachurus spp.	15.5-24.3	18.5-21.5	26-1550	40-140	EAC-MIX
Scomber australasicus	16.8-22.5	18.5-20.5	38-1000	40-200	MIX
Emmilichthys nitidus	14.7-14.1	14.5-17	85-1550	>100	TAS

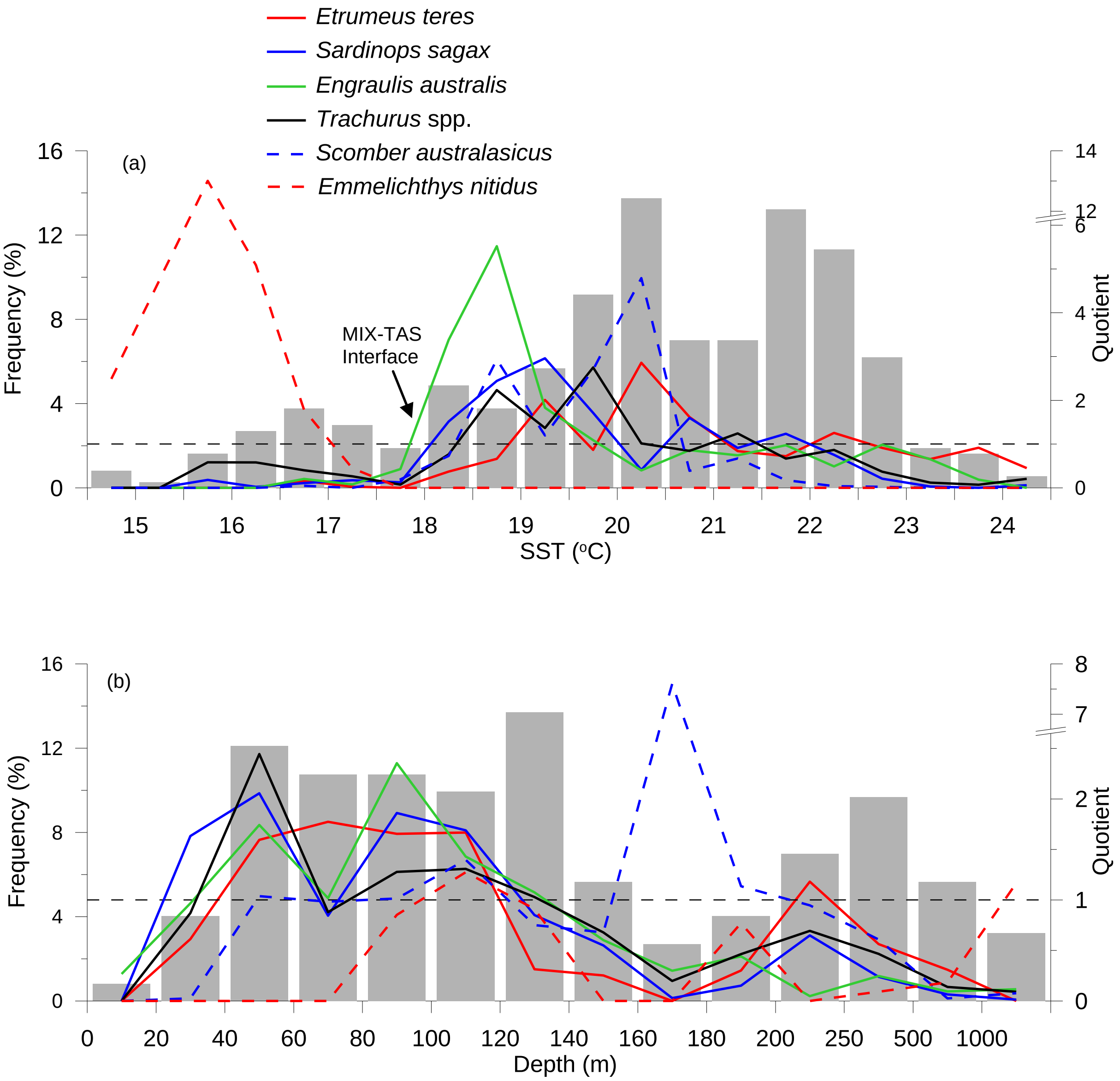

Figure 1. Comparison of quotient analyses on larval abundances (numbers/10m^2) of small pelagic taxa by a) SST (ºC) and b) depth (m). Data was obtained across positive surveys for each taxon along south-eastern Australia in 2002-2004. Quotient values >1 (broken lines) indicate positive temperature selection. Arrow points the location of the MIX-TAS interface (18ºC).

International travel

Travel was conducted to La Jolla, California and meetings were set up with Dr Tony Koslow, Research Oceanographer and Director of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) as well as Professor David Checkley, an oceanographer at SCRIPPS as well as the Editor-in-Chief of the international journal Fisheries Oceanography.

Dr Koslow's research lies with biological oceanography, focusing on micronekton: the krill and small pelagic and mesopelagic fishes that dominate the water column. Discussions were had in relation to linking biological and oceanographic data in the southern California Current using the California Cooperative Oceanic Fisheries Investigations ichthyoplankton data set. The California Current small pelagic species (northern anchovy and Pacific sardine) are primarily correlated with sea surface temperature with the boarder fish assemblages predominantly influenced by environmental forcing of their ocean habitats.

Professor Checkley's key research interests lay in long-term change in pelagic zooplankton and fish, in particular the effects of climate variability on small pelagic fish and their ecosystems and fisheries. Discussions were had on how climate influences fish stocks, particularly in relation to the eastern pacific small pelagic species and the influence of El Niño/ La Niña. Following this we discussed the potential effects of the East Australian Current on small pelagic fishes.

After the meetings travel to Portland, Oregon was undertaken to attend the 33rd annual Larval Fish Conference (LFC) of the Early Life History Section (ELHS) of the American Fisheries Society (AFS).The LFC symposia spanned four days and included many interesting, relevant and stimulating presentations. Some of the key presentations are listed below (* indicates researchers I had discussions with). The presentation on small pelagic fishes in the EAC was well received and attracted lots of questions and positive feedback. The talk given was significant as it was the first presentation linking small pelagic fish distributions to oceanographic conditions at a large scale in Australia. Furthermore, attendance at this conference and workshop was highly beneficial in discussing and developing theories and hypothesis regarding links between the early life history of small pelagic fishes and oceanographic processes, as well as predicting possible effects of imminent climate change within south-eastern Australia. Knowledge gained is applied to the discussion below.

Key talks at the AFS/ELHS/LFC

- P Munday* - Ocean Temperature, Global Warming And Population Connectivity Of Tropical Marine Fishes
- B Cowen - Connectivity and Conservation Physiology in Cold-Oceans
- R Cowen* - Perception versus reality: Does larval biology differ with latitude?
- J Leis* - How Do Biogeography and Study Species Influence Connectivity?
- A Shanks - Pelagic Larval Duration and Dispersal Distance
- J Hare* - Population Connectivity and Temperate Nursery Habitats: Are Estuaries and Seagrasses So Special?

- S Swearer* - Does Landscape Context Influence the Magnitude of Connectivity in Marine Metapopulations?
- J Shima* - Demographic Connectivity in a Temperate Reef Fish Metapopulation: The Critical Role of the Dispersal Matrix
- J Hyde - Examination of Population Connectivity in Sardine (Sardinops sagax caeruleus) in the North East Pacific using Microsatellite Markers
- M Peck* - Climate-driven Changes in the Survival and Growth of Marine Fish: Individual-based Model Estimates for Larval Herring (Clupea harengus) in the North Sea
- D Richardson - Does Haddock Egg Predation Decouple the Abundance of Atlantic Herring Larvae from Spawning Stock Biomass on Georges Bank?
- C Grimes* - The Role of Oceanographic Features in the Reproductive Strategies of Some Scombrid Fishes
- R Borges - Tidal and Vertical Distribution of Nearshore Fish Larval Assemblages at a Temperate Rocky Shore
- G Aceves-Medina* - Multivariate Characterization of Spawning and Larval Environment of Small Pelagic Fishes in the Gulf of California
- P Munday* - Ocean Acidification Affects Larval Growth and Olfactory Discrimination of a Marine Fish
- S Acevedo* - The Vertical and Horizontal Distribution of Fish Larvae in Central Bass Strait, South-Eastern Australia

Discussion

Small pelagic fishes

Characterisation of small pelagic fish larval habitats along the south-east Australian shelf revealed species-specific associations strongly linked to water mass structure within the region. Taxa were generally associated with EAC/MIX waters (e.g. *S. sagax*, *S. australasicus*) or TAS waters (*E. nitidus*). While most taxa showed distinct habitat preferences, *Trachurus* spp. was abundant across all water masses. No taxa were exclusive to the MIX water mass. The greatest abundances of many larval taxa, including*, S. australasicus* and *S. sagax,* were recorded within MIX waters.

The finding of higher abundances of many taxa within the MIX water mass coincides with upwelling within these waters both off mid-NSW during spring and off eastern Bass Strait during summer. Current-driven upwelling of slope water south of the EAC separation point (i.e. south of the EAC-MIX interface) is a persistent feature off mid-NSW during spring, while short-lived wind-driven upwelling events frequently bringing cool, subantarctic water shoreward over north-eastern Bass Strait during summer (Hallegraeff and Jeffery, 1993; Oke and Middleton, 2001; Neira, 2005). Such events bring nutrient-rich water to the surface triggering phytoplankton and subsequently zooplankton blooms (Hallegraeff and Jeffery, 1993; Bax *et al*. 2001). As maximum recruitment of young fish to adult stocks is largely dependent on a sufficiently dense and appropriate food source for larvae, evidence suggests that some fish time their spawning to coincide with such peak periods of primary productivity (Lasker, 1975; Cushing, 1990). While evidence is insufficient to determine species-specific relationships between spawning fishes and biological processes, the substantially elevated numbers of larvae in nutrient enriched areas indicates at least some level of biological influence on spawning behaviour within the region.

The distributional limits of taxa frequently corresponded to the location of water mass interfaces, with the MIX-TAS interface during spring being most noteworthy. This interface frequently corresponded to the southern limits of *E. teres*, *E. australis*, and *S. australasicus*, as well as the northern extent of *E. nitidus*. Such results are likely a reflection of the EAC-MIX interface being very fluid and dynamic, as this boundary corresponds with EAC separation, as well as upwelling and eddy formation regions. Although a clear shift in the assemblage structure occurs at the EAC-MIX interface, the high velocity and vigorous nature of the currents associated with this boundary creates conditions more apt in the flux of larvae between the water masses.

Distributions of larvae varied both seasonally and annually, generally reflecting the strength and extent of the EAC and the related shift in water mass distributions. Taxa that were present in multiple seasons generally showed a more southerly distribution during spring than in winter, and likewise between summer and spring. This includes northern and southern boundaries, as well as areas of peak abundances. For example, *E. australis*, were absent off southern NSW during spring when the TAS water mass prevailed, but were abundant in this region during summer following a southerly shift in water masses. Furthermore, distributional boundaries and areas of peak abundance were often located further to the south in spring 2002 than in spring

2003. Such findings, which were most evident in *S. australasicus*, parallel the fact that the EAC was stronger and further advanced to the south during 2002.

Based on larval distributions, results from this mesoscale study suggest that spawning of small pelagic fishes is closely linked to the extent, strength and timing of the seasonal EAC cycle. Basing spatio-temporal limits of spawning on larval distributions is considered not unreasonable in this instance given the scale of the study, the high proportion of preflexion larvae (e.g. 94% in *S. australasicus*), as well as the similar broad-scale egg and larval distribution evidenced by *S. australasicus* within this study (Neira and Keane, 2008). The similar distribution and habitat preference exhibited by larvae of the above-mentioned small pelagic taxa indicates that adults of these species employ at least some common spawning strategies. Higher mean abundances of these taxa frequently occurred in MIX waters suggesting that their adults taxa may be selecting these waters to spawn due to increased primary productivity initiated by upwelling (Hallegraeff and Jeffery, 1993; Gibbs, 2000; Pritchard *et al*. 2003). Such results follow worldwide findings of increased production of small pelagics in upwelled waters (Bakun, 1996; Cury *et al*., 2000; Rykaczewski and Checkley, 2008). In addition, quotient values increased dramatically at temperatures >18.0ºC implying that this temperature front may be acting as a spawning trigger for these species as it propagates down the coast.

It is proposed here that peak spawning of *E. teres*, *S. sagax*, *Trachurus* spp. and *S. australasicus* during winter generally occurs off northern NSW when the EAC is at its seasonal minimum, and then protracts southward with the seasonal advancement of the EAC. Peak spawning regions of these taxa coincide with the southern EAC and MIX waters (i.e. 18-21ºC), particularly in the vicinity of the EAC-MIX interface off mid-NSW during spring. Such spawning strategy coincides with increased primary productivity off mid-NSW, which correlates to an increased food supply for larvae (Hallegraeff and Jeffery, 1993; Gibbs, 2000; Pritchard *et al*. 2003). Further, *E. teres*, *S. sagax* and *S. australasicus* were all rare in TAS waters, indicating the MIX-TAS interface is likely the southern limit of primary spawning, at least during spring. While such results and conclusions support previous findings that peak spawning of *S. sagax* and *E. teres* off southern QLD occurs during winter (Ward *et al*. 2003), they largely contradict the hypothesis of the authors that adults of these species migrate northwards into southern Queensland during early winter to spawn. Peak larval distributions of these taxa during this much more extensive study were located substantial distances further south during winter beyond the sampling area of the Ward *et al*. (2003) study. Furthermore, results of this study revealed high levels of spawning activity persisted into spring and summer, and were located even further to the south.

The broad distribution of *Trachurus* spp. in this study is more likely a strong reflection of this taxon consisting of two species, namely *T. novaezelandiae* and *T. declivis*, than a broad spawning habitat of adults. *Trachurus novaezelandiae* is more renowned to inhabit warmer EAC waters, while *T. declivis* more abundant in cooler TAS waters (Gomon *et al*., 2008; Kuiter, 2000). Larvae of these two carangids are morphometrically very similar, with identifications further confounded due to larvae used in descriptions being from geographically distinct areas (T. Trinski, pers. comm.). However, larvae of *T. declivis* become more heavily pigmented compared to *T. novaezelandiae* from the postflexion stage onwards (Neira *et al.*, 1998). Initial distributions based on postflexion larvae along the NSW shelf during spring surveys indicate *T. novaezelandiae* to be found in EAC, *T. declivis* in TAS, and an overlap of these two species in MIX. Further, preliminary genetic work has confirmed the presence of preflexion *T. novaezelandiae* off southern QLD in EAC waters and *T. declivis* off southern NSW during in TAS waters during spring 2002 (unpublished data). The premise that *T. declivis* favour TAS waters is further supported by high abundance of eggs captured in waters between 15.0-17.5ºC off eastern Tasmania (Jordan *et al*. 1995). Although there is some limited evidence showing specific water mass associations of larvae of these two carangids, identification issues need to be resolved before any robust conclusions can be drawn from distributions off eastern Australia.

Overall results indicate principal-spawning areas of many taxa can be identified by water mass distribution, and as such may be approximated by SST satellite imagery. This is viable as water masses within this region are largely defined by their temperature structure and, as such, their distribution can be approximated by SSTs. Such information on spatio-temporal spawning dynamics becomes crucial when designing species specific surveys, such as those for biomass estimates from the daily egg production method (DEPM). As common small pelagic species have similar spawning habitats, findings of this study suggest there is potential for multi-species egg production surveys along the Australian shelf waters, beginning off southern QLD and concluding at the southern extent of the MIX water mass

Climate change and larval fish ecology

In addition to recurrent climate-induced environmental fluctuations, global warming from the well-documented greenhouse effect is predicted to a have significant influence on marine ecosystems (Bopp et al., 2001; Boyd and Doney, 2002; Lima et al., 2007; Poloczanska et al., 2007). Climate models forecast oceanic warming, increased stratification, pH and dissolved CO2, as well as modified oceanic circulation, which will alter the distribution and diversity of marine populations worldwide (Poloczanska et al., 2007). As a result, climate change will modify the temporal and spatial structure of ichthyoplankton assemblages, with increased temperatures changing the timing of migration and spawning of temperate and subtropical species, as well as causing a poleward shift in distributional ranges (Sims et al., 2001, 2005; Beare et al., 2004; Byrkjedal et al., 2004; Greve et al., 2005; Perry et al., 2005; Rose, 2005a, b; Ahas and Aasa, 2006).

Global climate change models predict that the region off south-eastern Australia will undergo the greatest warming in the entire Southern Hemisphere, with temperatures rising by 1-2°C by 2030 and 2-3°C by 2070 (Hobday, 2006a, b; Poloczanska et al., 2007). This warming is associated with predicted systematic changes in the surface ocean currents (Poloczanska et al., 2007). To date, EAC strengthening has resulted in a greater poleward penetration of warm waters over the past 60 years, with ocean warming off south-eastern Australia occurring at approximately double the rate compared to the global average (Ridgeway, 2007). Temperatures off eastern Tasmania are increasing at a rate of 2.28°C/century, which equates to a poleward advance of the EAC of ~350km. These conditions have been linked to the range extension of the sea urchin Centrostephanus rodgersii via larval dispersal across Bass Strait to Tasmania (Johnson et al., 2005; Ling et al., 2009), and also suspected to have influenced the distribution of at least 36 species of Tasmanian marine fishes during the last decade (Poloczanska et al., 2007). Further strengthening of the EAC is thus likely to continue to alter the connectivity of marine populations and species distributions off southeastern Australia through changes in larval dispersal patterns, especially those of small pelagic species (Cowen et al., 2000). Poleward range extensions will be most evident through (i) increased occurrence of tropical larvae in the more temperate waters of NSW (e.g. Booth et al., 2007); and (ii) occurrence of mainland species dispersing across Bass Strait into Tasmanian waters (similar to that observed for sea urchin; Johnson et al., 2005; Ling et al., 2009). Furthermore, range contractions of temperate species may be observed in southern regions due to a lack of available habitat south of Tasmania.

It is well recognised that spawning patterns of many teleost fishes, and therefore the seasonal timing of ichthyoplankton, depend largely on seasonal changes in temperature (Wootton, 1998; Ottersen and Loeng, 2000; Alheit and Niquen, 2004; Greve et al., 2005; Vikebø et al., 2005). Consequently, warmer water temperatures resulting from climate change will alter the temporal and spatial occurrence of ichthyoplankton assemblages. As many species rely on changes in oceanographic conditions as a means of optimising their reproductive strategy (Vikebø, 2005; Alheit and Niquen, 2004; Bertram et al., 2001; Cubillos et al., 2001), climate induced variation is likely to greatly affect species production. As significant climate-induced change to marine ecosystems is predicted to occur off south-eastern Australia, monitoring of ichthyoplankton assemblages within this region appears essential for the early detection of changes to population dynamics and recruitment levels, particularly in the context of commercially and ecologically important fish stocks such as small pelagic fishes.

Benefits and Adoption

Knowledge gained has helped understand the spawning dynamics of small pelagic fishes off south eastern Australia. This will particularly benefit the commonwealth Small Pelagic Fishery, as well as the state fishery for small pelagics. In particular, this knowledge can be used to design egg surveys for DEPM stock assessments for small pelagic species off the east coast of Australia.

Further Development

The knowledge gained from this study will assist stock assessments of key small pelagic taxa, such as *Sardinops sagax, Scomber australasicus* and *Trachurus* spp., which need to be undertaken along the south-eastern Australian shelf to enable maximum economic and sustainable yields, given their commercial, ecological and social importance. Results of this study set a foundation for future fishery-independent biomass estimate surveys (e.g. DEPM) as larval habitats can be used a proxy for characterising spawning habitats, a key step before egg production can be estimated.

The application of molecular genetic approaches to discriminate Trachurus spp. is required before any further study based on ichthyoplankton for this genus is implemented. The accurate identification and discrimination between *T. novaezelandiae* and *T. declivis*, is particularly essential for the successful implantation of stock assessment methods via the DEPM. (Note a project to resolve this issue is near completion).

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Appendices

Appendix 1

Conference presentation

John Keane, Jeremy Lyle, Francisco Neira
Tasmanian Aquaculture and Fisheries Institute, Tasmania, Australia

EAC Variability and Spawning of Small Pelagic Fishes: Inferences from Larval Dynamics and Oceanography

The dynamics of larvae of five small pelagic fish taxa common in shelf waters of south-eastern Australia, namely *Trachurus* spp., *Sardinops sagax*, *Scomber australasicus*, *Etrumeus teres* and *Engraulis australis*, were linked with oceanographic features associated with the seasonal East Australian Current (EAC) to define essential habitats and predict key spawning areas. A novel approach involving multivariate analyses of water-column temperature frequencies clearly defined EAC water to the north (20.5-23.4°C), Tasman Sea water to the south (TAS; 14.8-17.5°C), and a mixed EAC-TAS water mass in between (MIX; 18.3-19.9°C). Along-shelf distributions and abundances varied markedly with water mass structure, with peak abundances frequently occurring in MIX waters just south of the EAC deflection point where upwelling of nutrient-rich slope water was evident. Quotient analyses revealed notable similarities in temperature preferences among all taxa with a marked decline in abundances in waters <18°C, i.e. those immediately south of the MIX-TAS interface, suggesting that this temperature front may be a barrier to the southward dispersal of larvae. Furthermore, cross-shelf patterns revealed variations in distribution that correspond with distinct cross-shelf variation in hydrographic conditions. Overall findings indicate larval distributions are determined by the strength and extent of the EAC, and suggest that variable hydrographic conditions play a key role in defining the timing and location of spawning of these small pelagic taxa. Our approach highlights the merits of characterising larval habitats in the context of water masses, and sets a foundation for assessing the impacts of climate change on resources within this highly susceptible region.

Larvae of small pelagic fishes in the East Australian Current

John P Keane

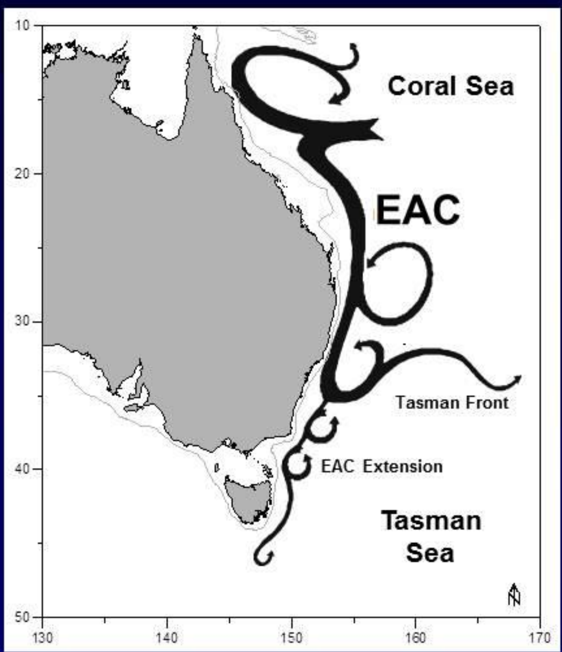
Francisco J. Neira
Jeremy Lyle

Tasmanian Aquaculture & Fisheries Institute
University of Tasmania

UTAS

Australian Government
Fisheries Research and Development Corporation

East Australian Current



- Western boundary current
- Transports warm, low-nutrient tropical water poleward
- Separation point varies seasonally
- Tasman front predominantly a thermal front
- Seasonally variable
  - –Twice as strong in summer
- Highly dynamic

FTV Bluefin surveys

3 surveys 2002 – 2004

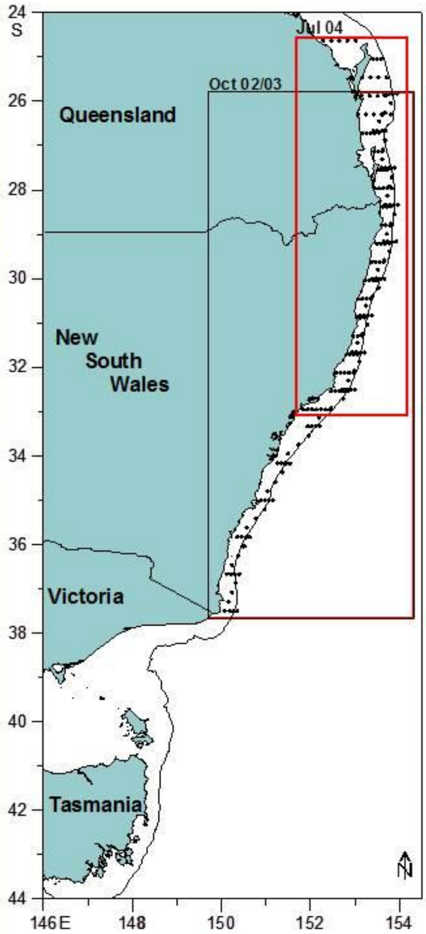
Spring – 775 nm of coastline, 102 stations

October 2002: Fraser Is. to Eden

October 2003: Fraser Is. to Eden

Winter - 450 nm of coastline, 85 ststions

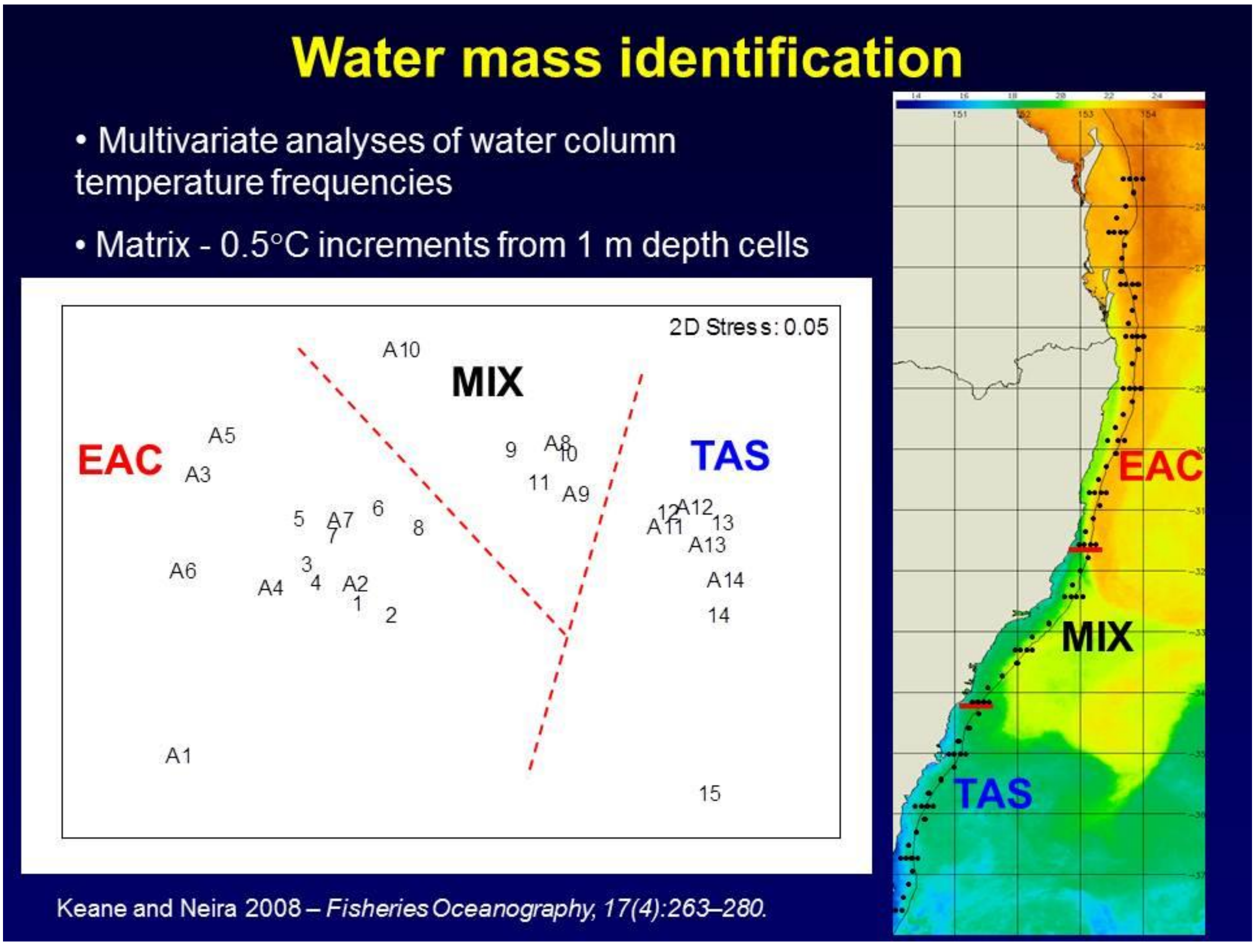
July 2004: Bundaberg to Newcastle



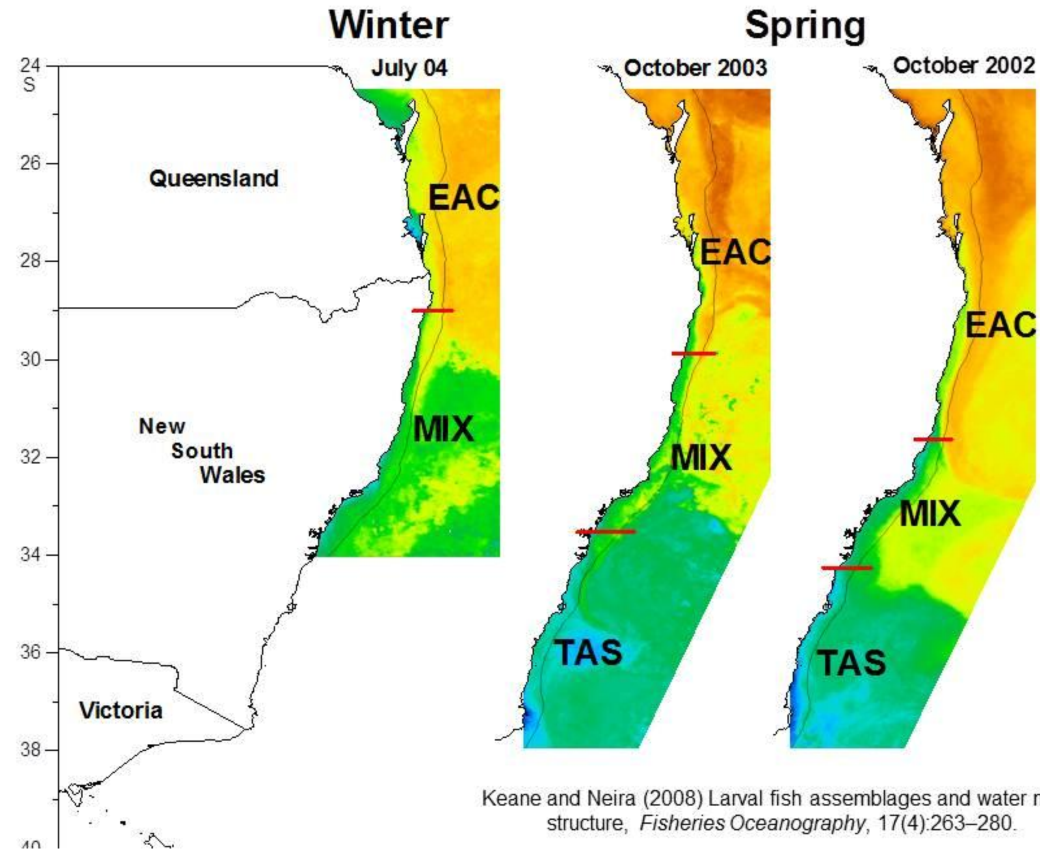
Bongo sampler used during ichthyoplankton surveys

Scanmar unit (depth)

Seabird CTD data logger



Water mass structure



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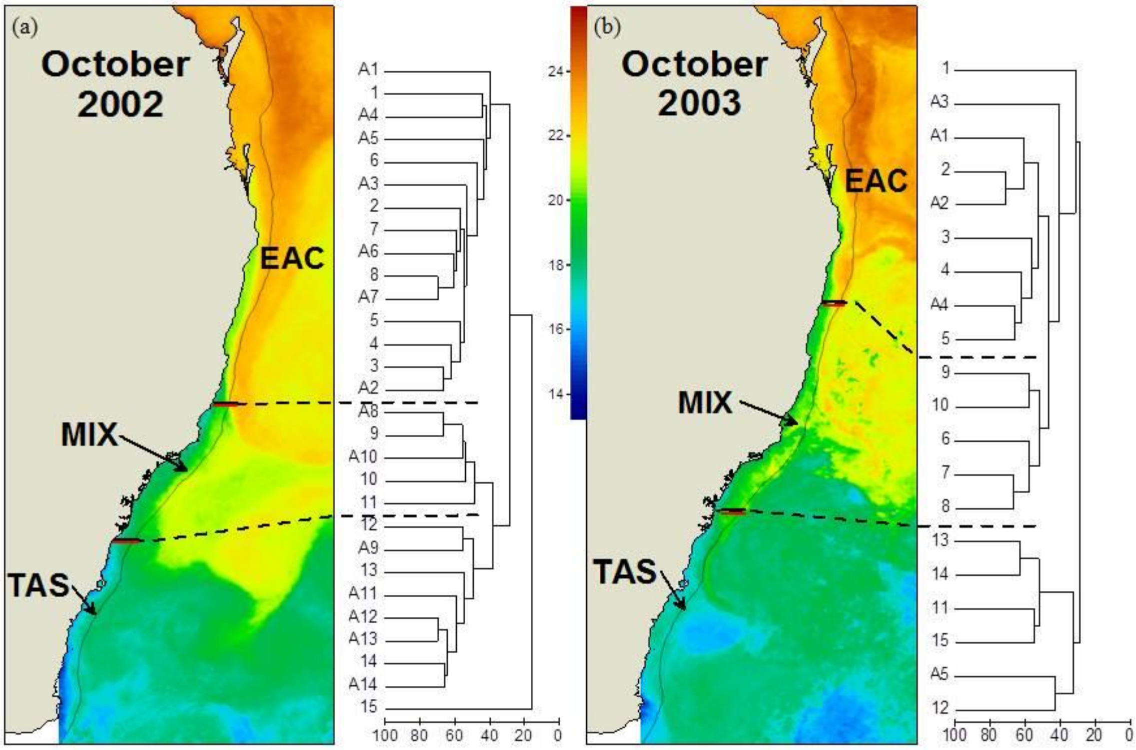
Larval fish assemblages



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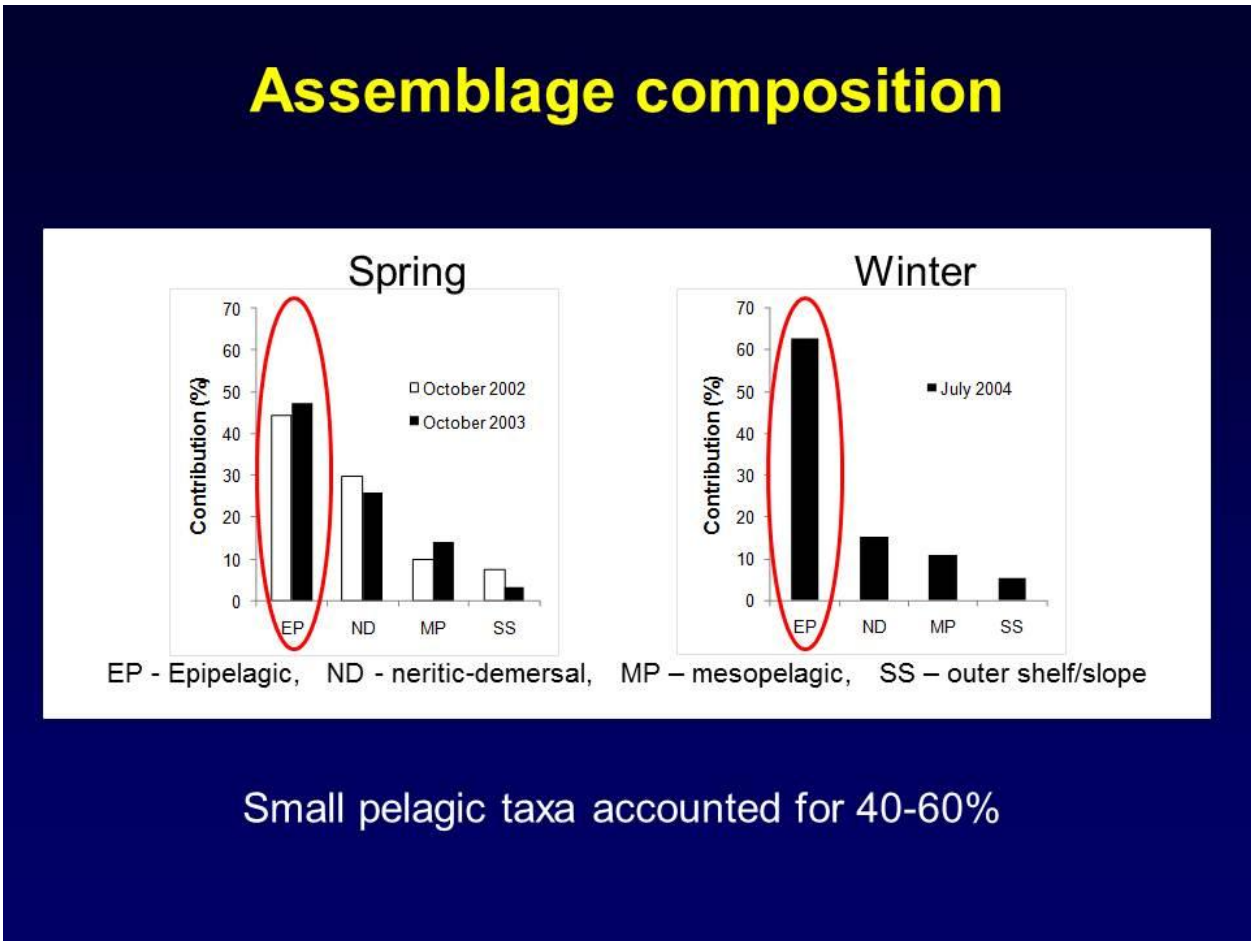
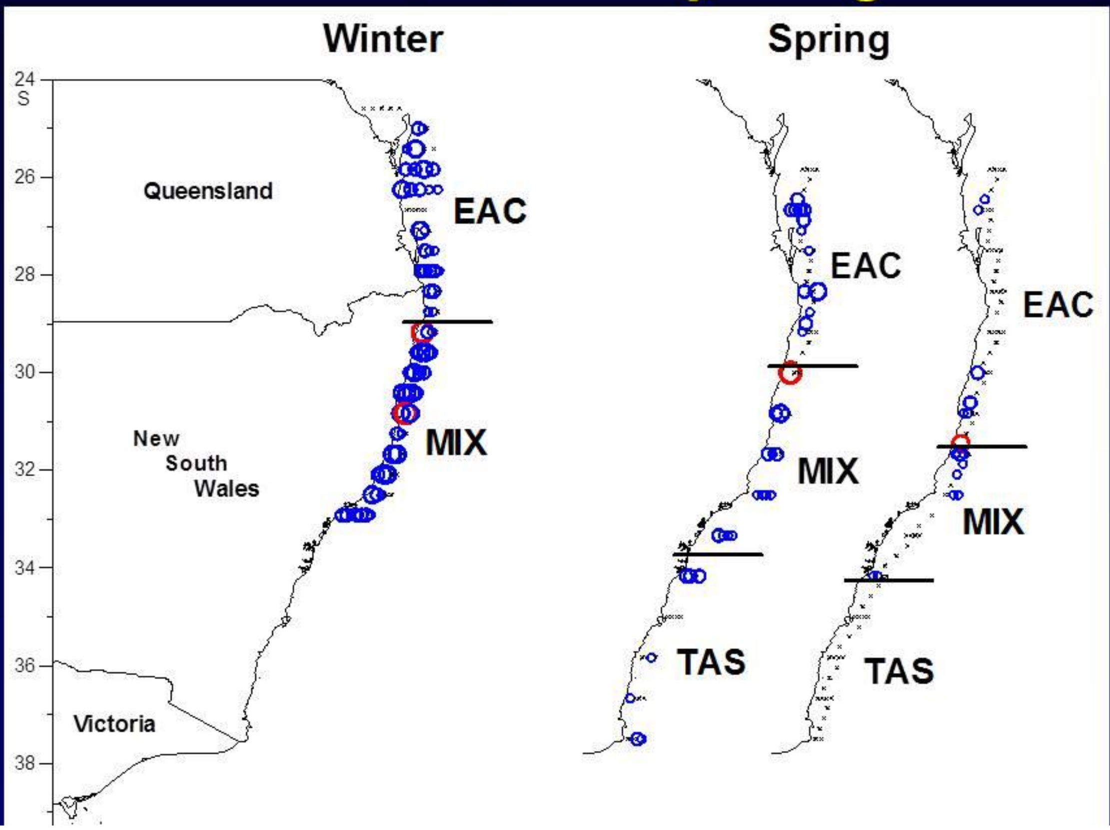
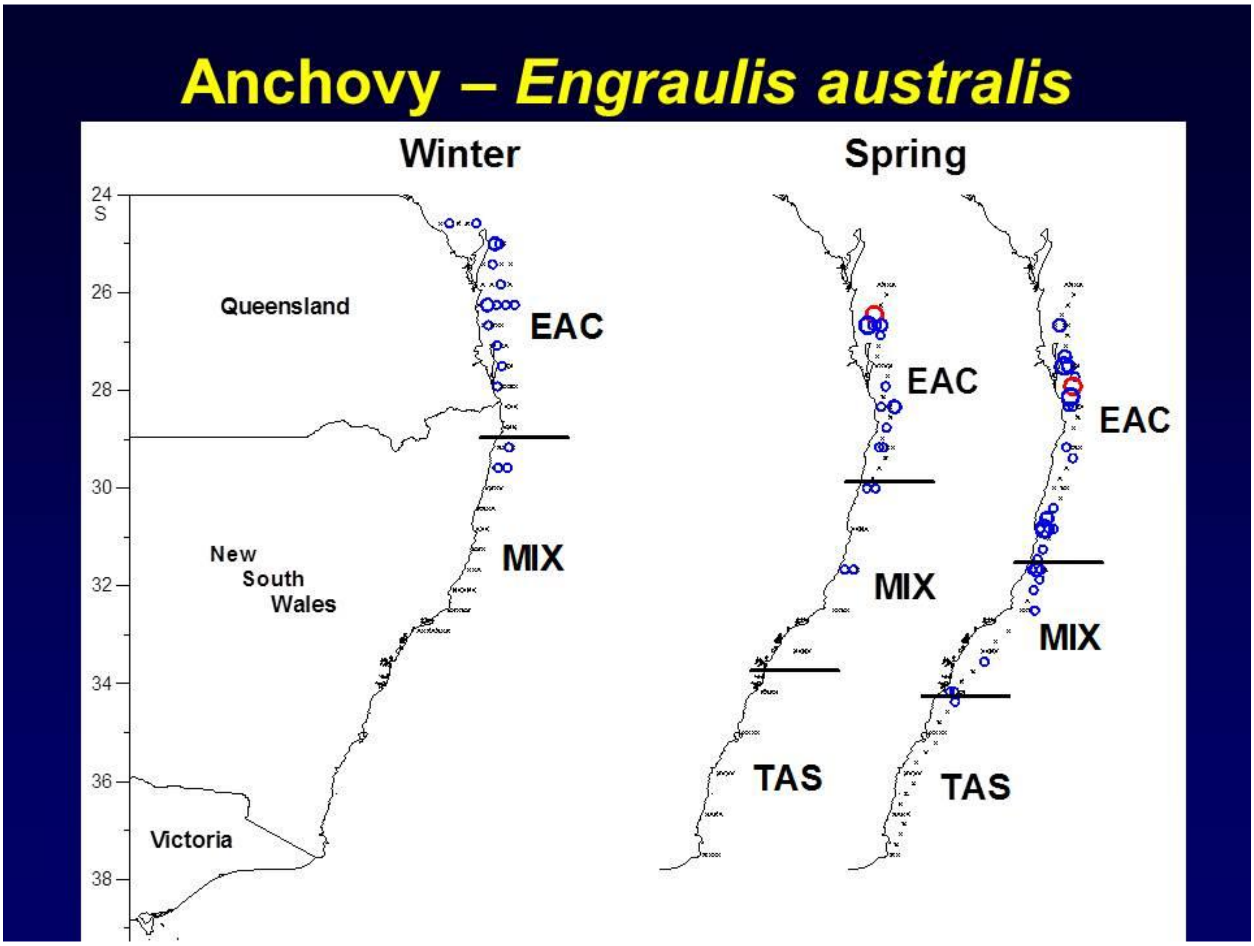


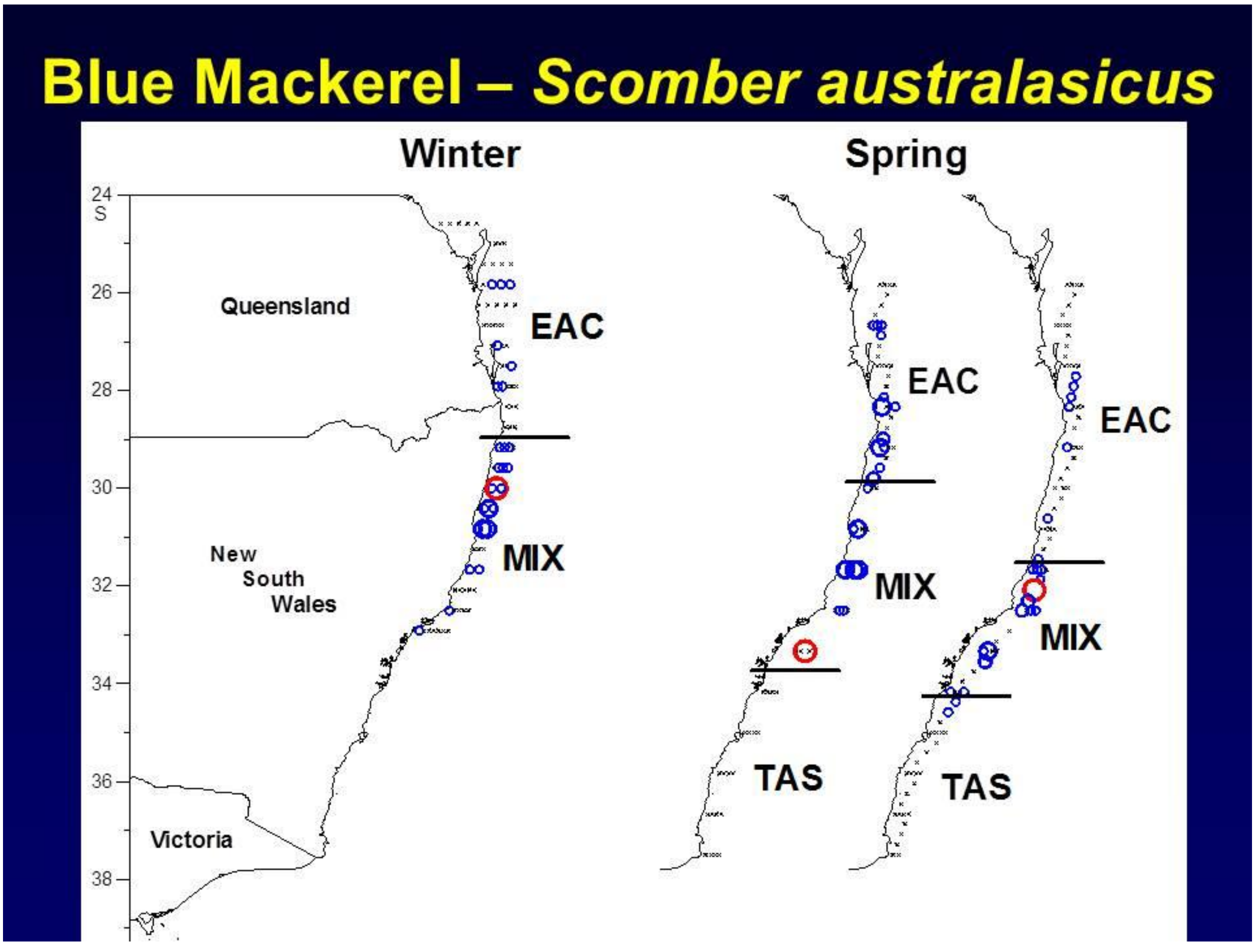
Small pelagic species

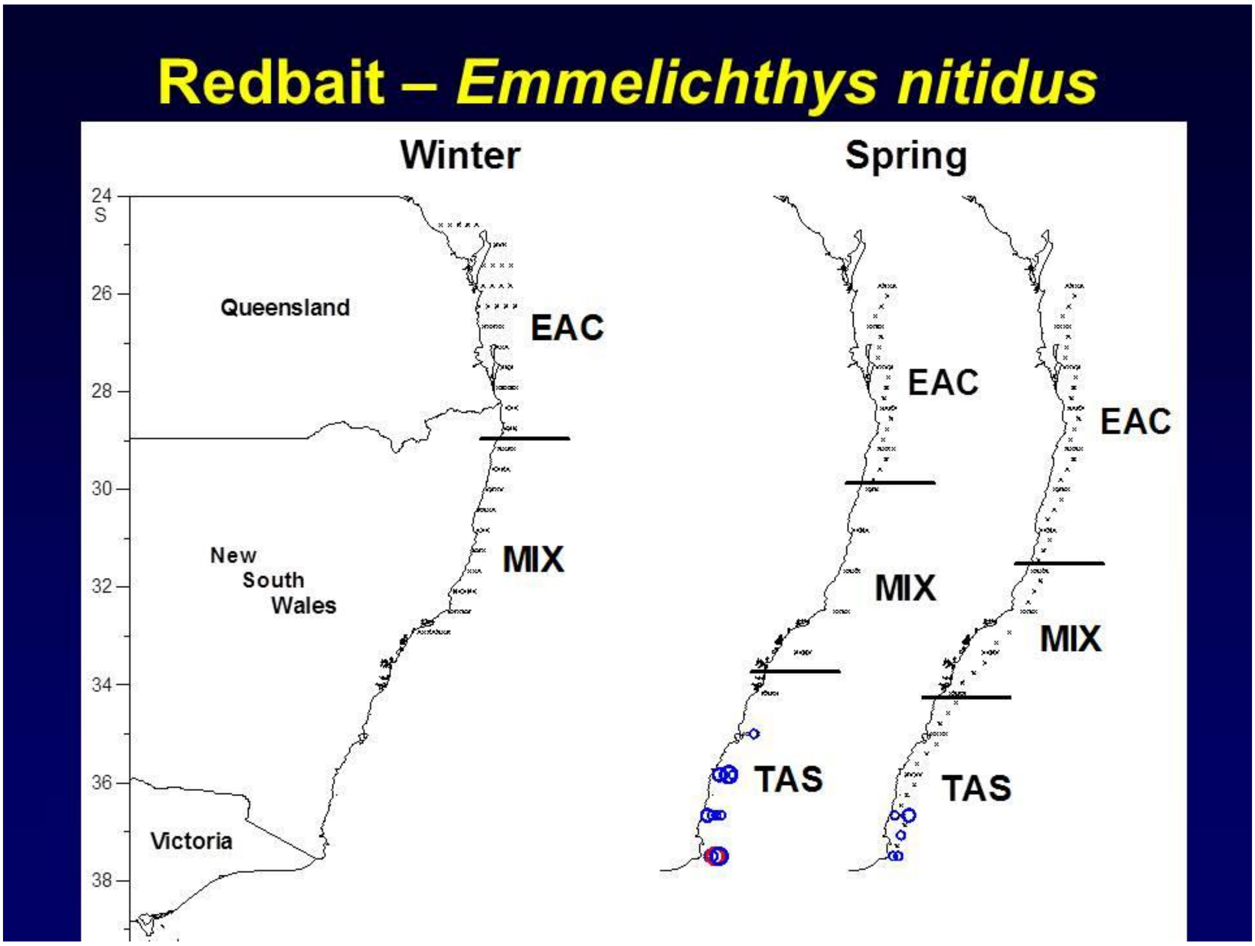
Etrumeus teres	1.2%
Sardinops sagax	18.0%
Engraulis australis	2.4%
Scomber australasicus	2.9%
Trachurus spp.	27.6%
Emmelichthys nitidus	0.3%

Pilchard – *Sardinops sagax*

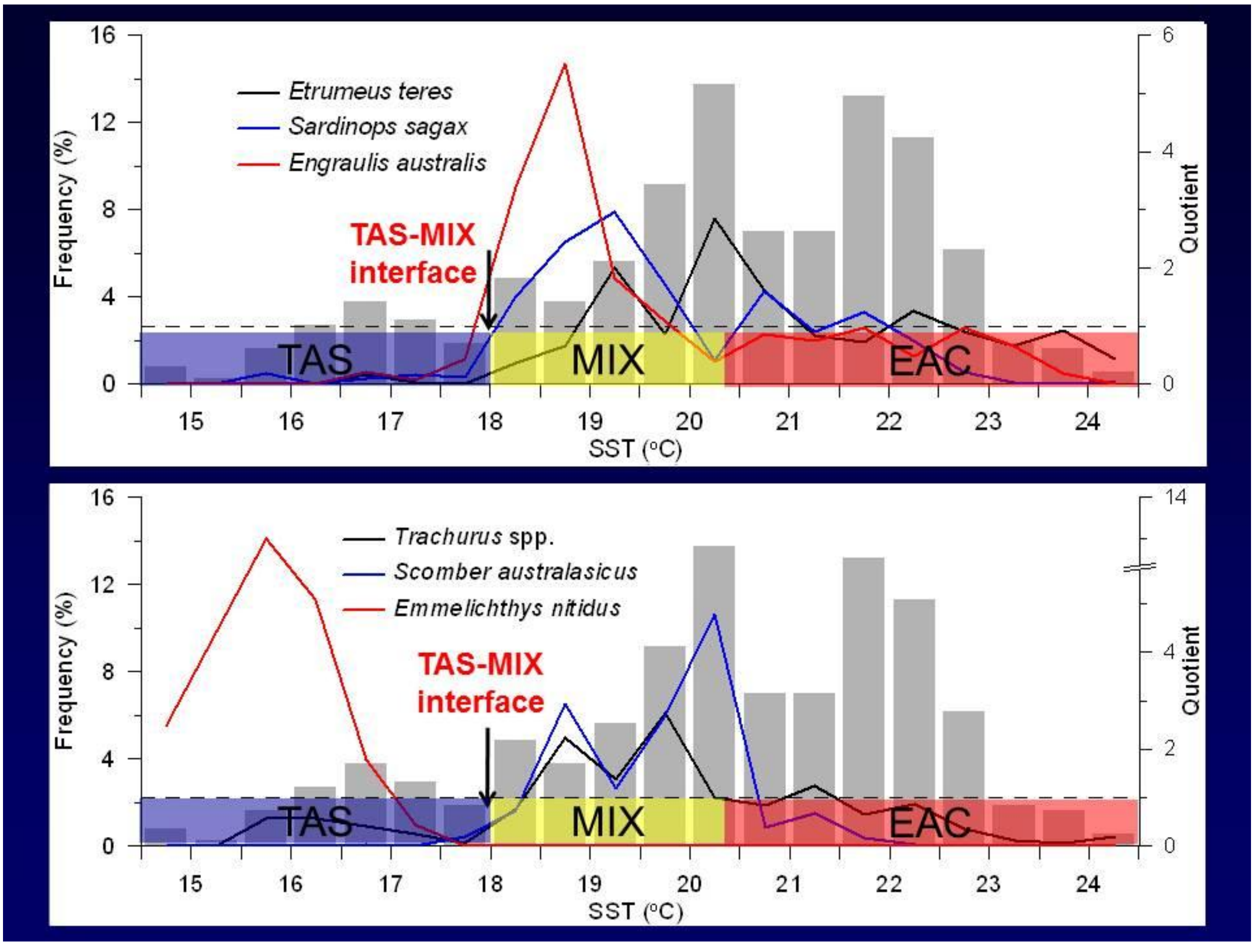



Anchovy – Engraulis australis
Winter
Spring
24 S
26
28
30
32
34
36
38
Queensland
New South Wales
Victoria
EAC
MIX
TAS

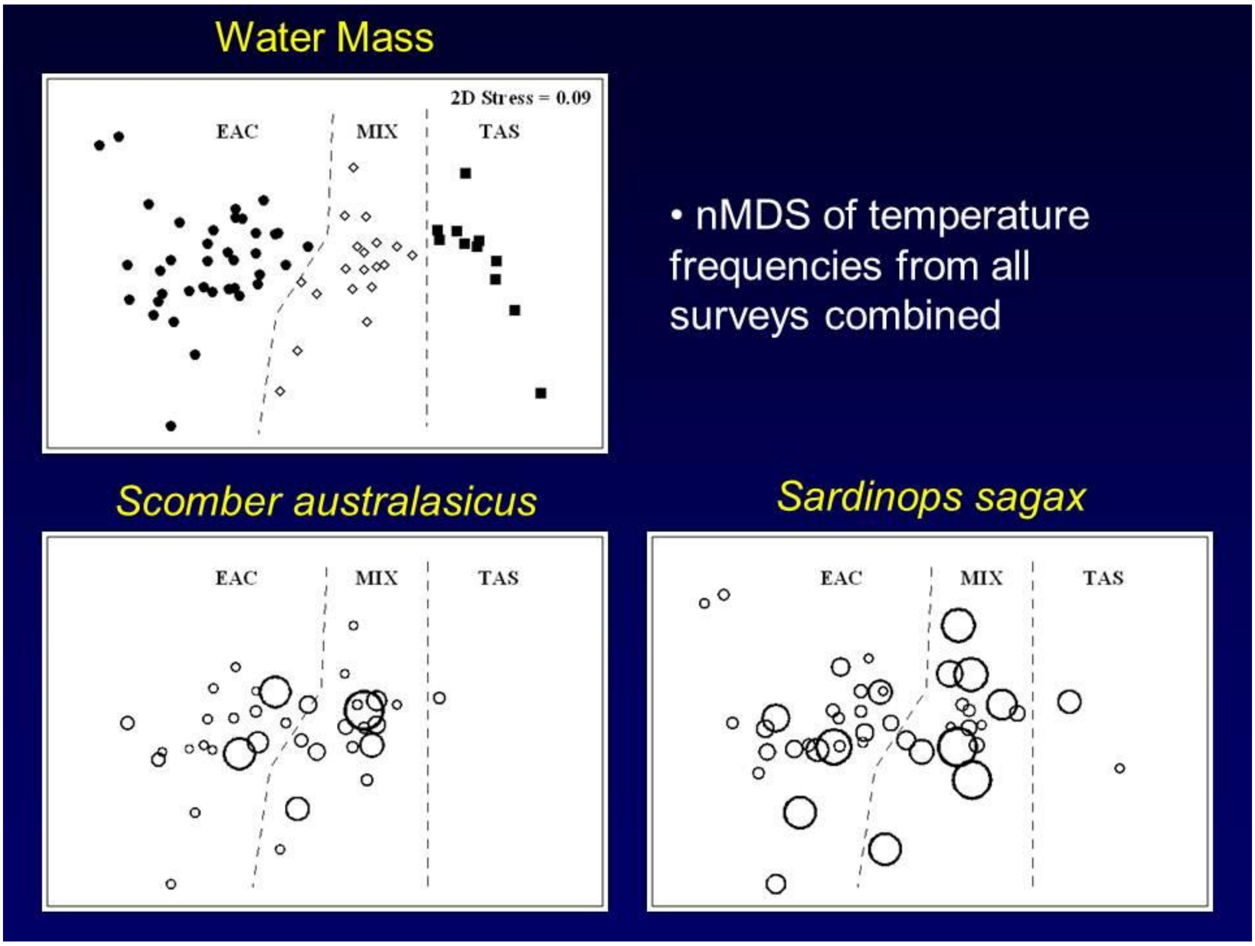

Blue Mackerel – Scomber australasicus
Winter
Spring
24 S
26
28
30
32
34
36
38
Queensland
New South Wales
Victoria
EAC
MIX
TAS

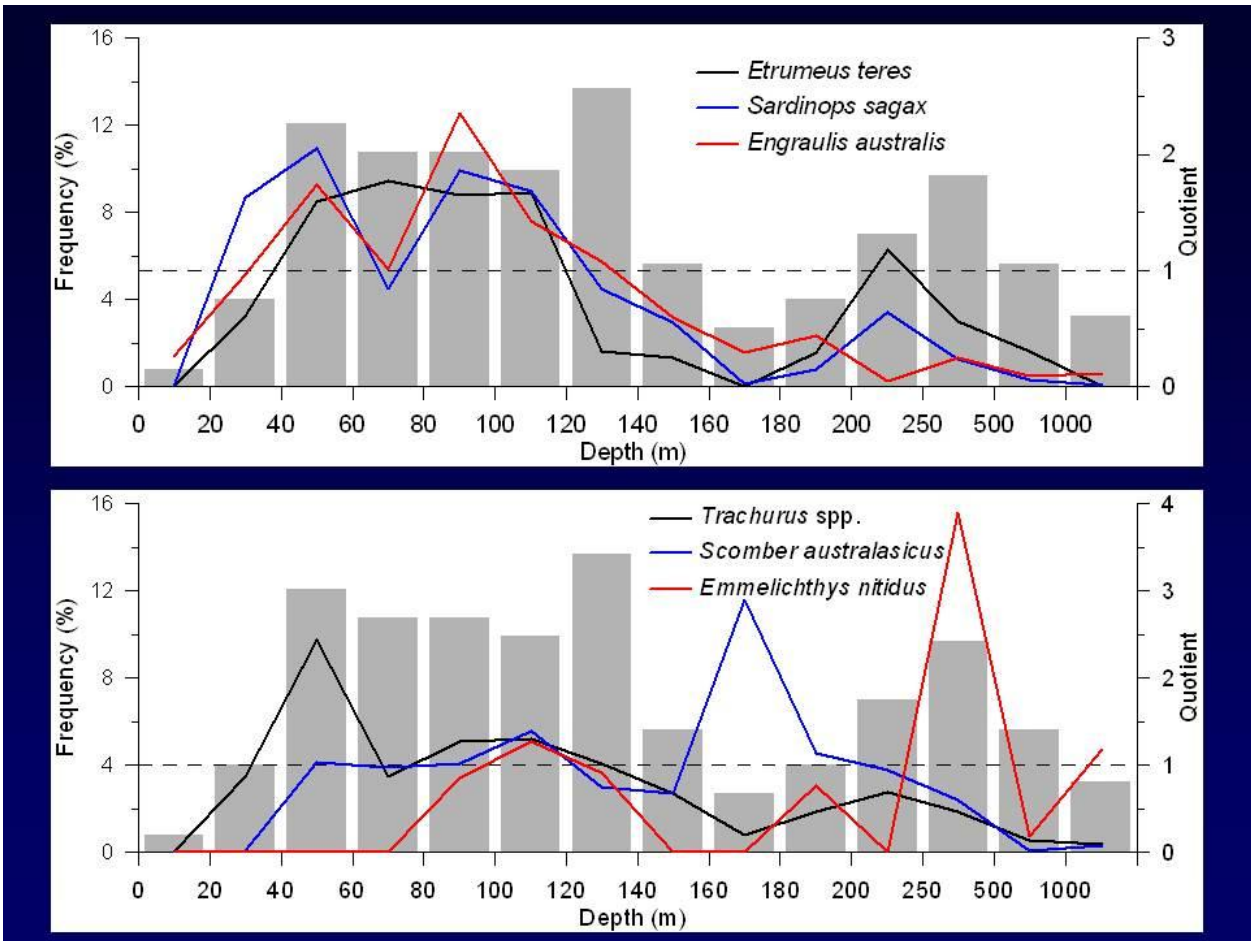


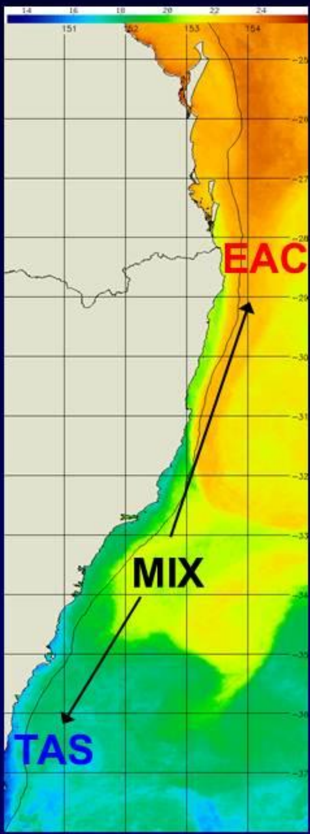
Redbait – Emmelichthys nitidus
Winter
Spring
Queensland
New South Wales
Victoria
EAC
MIX
TAS
24 S
26
28
30
32
34
36
38



Etrumeus teres
Sardinops sagax
Engraulis australis
TAS-MIX interface
TAS
MIX
EAC
Frequency (%)
Quotient
SST (°C)
Trachurus spp.
Scomber australasicus
Emmelichthys nitidus
TAS-MIX interface
TAS
MIX
EAC
Frequency (%)
Quotient
SST (°C)


Water Mass
2D Stress = 0.09
EAC
MIX
TAS
• nMDS of temperature frequencies from all surveys combined
Scomber australasicus
EAC
MIX
TAS
Sardinops sagax
EAC
MIX
TAS


Etrumeus teres
Sardinops sagax
Engraulis australis
Frequency (%)
Quotient
0
4
8
12
16
0
1
2
3
0
20
40
60
80
100
120
140
160
180
200
250
500
1000
Depth (m)
Trachurus spp.
Scomber australasicus
Emmelichthys nitidus
Frequency (%)
Quotient
0
4
8
12
16
0
1
2
3
4
0
20
40
60
80
100
120
140
160
180
200
250
500
1000
Depth (m)



Habitat selection

EAC/MIX

Etrumeus teres *Sardinops sagax* *Engraulis australis*	Inner to mid-shelf

MIX

Scomber australasicus	Entire shelf

TAS

Emmelichthys nitidus	Shelf break

All

Trachurus spp.	Inner to mid-shelf

Conclusions

Water mass boundaries play a key role in defining the distribution of small pelagic fishes

High abundances frequently occur near the EAC-MIX interface

MIX-TAS interface may act as a barrier to the southward dispersal of larvae

Water masses can be used as a proxy for determining spawning habitats/larval distributions

What we don't know

Effects of EAC variability and coastal separation on:

- Spawning
- Larval dispersal
- Recruitment
- Connectivity

Change over time

- Inter-annual
- Decadal variation (e.g. ENSO)
- Climate change – increase of $2^{\circ}C$ by 2070

"Global climate models predict that the greatest warming in the Southern Hemisphere oceans will be in the Tasman Sea associated with a strengthening of the EAC."

Want to know more about the EAC?

Special issue of Deep Sea Research Part II-Topical studies in oceanography, to be released in 2010

"Studies of the East Australia Current and its Ecosystem-Climate"

Editors: Iain Suthers, Moninya Roughan, Ken Ridgway and Jock Young

Appendix 2
Conference schedule and symposia

SESSION AND SYMPOSIA MASTER						
	ROOM	THURSDAY 23-Jul	FRIDAY 24-Jul	SATURDAY 25-Jul	SUNDAY 26-Jul	MONDAY 27-Jul
AM	Grand Ballroom I	Grand Ballroom I & II PLENARY	Catfish Symposium	Evolution & Ontology Symposium	Live Bearing Fishes Symposium	Darwin Symposium
	Grand Ballroom II		AES Functional Morphology Symposium	Snake Reproduction Symposium	Turtle Symposium	Herp Conservation II
	Pavilion East		Fish Ecology I	General Ichthyology I	Fish Ecology II	Fish Biogeography/ Fish Systematics
	Pavilion West		Storm Symposium	Amphibian Ecology I	Fish Phylogeography	Amphibian Ecology II/ Snake Conservation
	Parlor ABC		AES Conservation & Management/ Age & Growth	AES Conservation & Management II	General Ichthyology II/ Fish Conservation I	Fish Genetics II/ Fish Behavior
	Galleria North		SSAR Seibert Physiology Award/ SSAR Seibert Systematics & Evolution Award	Herp Biogeography	HL Graduate Research Award/ Herp Development & Morphology	Herp Physiology/ Herp Ecology
	Galleria South		ELHS/LFC Connectivity Symposium II/ ELHS/LFC Connectivity	AES Genetics & Reproduction	AES Physiology/ AES Ecology II	Fish Morphology & Physiology
	Broadway 1 & 2		Herp Reproduction & Behavior	ELHS/LFC Ichthyology I	ELHS/LFC Hypoxia/ Ecology II	
		LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
PM	Grand Ballroom I	ELHS/LFC Connectivity Symposium I	Catfish Symposium	Herp Conservation I	Live Bearing Fishes Symposium	Darwin Symposium
	Grand Ballroom II	Fish Systematics I	AES Functinal Morphology Symposium	Snake Repoduction Symposium	Turtle Symposium	Herp Conservation III
	Pavilion East	Fish Genetics I	Lizard Ecology	Fish Systematics II	Cypriniformes Tree of Life	Snake Ecology
	Pavilion West	Herp Systematics	Storm Symposium	AES Ecology I	Fish Conservation II	Fish Ecology III
	Parlor ABC	AES Gruber Award I	AES Gruber Award II	AES Systematics/ AES General Ichthyology	NIA Student Paper Award	
	Galleria North	SSAR Seibert Ecology Award	SSAR Seivert Conservation Award	Herp Genetics	HL Graduate Research Award II	
	Galleria South	AES Behavior & Morphology	ELHS/LFC Connectivity II	Hubbs Symposium	General Herpetology	
	Broadway 1 & 2	Amphibian Pathogen Ecology		ELHS/LFC Ecology I	ELHS/LFC Ecology II/ Condition	
	POSTER SESSIONS		POSTER I	POSTER II	POSTER III	
	BUSINESS MEETINGS (Rooms vary)		HL (6 - 8 p.m.)	AES (3:30 - 5:30 p.m.) SSAR (6 - 8 p.m.)	ASIH (6 - 8 p.m.) ELHS-AFS (5 - 6 p.m.)	
EVE	SOCIAL EVENTS	JMIH GENERAL RECEPTION (6 - 9 p.m.) Oaks Park		Hubbs Dinner (6:30 p.m.)	AES BANQUET (7 -11 p.m.) McMenamins Crystal Ballroom ELHS Social (6 - 11 p.m.) McMenamins Lola's Room SSAR-HL Live Auction (9PM) Pavilion Ballroom	JMIH BANQUET (6 -11 p.m.) Pavilion Ballroom