Effect of the Becher Point boat ramp on the food resources of Little Penguins on Penguin Island. Report for the Department of Parks and Wildlife

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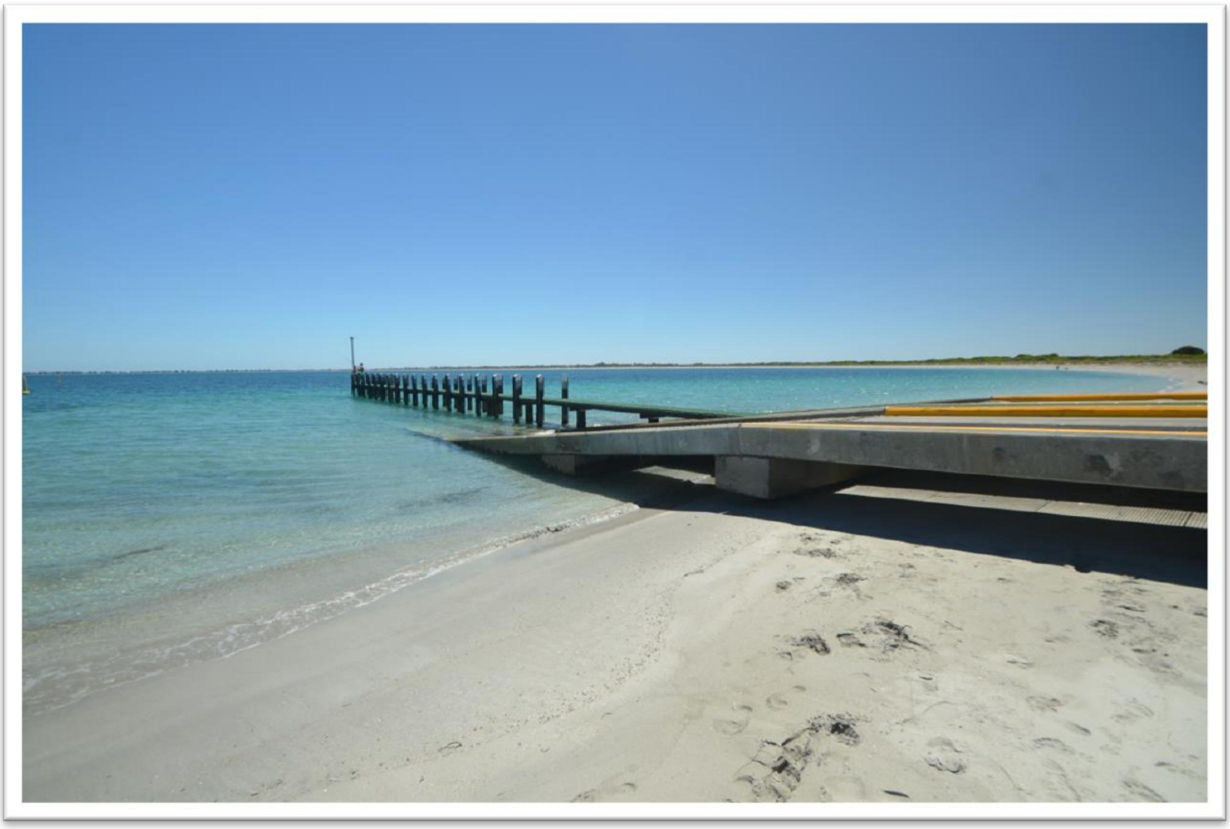

FINAL REPORT

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Prepared for the Western Australian Department of Parks and Wildlife

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Executive Summary

This study was focused around Becher Point, a cuspate foreland located at the southern tip of Warnbro Sound along the lower west coast of Australia in the Shoalwater Islands Marine Park. Becher Point is a well-known 'nursery' site for juvenile Whitebait, which are an important food source for Little Penguins from nearby Penguin Island. This study, which forms a companion project to that by Cannell (2013) to determine current penguin population estimates and diets, had two overarching aims.

The **first aim** centered on understanding the extent and key 'drivers' of any historical, interannual changes in both the (1) abundance of Whitebait and composition of the broader fish community in the nearshore waters at Becher Point since the mid-1990s ***(Objective 1)***, and (2) survival and breeding performance of Little Penguins since the mid to late-1980s ***(Objective 2)***. The data sets used to address this aim included (i) fishery-independent fish data collected by the WA Department of Fisheries (DoF) using a 60.6 m beach seine net in most years since 1996 for Whitebait and all years since 2007 for the full fish assemblage; (ii) penguin survival estimates and breeding performance measurements collected by Murdoch University researchers in various years since 1986; (iii) a suite of environmental variables that may influence fish abundance and/or penguin biology, collated from various sources since 1988, and; (iv) catch-per-unit-effort data for Whitebait and other penguin prey species (Blue Sprat, Australian Sardine, Australian Anchovy and Southern Garfish) obtained from commercial fish catches in the Warnbro Sound and surrounding regions.

The **second aim** was to determine whether a boat ramp constructed at Becher Point in 2010 has impacted the distribution and abundance of Whitebait, or the characteristics of the fish community, in this region ***(Objective 3)***, and design a cost-effective Whitebait monitoring regime for the future ***(Objective 4)***. The fish faunal data sets used here included those collected by Murdoch University researchers using a 21.5 m seine at (i) five nearshore sites around Becher Point (including at the boat ramp) from August-January of 2011-12, 2012-13 and 2013-14 (hereafter 2011, 2012 and 2013), and; (ii) two of the above sites in 1996/7 (hereafter 1997), 2000 and 2001, which was used to provide some comparable historical basis for understanding the 'pre-boat ramp' fish fauna. The inability, however, to collect fish data at the full suite of sites using the same net type in the year(s) immediately preceding boat ramp construction is recognised as a weakness of this part of the study.

The main findings and conclusions for each of the above objectives are provided below.

Objective 1: Interannual trends in Whitebait abundance and the broader fish community at Becher Point since the mid-1990s, and relationships with environmental variables

Whitebait densities in the nearshore waters at Becher Point, as recorded in samples collected by the DoF using a 61 m seine net, have declined markedly between 1996-2001 and 2006-13. Thus, while catches often exceeded ~40 and reached a maximum of 575 fish 500 m^{-2} in the first period, they rarely exceeded 10 fish 500 m^{-2} in the latter period. These trends were mirrored at Pinnaroo Point ~80 km to the north, another known Whitebait nursery along the metropolitan coast, suggesting that the main environmental drivers are operating at regional rather than highly localised scales.

Interannual shifts in Whitebait catches at Becher Point were positively and moderately-well correlated with more frequent light (<10 km/h) easterly winds (with either no time lag or with a one year lag imposed), greater inshore wave heights (no time lag) and higher rainfall (two-year lag), and negatively correlated with more frequent strong (20-30 km/h) easterly winds (one year lag). While it is important to recognise that these findings do not necessarily indicate a direct, causative relationship, it is feasible that the inshore transport of pelagic Whitebait eggs and larvae to suitable

coastal nurseries like Becher Point is promoted under lighter offshore winds and greater inshore wave activity. The latter could also create better feeding conditions for the zooplanktivorous larvae and juveniles of this species.

Few obvious interannual trends were detected in the mean species richness, density or species composition of the full fish assemblage at Becher Point from 2007-13, and no significant matches were found between the latter and any of the environmental variables in any season or lag state. These analyses were compromised, however, by the relatively small number of years able to be examined (2007-13), which reflected the fact that 'low priority' (presumably non-fishery) species were not recorded consistently in the DoF monitoring program prior to this time. When the fish faunal data was restricted to those fishery species known to be recorded over the full (1996-2013) monitoring period, thus enabling more years to be included in the analyses, it was revealed that, like Whitebait, several other species also tended to decline from earlier (1996-2001/06) to later years (2006/07-2013), *e.g.* Yellowfin Whiting, Yelloweye Mullet and Australian Herring. During autumn and spring, these trends were most clearly linked (across various lag states) with light easterlies, light southerlies and strong westerlies, all of which were more frequent in earlier years and may also enhance the inshore recruitment success of these species. Leeuwin Current strength and summer sea surface temperatures (in the same year) had the most obvious influence on the fish faunas in summer, with the assemblages in the 'marine heatwave' conditions of 2011 being particularly depauperate.

Objective 2: Interannual relationships between penguin biology and penguin prey and environmental variables

Little Penguin survival was lowest in 1989, 1997 and 1998 (~60%) and highest in 1986, 1987, 2000 and 2008 (~90-100%), while breeding performance (represented by six reproduction parameters) was generally poorest in 1986, 1994, 1999 and 2011 and best in 1991, 2006 and 2009.

Interannual trends in penguin survival and/or reproduction were most clearly correlated with those in select penguin prey abundances at Becher Point, air and sea surface temperatures and/or local wind conditions. Thus, higher survival was linked, in the same year, with greater Blue Sprat abundances at Becher Point (the timing of which corresponds with the fast growth and eight month life span of this key prey species) and less hot (>33 °C) days in December-January, which presumably reduces the likelihood of dessication. Higher survival was also linked with lower April sea surface temperatures in Warnbro Sound (following a two year lag) and particular wind conditions across various lag states, *i.e.* more frequent strong southerly and northerly winds (no lag), less frequent light easterly winds (two year lag) and more frequent light south-westerly winds (two year lag). Penguin breeding performance was also inversely related to April/autumn sea surface temperatures in Warnbro Sound (but in the same year) and positively related to strong westerly winds (also in the same year).

While the mechanism(s) by which the above wind conditions could be impacting penguin biology are less clear, they could include direct pathways such as terrestrial cooling or indirect pathways that impact prey availability. The ways in which April/autumn sea surface temperatures might influence penguin biology are also less clear and, while Cannell *et al.* (2012) suggested that warmer conditions at this time of year may negatively impact prey availability and thus penguin breeding performance, the current study did not find any substantial evidence to support this theory.

Some significant interannual relationships were occasionally found between penguin biology and the commercial catches of penguin prey species, but these relationships were generally inverse and likely to be spurious due to several issues with the representativeness of this fish data set.

Objective 3: Impact of the boat ramp on Whitebait abundance and the broader fish community at Becher Point

There is little evidence from the outcomes of this study to indicate that the boat ramp constructed at Becher Point in 2010 has impacted the abundance of Whitebait or the species richness, density or composition of the broader fish fauna in the nearshore waters of this region.

Thus, while far greater numbers of Whitebait were found in comparable samples collected with the 21.5 m seine net prior to (1997, 2000-01) than following (2011-13) construction of the ramp (*i.e.* maximum mean densities of ~3950 *vs* 140 fish 100 m^{-2}, respectively), these trends mirror those in the samples collected by the DoF (using a 61 m seine) at both Becher Point and also Pinnaroo Point, in which Whitebait catches fell markedly from 1996-2001 to 2006-13 and from 1998-2001 to 2005-12, respectively. Given that these latter datasets show that Whitebait catches were low for at least four consecutive years before the ramp, and that such interannual shifts were relatively well 'explained' by various climatic and oceanographic factors (see above), it is less likely that the reduction in Whitebait observed in the current study is due to any negative impacts of the boat ramp *per se*, and more likely to reflect the influence of the above regional-scale drivers. The design of the boat ramp and exclusion of motorised vessels in the shallows to the south of the ramp is also expected to reduce any impacts on the local nearshore fish fauna. However, any harvesting of detached macrophyte wracks from the boat ramp to increase its accessibility could negatively impact the quality of the Becher Point region as a fish nursery and/or habitat.

With respect to the spatio-temporal trends in Whitebait and the broader fish fauna at the five sites sampled around Becher Point (including near the boat ramp) between August and January in 2011-13, the greatest differences tended to occur among months rather than years or sites. These intra-annual trends reflected differences in the timing of the inshore migration/emigration of species that use this area as a nursery, and the reproductive cycles of resident species. The highest Whitebait catches were in spring, matching the findings of various other studies, and species composition generally shifted from winter to summer, driven by both an increase in species richness and a progressive change in species prevalence. While the otherwise episodic nature of Whitebait catches largely reflects its highly schooling behaviour, it is also noteworthy that the densities of this species (and fish overall) were notably lower in 2011 and/or 2012, which may be related to the impacts of the 'marine heatwave' that peaked along WA's west coast in the first of these years. Moreover, the highest mean Whitebait densities were found at the Becher Point site, which parallels the findings of Valesini *et al.* (1998), and suggests that the physical and/or ecological attributes of this site are particularly favourable for receiving, retaining or supporting the early life stages of Whitebait.

Objective 4: Design a cost-effective and robust monitoring regime to enable the abundance of Whitebait around Becher Point to be reliably measured into the future

To reliably and cost-effectively track the abundance and distribution of Whitebait, and also Blue Sprat, in the Becher Point area into the future, it is recommended that sampling is undertaken at the Boat Ramp, Becher Point and Comet Bay sites in each month from September-March on an annual basis. These sites have yielded the greatest catches of Whitebait and/or Blue Sprat in this and other studies, have the longest historical records for the target species, and/or enable any future impacts of the boat ramp to be assessed. The sampling period covers the main inshore recruitment times for both species, and annual sampling is imperative for understanding variability in recruitment strength. It is recommended that fish are collected using a 21.5 m beach seine net to maintain consistency in gear type with the current study and minimise resource costs and fish faunal impacts. Moreover, given the patchy distribution of both target species, a minimum of four replicate samples per site, month and year, ideally collected on separate occasions within each month, is suggested to provide a more reliable estimate of abundance.

Acknowledgments

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Disclaimer

1. Introduction

1.1 Background

Penguin Island, located in the Shoalwater Islands Marine Park to the south of Perth, Western Australia (WA), supports the States' largest breeding colony of Little Penguins, *Eudyptula minor*. This penguin population occurs at the northernmost and westernmost limits of this species (Wienecke *et al.* 1995) and, as such, it is particularly susceptible to any environmental shifts, which can impact survival and/or reproductive success. These impacts may occur along direct physiological pathways, such as through the effects of changes in land temperature on survival (*e.g.* Ropert-Coudert *et al.* 2004), or along indirect pathways, such as through changes in prey availability on breeding performance (*e.g.* Cannell *et al.* 2012).

Whitebait, *Hyperlophus vittatus* (Clupeidae), are a major food source for Little Penguins, comprising nearly 50% of their diet (Murray *et al.* 2011). These small schooling baitfish, which have a maximum length and age of 100 mm and three-four years, respectively, spawn in inshore marine waters when they are about one year old (65-80 mm long). The larvae then migrate or 'recruit' into shallow coastal areas and estuaries, which they use as nurseries until they are sexually mature (Gaughan *et al.* 1996a). Little Penguins typically forage for the adults of Whitebait and other prey species (*e.g.* Blue Sprat *Spratelloides robustus*, Australian Sardine *Sardinops sagax*, Australian Anchovy *Engraulis australis* and Southern Garfish *Hyporhamphus melanochir*; Murray *et al.* 2011) in inshore waters (within 10-20 km of the coast) just to the south of Penguin Island (*i.e.* Warnbro Sound and the adjoining Comet Bay), but will also venture further south towards Bunbury in search of food (Klomp and Wooller 1998; Bradley *et al.* 1997).

Along the lower west coast of Australia, Whitebait typically spawn from May to September (with a peak in June-July) in waters <11 km from shore and predominantly within the first 5 km (Gaughan *et al.* 1996b). Whitebait are batch spawners, with females producing pelagic eggs every three to five days at the peak of spawning. In the coastal stretch between Fremantle and Bunbury, egg concentrations are among the greatest and/or most consistent in the relatively sheltered Warnbro Sound embayment. Compared to those of various other fish species, however, these egg concentrations are generally low and sporadically distributed, indicating that the fish stock is small and patchy (Gaughan *et al.* 1996b).

Juvenile Whitebait (from ~20 mm in length) have also been regularly recorded in large numbers (up to 44,505 fish in any one month) near Becher Point at the southern tip of Warnbro Sound between August and January, with the greatest catches often in October-November (Valesini *et al.* 1998, Valesini *et al.* 2004a). Other known Whitebait nursery sites in the Perth metropolitan area include Pinnaroo Point to the north (Valesini *et al.* 2004a; Smith *et al.* 2008), the Swan-Canning Estuary (Gaughan *et al.* 1990) and, to the south, the Peel-Harvey Estuary (Fairclough *et al.* 1999; Young and Potter 2003) and the coastal waters just outside its natural entrance channel (Valesini *et al.* 2004a). Further south towards Bunbury, known Whitebait nurseries include the Leschenault Estuary (*e.g.* Potter *et al.* 1997, Veale *et al.* 2014) and adjacent Koombana Bay (Smith *et al.* 2008). However, stable isotope analysis of Whitebait otoliths (ear bones) in the stomach contents of Little Penguins from Penguin Island has provided direct evidence that the majority of Whitebait being preyed upon by these seabirds have originated from the Becher Point nursery site (Lenanton *et al.* 2003).

Blue Sprat, which comprises ~30% of the diet of Little Penguins from Penguin Island (Murray *et al.* 2011), also uses the Becher Point area as a nursery, with large numbers of its juveniles typically occurring from December to January (Valesini *et al.* 1998). Like Whitebait, Blue Sprat grow to ~100 mm (Rogers and Ward 2007), but they have a notably shorter life span (about eight months), spawn only once and produce demersal eggs (Rogers and Ward 2007).

Whitebait and Blue Sprat, together with small numbers of other species such as Sea and Yelloweye Mullet (*Mugil cephalus* and *Aldrichetta forsteri*), Southern Garfish and Yellowfin Whiting (*Sillago schomburgkii*), support small commercial bait fisheries in the metropolitan and Bunbury regions (*i.e.* the West Coast Beach Bait Fishery and the South West Beach Seine Fishery; Smith *et al.* 2013). Interannual trends in the commercial catches of Whitebait in this region have been shown to be correlated with those in various oceanographic and climatic factors, including the strength of the Leeuwin Current (see subsection 2.1.1) and rainfall. Thus, Gaughan *et al.* (1996a) demonstrated a strong positive relationship between Whitebait catches from 1977-1994 and Leeuwin Current strength in the previous one to two years and, depending on locality, a positive or negative relationship with rainfall in the same year. Leeuwin Current strength has also been implicated in the abundance and/or catchability of various other fishery species (*e.g.* Lenanton *et al.* 1991; 2009) and the composition of the broader fish assemblage (*e.g.* Muhling *et al.* 2008, Beckley *et al.* 2009) both on and off the continental shelf of WA. While the direct causative mechanisms are still unclear, it has been suggested that this poleward current could induce the transport (both across and along the shelf) of pelagic eggs and larvae to or from favourable settlement environments, impact food availability through its effects on biological productivity, and impact reproduction success and/or growth through its effects on water temperature (*e.g.* Gaughan 2007; Waite *et al.* 2007; Lenanton *et al.* 2009). It is interesting to note, however, that the inclusion of more recent data (1995-2007) in the examinations of commercial Whitebait-Leeuwin Current relationships has resulted in a notably weaker correlation than previously obtained (Lenanton *et al.* 2009). Such findings indicate the importance of other, as yet quantified, determinants of the abundance of this fish species along the lower west coast of Australia.

In addition to the above broader-scale factors, a host of other more localised factors may be implicated in interannual shifts in the abundance of coastal fish species. For example, Gaughan and Mitchell (2000) and Gaughan (2007) have suggested the influence of local winds on egg/larval distribution, and thus likely recruitment success, of Scaly Mackerel (*Sardinella lemuru*) and Australian Sardine along the WA coast. Gaughan *et al.* (1996b) have also suggested the effects of fishing pressure on the commercial catches of Whitebait in the Fremantle to Bunbury region. Anthropogenic changes to the coast, either through direct impacts such as coastal modification (*e.g.* shore realignment, land reclamation or establishment of infrastructure such as harbours, jetties or marinas), or indirect impacts such as those caused by contaminant or sediment runoff from coastal catchment development, can also impact the quality of fish habitat in coastal waters (*e.g.* Brazner, 1997; Clynick, 2008; Bulleri and Chapman, 2010).

1.2 Study Aims and Objectives

The **first broad aim** of this study was to investigate the nature, extent and potential environmental drivers of any interannual differences in the (i) abundance of Whitebait and composition of the broader fish community in fishery-independent samples collected at Becher Point since the mid-1990s and (ii) survival and breeding performance of Little Penguins from Penguin Island since the mid to late-1980s.

The **second broad aim** was to determine whether a boat ramp constructed at Becher Point in 2010 (see subsection 2.1.2) has had any significant impact on the distribution and abundance of Whitebait, or the composition of the broader fish community, at this site.

The historical, fishery-independent data sets for Becher Point that were employed in this study comprised two types. The first has been collected in most years since the mid-1990s by the WA Department of Fisheries (DoF) using a 61 m long beach seine net (see subsection 2.2.1). The second was collected in 1996-97 and 2000-01 by Valesini *et al.* (1998; 2004b) using a 21 m long beach seine net, the same gear type used in the current study to address the second of the above aims (see subsection 2.4.1). The former data set was used to address part (i) of the first study aim, given the considerably greater number of years it comprised. The latter data set was used to provide some historical context for the addressing the second broad aim, without introducing any sampling bias due to differences in gear type. The timing of the commencement of this project (January 2011) did not allow for any other comparable 'pre-boat ramp' fish faunal data to be collected.

This study also forms a companion project to one undertaken by Cannell (2013) to derive current population estimates and dietary information (including the importance of Whitebait) for Little Penguins on Penguin Island.

The **specific objectives** of the current study were as follows.

1. Determine whether there are any significant interannual differences in Whitebait abundance and fish community composition in samples collected at Becher Point by the DoF since the mid-1990s, and determine if any such trends are significantly correlated with those in a suite of environmental variables.
2. Determine whether any interannual trends in the breeding performance and survival of Little Penguins from Penguin Island since the mid-1980s are related to those in penguin prey (fish) abundances and a suite of environmental variables.
3. Undertake monthly sampling of the nearshore fish fauna between August and December/January 2011-2013 at and around the Becher Point boat ramp, and compare findings to those of Valesini *et al.* (1998; 2004) to determine whether there is any evidence that this construction has impacted Whitebait abundance and distribution, or the broader fish community, in the area.
4. Design a cost-effective and robust monitoring regime to enable the abundance of Whitebait in the Becher Point area to be reliably measured into the future.

2. Materials and Methods

2.1 Study area

2.1.1 Environmental setting

The study area was focussed around Becher Point (32.3706°S, 115.7154°E), a sandy cuspate foreland that separates two embayments (Warnbro Sound and Comet Bay) to the south of Perth along the lower west coast of Australia (Sanderson and Eliot 1996; Fig. 2.1). Becher Point lies within the Shoalwater Islands Marine Park, a Class A Reserve which covers ~6,650 hectares and includes three sanctuary zones, two special purpose zones and a general use zone. One of these sanctuary zones is located just offshore of Becher Point, and the shallow waters just to the north and south are closed to motorised vessels (http://www.transport.wa.gov.au/mediaFiles/marine/MAC_P_Rockingham_boating_guide.pdf). The Marine Park also includes Penguin Island, which lies within one of the special purpose zones, the Shoalwater Wildlife Conservation Zone.

The coastline in this region is microtidal (Davies 1964) and, while the total offshore wave climate has a mean significant wave height of 1.6 m in summer and 2.7 m in winter (Lemm *et al.* 1999), inshore wave energy is typically attenuated to ~55-60% of that offshore by an extensive limestone reef chain that runs parallel to the coast (Masselink and Pattiaratchi 2001). Indeed, it is the presence of this reef chain that has caused the formation of Becher Point, through providing a complex barrier to incoming swell and causing deposition of sediments which would normally be transported onshore (Sanderson and Eliot 1996). The northern side of Becher Point is moderately sheltered from prevailing seas and swell, while the southern side is slightly more exposed (Valesini *et al.* 2003).

Oceanographic currents in the region are dominated by the Leeuwin Current, an atypical eastern boundary current that flows southward along the west coast of WA (Batteen and Miller 2009) and carries warm, low salinity surface waters from the tropical north of the State. The strength of this poleward current varies both intra-annually (being strongest in winter) and interannually (being strongest in La Niña years; Pearce and Phillips 1988), and is typically estimated using the mean sea level height at Fremantle as a proxy (*i.e.* higher sea

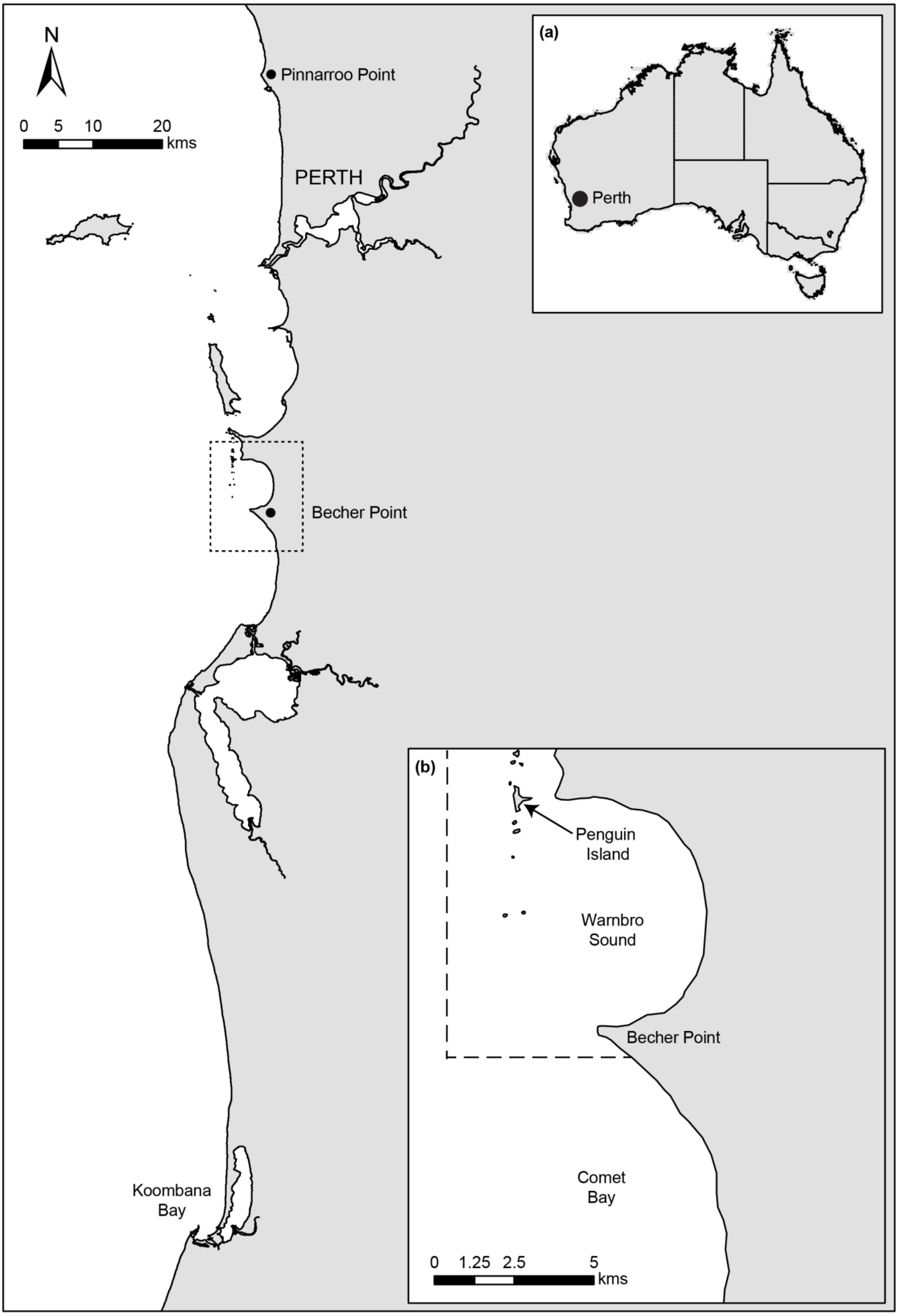

Fig. 2.1: Map of Perth metropolitan coastline from Pinnarroo Point to Koombana Bay. Insets show (a) the location of Perth in Australia and (b) the Becher Point area. Dotted line shows the location of inset (b), while the dashed line within inset (b) delineates the southern half of the Shoalwater Islands Marine Park.

levels indicate a stronger current; Feng *et al.* 2003). While the main current flows along the edge of the continental shelf, mesoscale eddies that form off the main stream can entrain shelf waters and induce strong cross-shelf transport (*e.g.* Feng *et al.* 2007; 2010). Another influential component of the surface current system in the study region is the Capes Current, a northward current that flows inshore of the Leeuwin Current along the lower west coast during summer, driven by persistent southerly winds at that time of year (see below; Pearce and Pattiaratchi 1999).

The Perth coastline experiences one of the most consistent and energetic sea-breezes in the world, which occurs on ~60% of summer days and frequently exceeds speeds of 15 m s^{-1} (Pattiaratchi *et al.* 1997; Masselink and Pattiaratchi 2001). Local winds switch predominantly between easterly land-breezes in the morning to southerly to south-westerly winds in the early afternoon, and the strength and persistence of this wind system has a major impact on local coastal processes, including beach morphology sediment transport, wave activity and surface layer mixing. As a consequence of these sea breezes, strong currents flow north along the coast in summer (Pattiaratchi *et al.* 1997). Local winds are more variable during winter, but the strongest are typically from the south-west, west and/or north-west. Alongshore currents switch to a predominantly southward flow in this season (Masselink and Pattiaratchi 2001).

Substantial beds of macrophytes (predominantly *Posidonia* and *Amphibolus* spp.) occur in the vicinity of Becher Point (Gordon 1986; Wildsmith *et al.* 2008). Large quantities of macrophyte wrack also accumulate on the beach and in the shallows at this site, predominantly in winter (Valesini *et al.* 2004b).

2.1.2 Boat ramp

The Port Kennedy Boat Launching Facility (hereafter the 'boat ramp'), is located at the terminus of Bridport Point, just to the north-east of Becher Point (Fig. 2.2b). The boat ramp was constructed during 2010 and officially opened on the 14th of December in that year. It is a two-lane facility with a central finger jetty that is ~11 m wide and extends for ~80 m from a sealed car park on the mainland to the shallows of Warnbro Sound. The submerged part of the ramp is ~35 m long (Fig. 2.2c-e). It was constructed from 490 tonnes of precast marine grade concrete, and is built on concrete sleepers that raise the ramp above the beach before tapering down to the seabed (Fig. 2.2f, g).

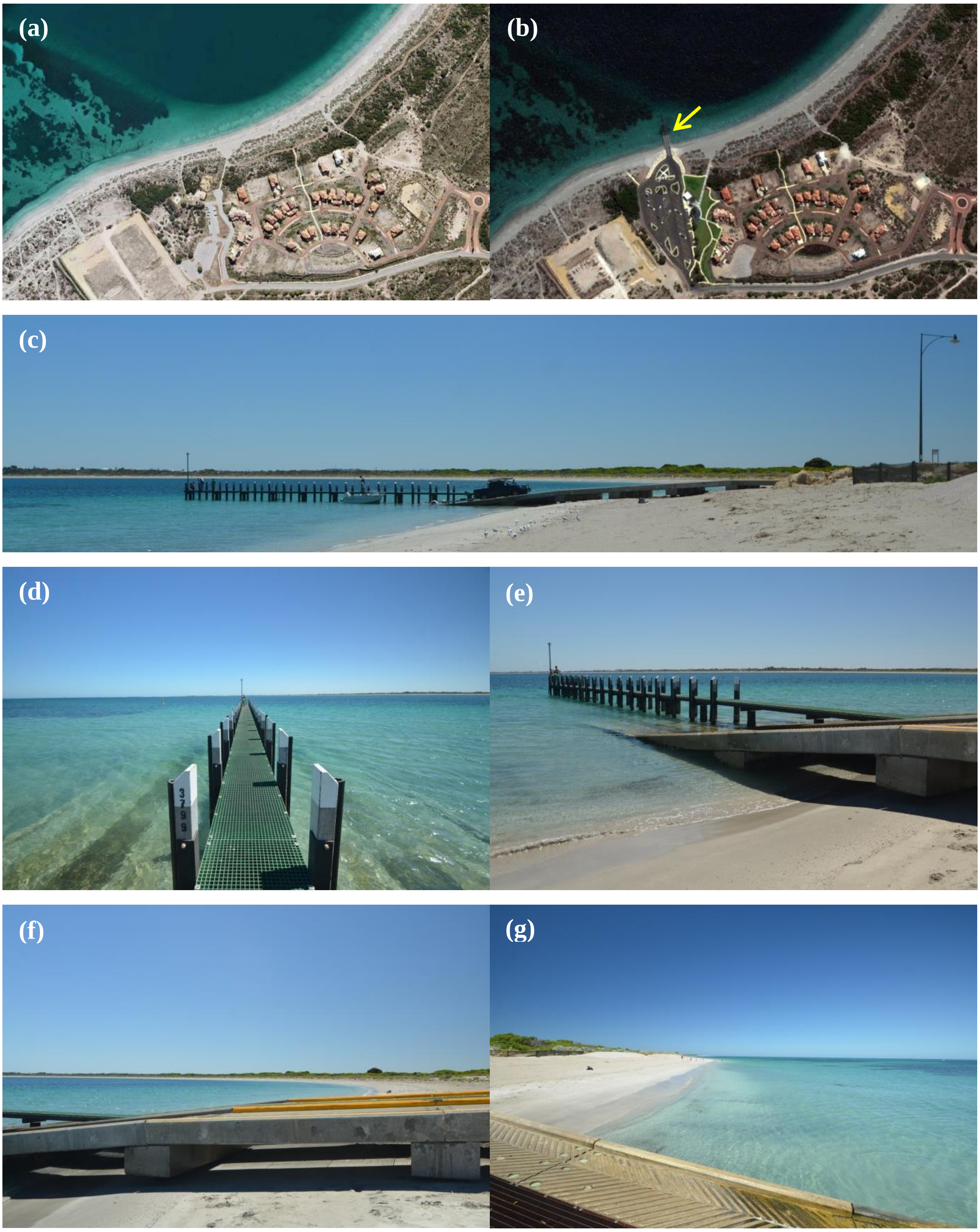

Fig. 2.2: Satellite (Google Earth) photographs of Bridport Point (a) before (May 2010) and (b) after (March 2011) the construction of the boat ramp (denoted by yellow arrow). Photographs of (c) the boat ramp, looking north-east across Warnbro Sound, (d) the central finger jetty, (e) the submerged portion of the ramp, (f) the raised concrete sleepers supporting the beach section of the ramp, and (g) the view from the boat ramp, looking south-west across Warnbro Sound.

2.2 Objective 1: Interannual trends in Whitebait abundance and the broader fish community at Becher Point since the mid-1990s, and relationships with environmental variables

2.2.1 Fish and environmental data sets

- *Nearshore fish assemblage data collected by the WA Department of Fisheries*

Since the early to mid-1990s, the DoF have undertaken a 'fish recruitment monitoring program' in the nearshore shallow waters (<2.5 m deep, within ~50 m of the shoreline) at 52 sites along the south-western Australian coastline from Cervantes in the north to Eucla in the east (Smith *et al.* 2008). The primary aim of this program is to monitor the annual recruitment of the juveniles of key fishery species. However, the abundance of all fish species caught has also been recorded consistently in more recent years (see below), thus providing data on the broader fish assemblages in the region. Samples were collected during the day, predominantly over sandy substrates, using a seine net laid parallel to the shore and hauled onto the beach. The seine net was 60.6 m long, 2 m deep, swept an area of ~592 m^2 and comprised two wings that were each 29.1 m long (22 mm stretched mesh) and a central pocket that was 2.4 m long (8 mm mesh; Smith *et al.* 2008).

Of the various sites monitored by DoF, two are of relevance to the current study. The first is located just south-west of the boat ramp near Becher Point, and is thus of core interest for examining historical trends in Whitebait abundance and broader fish community composition in this area. The second is at Pinnaroo Point, ~80 km north of Becher Point, which shares several similarities with the latter site in that it is also a north-west facing cuspate foreland (although less pronounced), has nearby seagrass beds and is a known recruitment locality for juvenile Whitebait (Valesini *et al.* 2004a). Pinnaroo Point is thus also of interest for determining whether any historical trends in Whitebait abundance at Becher Point are also mirrored at this site (*i.e.* and are thus more likely a consequence of broader scale factors), or are unique to the latter (*i.e.* and thus more likely a consequence of local-scale factors).

Sampling effort has varied considerably throughout the DoF monitoring program, including among sites, the frequency of sampling at each site, and the consistency with which species have been recorded (Tables 2.1 and 2.2). At Becher Point, fish samples have been collected annually between mid-1995 and 2013, except for most of 2003-05 due to a lack of resources

Table 2.1: Summary of the years in which the fish, environmental and penguin biology data sets employed in objectives 1 and 2 of the study were collected (see subsections 2.2.1 and 2.3.1 for further details). All data sets comprised annual totals or averages, except for the nearshore fish data which was also recorded in select months of each sampling year (and = data used in Whitebait analyses; = data used in full fish assemblage analyses), and some of the environmental variables which were recorded monthly or seasonally (see Tables 2.4 and 2.6 for further details on the latter). DoF= WA Department of Fisheries; CPUE=catch-per-unit-effort.

Year	**Nearshore fish assemblage data collected at Becher Point by DoF***												**Environmental data**	**Commercial CPUE of penguin prey species**	**Penguin survival data**	**Penguin breeding performance data**
	J	F	M	A	M	J	J	A	S	O	N	D				
1976-85														•		
1986														•	•	•
1987														•	•	•
1988													•	•	•	•
1989													•	•	•	•
1990													•	•	•	•
1991													•	•		•
1992													•	•		
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1994													•	•	•	•
1995								•	•	•	•	•	•	•	•	•
1996	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•
1997	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•
1998	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
1999	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2000	•	•	•	•		•		•	•	•	•	•	•	•	•	•
2001	•	•	•	•		•	•	•	•	•	•	•	•	•		•
2002	•	•	•	•	•	•							•	•		•
2003													•	•		•
2004													•	•		
2005										•	•		•	•		
2006	•	•	•						•	•	•		•	•		•
2007	•	•	•	•					•	•	•	•	•	•	•	•
2008	•	•	•							•	•		•	•	•	•
2009	•	•	•	•						•	•	•	•	•		•
2010	•	•	•	•					•	•	•	•	•	•		•
2011	•	•	•	•					•	•	•	•	•	•		•
2012	•	•	•	•					•	•	•	•	•			
2013	•	•	•	•						•	•	•	•			

** Three-four replicate fish samples were collected on each sampling occasion, except for August 1995-May 1996 in which six were collected. Only four of the latter samples were employed in the data analyses for this study.*

Table 2.2: Summary of the years and months in which nearshore fish assemblage data were collected at Pinnaroo Point by the WA Department of Fisheries (DoF; see subsection 2.2.1 for further details). = data used in Whitebait analyses.

Year	Nearshore fish assemblage data collected at Pinnaroo Point by DoF*											
	J	F	M	A	M	J	J	A	S	O	N	D
1997		●	●								●	
1998		●		●	●			●	●	●	●	●
1999	●		●	●			●			●	●	●
2000	●	●	●		●	●			●	●	●	●
2001	●	●	●	●	●	●	●			●	●	●
2002	●	●	●	●	●							
2003												
2004												
2005										●	●	●
2006										●		●
2007										●	●	●
2008	●	●	●								●	●
2009										●	●	●
2010	●	●							●	●	●	
2011					●							●
2012	●	●	●	●							●	●
2013	●		●	●						●		

** Three-four replicate fish samples were collected on each sampling occasion, except February, March and/or April in 2000-01 (20-60 replicates collected) and December 2012 (eight replicates collected). Only four of these additional samples were employed in the data analyses for this study.*

(Smith *et al.* 2008; Table 2.1). Sampling months have differed among years, especially between 1996-2001 (when most months were sampled) and 2006-2013 (when mostly only January-April and September-December were sampled). Three to four replicate hauls were collected on all sampling occasions, except August 1995-May 1996 when six were collected (Table 2.1). Sampling effort at Pinnaroo Point has been considerably more variable. While samples have been collected between 1997 and 2013 (except 2003-04) at this site, sampling months have varied substantially (Table 2.2). Three to four replicates were collected on most sampling occasions, except for February, March and/or April in 2000-01 when 20-60 replicates were collected, and December 2012 when eight replicates were collected.

Additionally, while Whitebait and various other fishery species (*e.g.* Tailor *Pomatomus saltatrix*, Australian Herring *Arripis georgianus*, Western Australian Salmon *Arripis truttaceus*, King George Whiting *Sillaginodes punctatus*, Yellowfin Whiting, Sea Mullet, Yelloweye Mullet and Blue Sprat) have been recorded consistently during the DoF monitoring program, unknown ‘low priority’ species were not. Full records of the abundances of all species caught have only been made since 2007 (Smith *et al.* 2008).

Given the above variations in sampling effort and consistency, the DoF fish data sets for Becher and Pinnaroo Point were restricted to the years, months and replicates listed in Table 2.3 to maximise interannual comparability at each site.

Table 2.3: Fish data sets collected by DoF at Becher and Pinnaroo Point that were employed in the data analyses for the current study.

		Becher Point	**Pinnaroo Point**
Whitebait only	Years	1996-2001, 2006-2013	1998-2001, 2005-2010, 2012
	Months (seasons)	Jan-Apr and Sept-Dec (summer, autumn, spring)	Oct-Dec (spring/summer)
	N^{o} replicates	3-4	3-4
Full fish assemblage	Years	2007-2013	NA
	Months (seasons)	Jan-Apr and Sept-Dec (summer, autumn, spring)	NA
	N^{o} replicates	3-4	NA

While some inconsistencies still remained within the above restricted data sets, these were considered less important than forsaking data for additional years, and thus further reducing the ability to detect longer-term trends.

- *Environmental data*

A suite of candidate environmental variables that may potentially contribute to any interannual differences in Whitebait abundance and/or fish faunal composition at Becher Point, and whose measurements were readily obtainable, were compiled for each of the years in which fish data were available (Table 2.4). They comprised five broad categories, namely wind direction and speed, mean wave height in inshore waters, rainfall, mean sea level height (proxy for Leeuwin Current strength) and sea surface temperature. Given the potential for these environmental variables to influence coastal fish species at various stages of their life cycle (*i.e.* the effects of which may not be observable in nearshore catches until sometime

Table 2.4: Suite of candidate environmental variables used to examine interannual relationships with Whitebait abundance and the full fish assemblage in the nearshore waters at Becher Point. N=north; S=south; E=east; W=west; SW=south-west.

Category	Variable	Unit of measurement	Data transformation	Data source†
Wind direction and speed	N <10 km/h*	Number of days	√	Bureau of Meteorology (Mandurah recording station)
	N 20-30 km/h*	“	√	“
	E <10 km/h*	“	√	“
	E 20-30 km/h*	“	√	“
	S <10 km/h*	“	√	“
	S 20-30 km/h*	“	√	“
	SW <10 km/h	“	√	“
	SW 20-30 km/h	“	√	“
	W <10 km/h*	“	√	“
	W 20-30 km/h*	“	√	“
Mean wave height (seas and swell)	Mean wave height-summer	m	none	Department of Transport (Rottnest wave rider buoy)
	Mean wave height-autumn	“	√	“
	Mean wave height-winter	“	none	“
	Mean wave height-spring	“	none	“
	Mean wave height-full year*	“	none	“
Rainfall	Total rainfall*	mm	none	Bureau of Meteorology (Medina recording station)
Mean sea level height	Mean Fremantle sea level height*	cm	none	University of Hawaii Sea Level Centre
Mean sea surface temperature (SST)	Mean Reynolds SST-summer	°C	none	CSIRO (data for latitude 32-33°S)
	Mean Reynolds SST-autumn	“	none	“

Category	Variable	Unit of measurement	Data transformation	Data source†
	Mean Reynolds SST-winter	“	none	“
	Mean Reynolds SST-spring	“	none	“
	Mean Reynolds SST-full year*	“	none	“
	Mean Reynolds SST-winter anomaly	“	NA - removed	“

† measurements were obtained from recording stations as close as possible to the Warnbro Sound region and where data had been recorded over a comparable period as the DoF fish recruitment monitoring program. In those cases where recording stations were not within the immediate vicinity of Warnbro Sound, the relative extent of any interannual differences in the environmental variable of interest were considered likely to be also reflected in the Warnbro Sound region.

***** subset of environmental variables used in the DISTLM analyses to examine interannual relationships with the Whitebait data. Note that all variables listed in the table were included in the BIOENV analyses for both the Whitebait and full fish assemblage data.

Mean Reynolds SST-winter anomaly was highly correlated (>0.95) with Mean Reynolds SST-winter. The former was removed from subsequent analyses.

later), measurements for each environmental variable were examined not only in the year in which they were recorded, but also after a one and two year lag was introduced, *e.g.* fish faunal data recorded in 2000 was correlated with environmental data recorded in 2000 ('no lag'), 1999 ('1 year lag') and 1998 ('2 year lag').

2.2.2 Statistical analyses

The following statistical analyses were undertaken to (i) examine interannual trends in Whitebait abundance and the characteristics of the broader fish assemblage in the nearshore waters at Becher Point (Table 2.3), and (ii) test whether any such trends were significantly correlated with those in the suite of environmental variables (Table 2.4), either in the year in which they were recorded or after a one- and two-year lag had been introduced. Interannual differences in Whitebait abundance at Pinnaroo Point were also examined to assess whether any such trends paralleled those at Becher Point.

Except where specified, all analyses were undertaken using the Primer v6 multivariate statistics package (Clarke and Gorley 2006) with the PERMANOVA+ add-on module (Anderson *et al.* 2008).

- *Data pretreatment*

The raw counts of both Whitebait and the total of all fish species in each replicate sample from Becher Point, and also of Whitebait in replicate samples from Pinnaroo Point, were firstly converted to a density (number of fish 500 m^{-2}) then $\log_{10}(n+1)$ transformed to ameliorate considerable right-skewness in their distributions and thus approximate normality. The total number of species in each sample from Becher Point was also calculated, then subjected to a square-root transformation to ameliorate a mild right skew in its distribution.

In a separate data pretreatment, the fish assemblage data in samples from Becher Point was firstly dispersion weighted (Clarke *et al.* 2006) to downweight the contributions of those species that exhibited large and erratic differences within groups of replicate samples (*i.e.* each year*month combination). The dispersion-weighted data was then square-root transformed to 'balance' the contributions of highly abundant species with those that were less abundant yet still consistently-occurring. This combination of data pretreatment has been shown by Clarke *et al.* (2014a) to be most appropriate for nearshore fish assemblages in south-western Australia.

The data for the suite of environmental variables was firstly used to construct 'Draftsman plots', or scatterplots between all pairs of variables, to (i) enable visual detection of whether the distribution of any variable was notably skewed, and thus which transformation was required (if any) to minimise such effects, and (ii) assess whether any pair of variables was highly correlated (>0.95), and thus minimise redundancy in the data set. The data transformations applied to each variable are given in Table 2.4, and those removed from the data set given high correlations with other variables are also identified. Secondly, to overcome the fact that several environmental variables were measured in different units, the transformed data were then normalised to place each variable on the same (dimensionless) scale. Finally, to ensure that each of the five environmental categories contributed equally to the analyses, each variable was then weighted on the basis of the total number in its category. Thus, each category was assumed to contribute an equal proportion of 100% to the overall data matrix, which was then divided equally among its representative variables, *e.g.* each of the 10 variables in the wind category were assigned a weight of 10, each of 5 variables in the wave category were assigned a weight of 20 etc.

- *Examining interannual trends in Whitebait densities and fish faunal characteristics*

The pretreated Whitebait densities, total fish densities and total number of species in replicate samples from Becher Point were each subjected to a two-way crossed Analysis of Variance (ANOVA) using the SPSS Statistics v21 software to test whether they differed significantly among years, accounting for any influence of season. The pretreated Whitebait densities in samples from Pinnaroo Point were subjected to a one-way ANOVA for year only, given that the restricted data set for this site largely comprised samples from just one season (see Table 2.3). All factors were considered fixed, and the null hypothesis of no significant differences among groups was rejected if the significance level (P) was ≤ 0.05. Where significant interannual differences were detected, back-transformed plots of the marginal means (± 95% confidence intervals) were used to determine the main cause(s) of those differences.

The pretreated fish assemblage data from Becher Point was firstly used to construct a Bray-Curtis similarity matrix, which was then subjected to a year x season Permutational MANOVA (PERMANOVA; Anderson 2001) to test for any interannual differences in fish species composition, accounting for any seasonal influences. The null hypothesis and criteria for rejecting it was the same as above, and the relative importance of all significant model terms was gauged by the magnitude of their components of variation (Anderson 2001). Given that this test detected a significant year x season interaction, interannual differences in fish species composition were then further explored by subjecting seasonal subsets of the above Bray-Curtis matrix to separate one-way Analysis of Similarities (ANOSIM; Clarke 1993) tests. The extent of any significant differences (P <0.05) was gauged by the magnitude of the R statistic, *i.e.* values close to zero indicate small differences between groups of samples, while those close to +1 indicate large group differences. The same seasonal subsets of the above Bray Curtis matrix were also subjected to multidimensional scaling (MDS) ordination (an unconstrained ordination technique) to illustrate interannual trends in fish faunal composition.

The species most responsible for causing any significant interannual differences were determined by subjecting the pretreated fish assemblage data to a shade plot analysis using a new version of the Primer 7 software (Clarke *et al.* 2014a, b). This routine was used to produce a visual display of the abundance matrix of the most influential species in each year*season combination, where the intensity of grey-scale shading is proportional to species abundance (*i.e.* white=absent; black=most abundant). The order of the species displayed on the y axis was determined by group-average hierarchical agglomerative clustering of an Index of Association resemblance matrix calculated from species-standardised data. The samples (displayed on the x axis) were ordered by year and, within each year, by season. Only those fish species accounting for >10% of the pre-treated and averaged abundances in at least one year*season group were included in this analysis.

- *Examining interannual relationships between fish and environmental data*

Two statistical routines were used to test whether any interannual trends in Whitebait densities at Becher Point were significantly correlated with those in any combination of candidate environmental variables, and more particularly which subset produced the 'best' match[1]. Only one of these routines could be employed for the full fish assemblage data, however, given the far smaller number of samples (years) able to be included in that data set

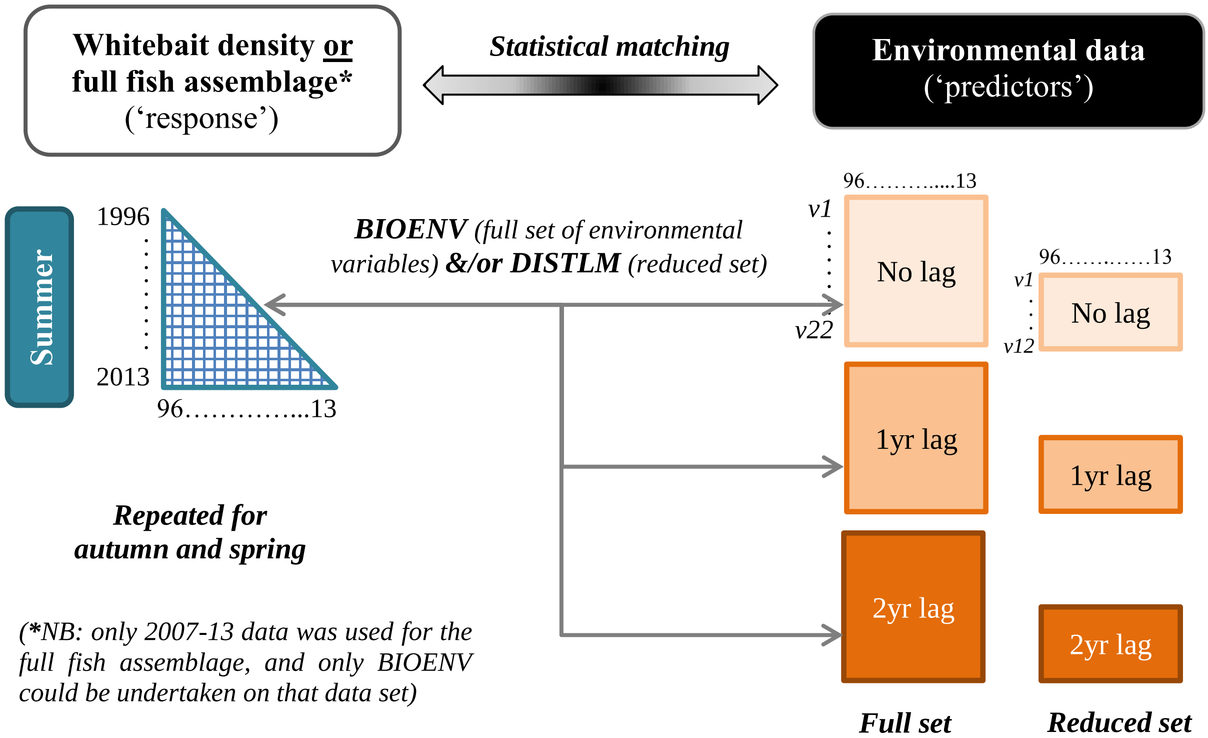
[1] It must be noted that any significant correlations detected ***do not necessarily reflect a direct, causative relationship*** between the selected environmental variables and the fish fauna.

(see Table 2.3 and below). All analyses were repeated using environmental data in which no time lag, a one year lag and two year lag had been introduced.

The first method was the Distance-based Linear Modelling routine (DISTLM; McArdle and Anderson 2001), a semi-parametric regression approach that fits a linear model of the predictor (environmental) variables to the response (fish) data 'cloud'. This routine thus quantifies the level of response variation that is 'explained' by the predictor variables, both individually and collectively for selected subsets. The second was the Biota and Environment matching routine (BIOENV; Clarke and Ainsworth 1993), a non-parametric approach that finds the best match in 'rank-order pattern' between samples in complementary response and predictor resemblance matrices. This latter method does not explicitly measure and model multivariate variation, but instead provides a non-metric index (*i.e.* a rank correlation coefficient) of how closely the selected predictor variables capture the overall 'pattern' in the response data. While the non-metric nature of the latter routine may be perceived as a weakness, BIOENV has several advantages over DISTLM in that it (i) can cater for non-linear relationships between the response and predictor data, and (ii) is unaffected by the number of predictor variables, whereas DISTLM is restricted to at least two less predictor variables than samples to achieve sensible results (Anderson *et al.* 2008). Given this latter restriction, DISTLM could not be used to reliably examine interannual relationships between the full fish assemblage (containing only seven samples) and the environmental data (containing at least 12 variables – see below).

The pretreated response data was firstly separated by season, averaged for years, then used to construct a Euclidean distance matrix in the case of the Whitebait densities and a Bray-Curtis similarity matrix in the case of the full fish assemblage data. The pretreated environmental data (with 22 variables in the full set; see Table 2.4) was also averaged for years. A reduced environmental data set of only 12 variables (see Table 2.4) had to be employed for the DISTLM analyses of the Whitebait data, however, in order to satisfy the above restrictions on the number of predictor variables relative to samples. In both the DISTLM and BIOENV routines, the null hypothesis of no significant interannual relationship between the fish and environmental data was rejected if $P < 0.05$. For DISTLM, a step-wise selection procedure was employed, and a modified version of the Akaike (1973) information criterion, AIC_C, (which better handles situations like the current one where the number of samples is small relative to the number of predictor variables) was used as the selection criterion. The R^2 value associated with the 'best' model was used to ascertain the proportion of the total data variation 'explained' by that model. In the BIOENV analyses, the Spearman rank correlation coefficient (ρ) was used as the matching coefficient, and was used to gauge the extent of any significant match, *i.e.* values close to 0 indicate little correlation in rank order pattern between matrices, while those close to +1 indicate a near perfect agreement. Euclidean distance was used to define sample resemblances for the environmental data.

A summary of the matching procedure is given below:



When DISTLM detected significant results, a distance-based redundancy analysis (dbRDA, a constrained ordination technique), was used to illustrate the 'modelled' (or fitted) relationships between the Whitebait densities and selected environmental variables. The dbRDA axes were considered to well represent the underlying model if they explained >70% of the fitted variation. This was considered in conjunction with the proportion of the total variation explained by the dbRDA axes (*i.e.* the R^2 value described above). For ease of interpretation of the dbRDA plots, the unpretreated magnitude of each selected environmental variable was also overlaid on each year as circles of proportionate sizes. Significant matches detected by BIOENV were illustrated by subjecting the above fish resemblance matrices to (unconstrained) MDS ordination, then overlaying the selected environmental data as described above.

2.3 Objective 2: Interannual relationships between penguin biology and penguin prey and environmental variables

Several data sets were compiled to investigate the extent of any interannual relationships between Little Penguin breeding performance and survival on Penguin Island (‘response variables’) and range of penguin prey and environmental parameters in the surrounding coastal waters (‘predictor variables’). The variables comprising each of these data sets are summarised in Tables 2.5 and 2.6 and described further below.

2.3.1 Penguin, penguin prey and environmental data sets

- *Penguin breeding performance and survival data*

A suite of Little Penguin breeding performance (reproduction) parameters, and also penguin survival, have been recorded on Penguin Island by Murdoch University researchers since the mid-1980s (Table 2.1). Reproduction parameters, which have been recorded in most years from 1986-2011, included number of eggs laid (as a proportion of the number of penguin nestboxes checked); percentage of eggs laid that hatched; percentage of eggs laid that resulted in successful fledglings; chicks mass at fledgling; mean egg laying date over the breeding season, and; number of chicks produced per pair (Table 2.5). Further details are provided in Cannell *et al.* (2012).

Estimates of penguin survival, expressed as a proportion of the total number of penguins monitored in nestboxes on Penguin Island, have been recorded periodically from 1986-2008 (Tables 2.1 and 2.5). Note that these survival estimates are best viewed as ‘apparent survival’, as any penguins which may have moved from monitored nestboxes to unmonitored natural burrows were not accounted for.

Table 2.5: Summary of the data sets used to investigate interannual relationships between Little Penguin biological attributes ('response data') and a range of environmental and penguin prey (fish) characteristics ('predictor data'). DoF= WA Department of Fisheries; CPUE=catch-per-unit-effort (live weight [T]/n^{o} commercial vessels).

Response data				***Predictor data***					
Penguin breeding performance	Unit	**Penguin survival**	Unit	**Environmental data** (see Table 2.6)	Unit	**Nearshore fish at Becher Point (DoF)**	Unit	**Commercial CPUE**	Unit
N^{o} eggs laid: boxes checked	prop^{n}	Survival estimate	prop^{n}	Wind direction and speed	N^{o} days	Whitebait	N^{o} fish	Whitebait	CPUE
Eggs hatched	%			Rainfall	mm	Blue sprat	"	Blue sprat	"
Eggs fledged	%			Mean sea level height	cm	Anchovy	"	Anchovy	"
Fledgling mass	G			Mean air temperature	°C, N^{o} days	Sardine	"	Sardine	"
Mean egg laying date	day of year			Mean sea surface temperature (32-33°S)	°C	Garfish	"	Garfish	"
N^{o} chicks per pair	Number			Mean sea surface temperature-Warnbro Sound	°C				

Table 2.6: Suite of environmental variables used to examine interannual relationships with Little Penguin breeding performance and survival. N=north; S=south; E=east; W=west; SW=south-west.

Category	Variable	Unit of measurement	Data transformation	Data source†
Wind direction and speed	N <10 km/h*	Number of days	$\log_e$	Bureau of Meteorology (Mandurah recording station)
	N 20-30 km/h*	"	√	"
	E <10 km/h*	"	none	"
	E 20-30 km/h*	"	$\log_e$	"
	S <10 km/h*	"	√√	"
	S 20-30 km/h*	"	√√	"
	SW <10 km/h	"	none	"
	SW 20-30 km/h	"	√	"
	W <10 km/h*	"	√	"
	W 20-30 km/h*	"	none	"
Rainfall	Total rainfall	mm	√	Bureau of Meteorology (Medina recording station)
	May-Aug rainfall*	"	none	"
Mean sea level height	Mean Fremantle sea level height-full year	cm	$\log_e$	University of Hawaii Sea Level Centre
	Mean Fremantle sea level height-May-Aug*	"	none	"
Mean air temperature	Days > 33°C (Dec and Jan only)*	Number of days	√√	Bureau of Meteorology (Medina recording station)
Mean sea surface temperature	Mean Reynolds-SST Mar	°C	√√	CSIRO (data for latitude 32-33°S)
	Mean Reynolds-SST Apr	"	none	"
	Mean Reynolds-SST May	"	$\log_e$	"
	Mean Reynolds-SST Jun	"	none	"
	Mean Reynolds-SST Jul	"	√	"
	Mean Reynolds-SST Aug	"	none	"
	Mean Reynolds-SST Sept	"	none	"
	Mean Reynolds-SST Oct	"	√	"
	Mean Reynolds SST-autumn anomaly	"	NA - removed	
	Mean Reynolds SST-winter anomaly	"	NA - removed	
	Mean Reynolds SST-Autumn*[R]	"	$\log_e$	"

Category	Variable	Unit of measurement	Data transformation	Data source†
	Mean Reynolds SST-Winter*R	"	none	"
	Mean Reynolds SST- Spring*R	"	none	"
	Mean Reynolds SST- Mar-Oct*S		none	
Mean sea surface temperature - Warnbro Sound (WS) only	Mean Reynolds WS-SST Mar	°C	none	CSIRO (data for latitude 32.335°S)
	Mean Reynolds WS-SST Apr	"	$\log_e$	"
	Mean Reynolds WS-SST May	"	$\log_e$	"
	Mean Reynolds WS-SST Jun	"	none	"
	Mean Reynolds WS-SST Jul	"	none	"
	Mean Reynolds WS-SST Aug	"	none	"
	Mean Reynolds WS-SST Sept	"	none	"
	Mean Reynolds WS-SST Oct	"	none	"
	Mean Reynolds WS SST-Autumn*R	"	$\log_e$	"
	Mean Reynolds WS SST-Winter*R	"	none	"
	Mean Reynolds WS SST- Spring*R	"	none	"
	Mean Reynolds WS SST- Mar-Oct*S	"	none	"

† measurements were obtained from recording stations as close as possible to the Warnbro Sound region. In those cases where recording stations were not within the immediate vicinity of Warnbro Sound, the relative extent of any interannual differences in the environmental variable of interest were considered likely to be also reflected in the Warnbro Sound region.

Mean Reynolds SST-autumn and winter anomaly were highly correlated (>0.95) with Mean Reynolds SST-Apr and July, respectively. The former variables were removed from subsequent analyses.

***** subset of environmental variables used in the DISTLM analyses to examine interannual relationships with the penguin reproduction and survival data. Note that all variables (except for those marked *R or *S; see below) were included in the BIOENV analyses.

***R** subset of environmental variables that, together with those marked *, were employed in the DISTLM analyses to examine interannual relationships with the penguin reproduction data. Note that these variables were not employed in the BIOENV analyses.

***S** subset of environmental variables that, together with those marked *, were employed in the DISTLM analyses to examine interannual relationships with the penguin survival data. Note that these variables were not employed in the BIOENV analyses.

- *Penguin prey (fish) data*

Abundance data for various fish species that Little Penguins from Penguin Island are known to prey upon, namely Whitebait, Blue Sprat, Australian Sardine, Australian Anchovy and Southern Garfish, were collated from two data sources recorded by DoF.

The first of these was the nearshore fish recruitment monitoring program outlined in subsection 2.2.1, employing data from the Becher Point site in 1996-2001 and 2006-2013[2]. These data comprise predominantly juvenile fish, and some adults.

The second was total annual catch data (1976-2011) recorded from commercial fishers operating in two-three of the 60 x 60 nautical mile 'fishing blocks' that are employed by the DoF for assessing commercial catch-per-unit-effort of fishery species (*i.e.* 3115, 3215 and/or 33151; see Fig. 2.3). Although block 3215 comprises the main area in which penguins typically forage (Bradley *et al.* 1997), catch data from block 3115 and in some years also 33151 were included to minimise the number of years in which the DoF confidentiality policy around commercial catch reporting would prohibit their ability to provide data, *i.e.* those cases where data is derived from less than three commercial vessels. Catches were obtained using a combination of purse seines and haul nets in the deeper inshore waters and seine nets in the shallow nearshore waters, with catches comprising predominantly adult fish. Catch data has been expressed as catch-per-unit-effort (CPUE), namely live catch weight (tonnes)/number of vessels.

[2] While Smith *et al.* (2008) indicates that Whitebait, Blue Sprat and Southern Garfish were recorded consistently in the DoF fish recruitment monitoring program at Becher Point since the mid-1990s, this is not stated explicitly for the other two penguin prey species. However, given that Sardine and Anchovy also support fisheries along the lower west coast of Australia, it was assumed that they were also considered to be 'priority species' and thus recorded consistently.

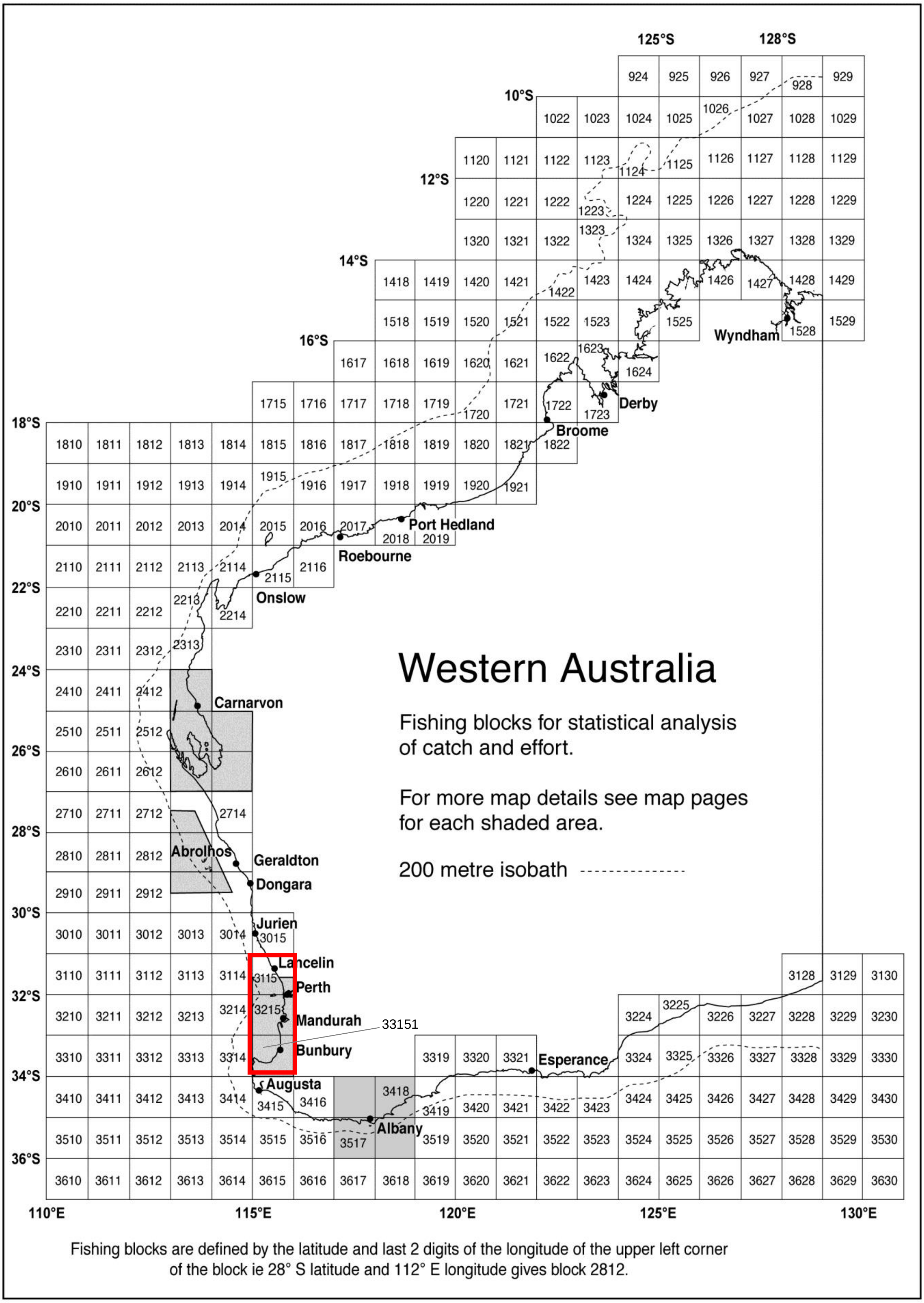


Fig. 2.3: Fishing blocks employed by DoF for assessing commercial fish catch and effort throughout WA. Blocks from which penguin prey (fish) data were derived for this study are outlined in red.

- *Environmental data*

A suite of environmental variables that may potentially contribute to any interannual differences in penguin breeding performance and/or survival were compiled for each of the years in which penguin data were available. These variables, listed in Table 2.6, were similar to those employed for examining relationships with the nearshore fish faunas at Becher Point (subsection 2.2.1; Table 2.4), but (i) focussed mainly on measurements made between the March/May to August/October period, which encompasses the main penguin breeding cycle, and (ii) included sea-surface temperature data specifically from Warnbro Sound, rather than just from the broader 32-33°S region.

2.3.2 Statistical analyses

The extent and nature of any significant interannual relationships between penguin biology (breeding performance and survival) and any of the above penguin prey and environmental variables were explored using the following suite of statistical analyses. Given the potential for prey abundance and environmental conditions to have delayed impacts on penguin biology, the above relationships were examined after no time lag, a one year lag and two year lag had been introduced into the former (predictor) data sets.

All analyses were undertaken using the Primer v6 multivariate statistics package (Clarke and Gorley 2006) with the PERMANOVA+ add-on module (Anderson *et al.* 2008).

- *Data pretreatment*

The penguin breeding performance data was firstly used to construct Draftsman plots to visually assess whether any variables required transformation to address notable skewness in their distributions. These plots showed that the percentage of eggs hatched required a square-root transformation, the mean egg laying date required a fourth-root transform and the remainder did not require transformation. These data were then normalised to account for differences in their measurement scales. The penguin survival data did not require pretreatment.

The environmental data were pretreated in the same manner as described in the environmental component of subsection 2.2.2, except that the particular transformations applied to each variable were re-tailored to this data set (see Table 2.6).

The penguin prey abundance data recorded by DoF in the nearshore waters at Becher Point was pretreated in the same manner as described in the fish assemblage component of subsection 2.2.2, while the CPUE data for these species in the commercial catches were subjected to an overall fourth-root transform. Note that the latter data could not be pretreated in the same way as the nearshore fish data, as it only comprised a total value for each year with no replication.

- *Examining interannual relationships between penguin biology and penguin prey and environmental data*

The pretreated penguin breeding performance and survival data were each firstly used to construct Euclidean distance matrices to 'summarise' their interannual trends.

The extent and nature of any significant interannual relationships between each of these penguin 'response' matrices and any combination of variables in each of the three 'predictor' data sets (Tables 2.5 and 2.6) were examined using the same approaches outlined in subsection 2.2.2. The only exceptions were as follows:

- For the penguin biology-environment matching, BVSTEP was used instead of the closely-related BIOENV routine to cater for the relatively large number of environmental variables.
- For the penguin biology-fish matching using BIOENV, interannual resemblances in fish species composition were calculated using the Bray-Curtis similarity coefficient, rather than Euclidean distance.
- Relationships between the penguin biology and nearshore fish data were explored separately for each season (summer, autumn and spring).
- DISTLM could not be used to explore relationships between the penguin survival and nearshore fish data when a one and two year lag was introduced into the latter, due to an insufficient number of common samples (years) between these data sets. Similarly, BIOENV analyses between the penguin survival and nearshore fish data with a two year lag were also precluded for this reason.
- DISTLM analyses between the penguin survival and reduced environmental data set (see Table 2.6) were undertaken in two separate runs to overcome limitations imposed by the relatively small number of samples to variables. The first run comprised wind variables with speeds of <10 km/h and all other variables in the reduced set, and the second run comprised wind variables with speeds of 20-30 km/h and all other variables in the reduced set.

2.4 Objective 3: Impact of the boat ramp on Whitebait abundance and the broader fish community at Becher Point

2.4.1 Sampling regime and laboratory analyses

The nearshore fish faunas at five sites around Becher Point were sampled monthly between August and January of 2011-12, 2012-13 and 2013-14 (hereafter 2011, 2012 and 2013, respectively). The five sites included one in the immediate vicinity of the boat ramp at Bridport Point, a site to each the north and south of the boat ramp, one on the northern (Warnbro Sound) side of Becher Point, and one on the southern (Comet Bay) side of the Point (Fig. 2.4). In each sampling month, four replicate samples of the fish fauna were collected at each site, with the collection of these replicates being divided over two separate occasions spaced approximately one week apart (*i.e.* two replicates on each occasion) to better account for natural variability within each month. All sampling was undertaken between 0800 and 1600 h.

Samples of the fish fauna were collected using a beach seine net that was 21.5 m long, 1.5 m high and comprised two 10 m long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m long bunt (3 mm mesh). The net, which swept an area of 116 m^2, was deployed parallel to the shore then hauled in a semi-circle onto the beach. Larger fish that could immediately be identified to species were counted and returned to the water alive, while the remainder were placed into polythene zip-lock bags and immediately euthanised in an ice slurry. In those cases in which large numbers (thousands) of small fish were caught, an appropriate sub-sample was retained and the remainder returned alive. In the laboratory, the total number of individuals of each fish species in each sample was recorded, and the total length (mm) of each individual measured, except when a large number of any one species was caught, in which case the lengths of a random subsample of 100 fish were measured.

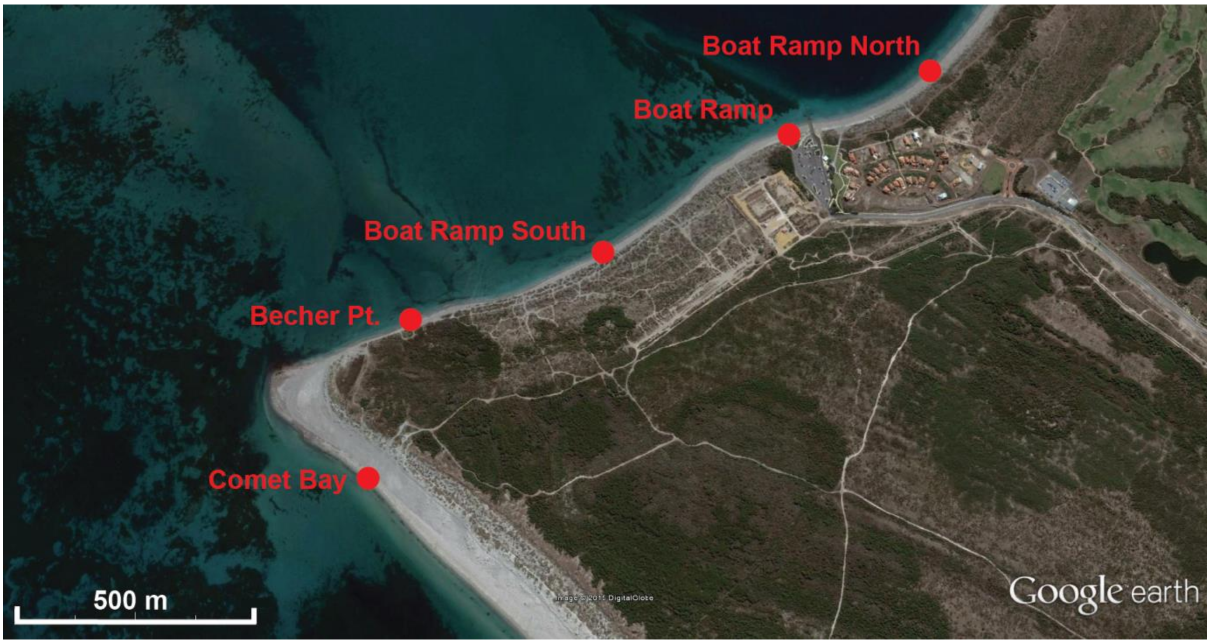


Fig.2.4: Map showing the location of the sites around Becher Point at which the nearshore fish fauna were sampled between August 2011 and January 2014.

While the objective of this component of the study was to determine whether the construction and use of the boat ramp has significantly influenced the nearshore fish fauna, and particularly Whitebait, in the Becher Point area, this project did not commence until January 2011 (with fish sampling initiated in August 2011), and thus well after the building and opening of the ramp in December 2010. There was thus no opportunity to obtain comparable ‘pre-boat ramp’ fish faunal data in the year(s) immediately preceding construction. Although DoF has sampled the full nearshore fish assemblage at Becher Point in each year since 2007 (subsection 2.2.1), the differences in gear type between that program and the current study (61 *vs* 21 m seine) preclude direct comparability of the resultant data (*e.g.* see Hallett and Hall, 2012). The only other comparable fish faunal data available is that collected by Valesini *et al.* (1998; 2004a, b) in 1996/7 (hereafter 1997) and 2000-01, respectively. Thus, these workers collected samples of the nearshore fish assemblages at the Becher Point, Comet Bay and/or Boat Ramp South sites using a 21.5 m seine net during summer (February), winter (August) and spring (November) in each of the above years. Three to four replicate samples were collected at each site on each sampling occasion between 0800h and 1600h. The other field and laboratory methods employed by these workers were the same as in the current study. These data have thus been used to provide some historical basis for assessing any shifts in the characteristics of the Becher Point fish fauna in years preceding and following construction of the boat ramp. It is recognised, however, that their timeframe of collection and lack of sampling at the full suite of sites sampled in the current study is not ideal.

2.4.2 Statistical analyses

The following statistical analyses were undertaken to (i) examine spatial and temporal trends in Whitebait abundance and the characteristics of the broader nearshore fish assemblage at Becher Point between 2011 and 2013, and (ii) examine any inter-period shifts in Whitebait density and fish assemblage composition in this region between years preceding (1997, 2000, 2001) and following (2011, 2012, 2013) construction of the boat ramp.

- *Examining spatial and temporal trends in Whitebait density and fish faunal characteristics from 2011-2013*

The Whitebait and fish faunal data collected during the current study were each pretreated in the same manner as described in the relevant component of subsection 2.2.2.

The pretreated Whitebait densities, total fish densities and number of species in replicate samples were each subjected to a three-way crossed ANOVA to test whether they differed significantly among years, months and/or sites. All other aspects of these ANOVAs and the method of interpretation were the same as outlined in subsection 2.2.2.

The pretreated replicate fish assemblage data was firstly used to construct a Bray-Curtis similarity matrix, which was then subjected to a three-way crossed year*month*site PERMANOVA to test for any spatial and/or temporal differences in fish faunal composition (see subsection 2.2.2 further details on the method of interpretation of these tests). Given that this test showed that the three-way interaction term was significant and relatively important, differences in fish composition were then further explored by subjecting relevant subsets of the above Bray-Curtis matrix to one- or two-way ANOSIM tests (further detail of which is given in subsection 3.3) . The interpretation of these latter tests was also the same as described in subsection 2.2.2. The same Bray-Curtis sub-matrices were subjected to nMDS ordination to illustrate spatio-temporal trends in the fish fauna. Note that, in some cases, averaged rather than replicate data was used to improve clarity of these plots.

Finally, the species most responsible for driving significant spatio-temporal trends in the fish community were determined by subjecting the pretreated and averaged species abundance data to various shade plot analyses. On all shade plots, the species on the *y* axis were ordered using the same approach as described in subsection 2.2.2, while samples on the *x* axis were ordered by month, site and/or year. Only those species found in ≥5 of the 360 samples were included in these analyses.

- *Inter-period trends in Whitebait density and fish faunal characteristics prior to and following boat ramp construction*

To achieve comparability across the Valesini *et al.* (1998; 2004a, b) and current fish faunal data sets at Becher Point, and thus enable sensible comparisons between the pre- and post-boat ramp periods, all data were restricted to a common set of sites and sampling seasons. This new composite data set comprised two sites (Becher Point and Comet Bay), three seasons (summer, winter and spring) and six years across two periods, *i.e.* pre-boat ramp (1997, 2000 and 2001) and post-boat ramp (2011, 2012 and 2013).

These data were subjected to the same pretreatments and suite of analyses as described above for the 2011-13 Whitebait and fish faunal data. The only exception was that a fourth factor (period) was incorporated into the analyses. In the ANOVA and PERMANOVA tests, period was considered fixed, year (which was nested inside period) was considered random, and both site and season (which were crossed with the above factors) were treated as fixed. Focus was placed on interpreting the period component of these analyses.

3. Results

3.1 Objective 1: Interannual trends in Whitebait abundance and the broader fish community at Becher Point since the mid-1990s, and relationships with environmental variables

3.1.1 Interannual trends in Whitebait density at Becher Point (including comparisons with Pinnaroo Point) since the mid-1990s

Whitebait *Hyperlophus vittatus* densities in the nearshore waters at Becher Point, recorded by DoF as part of their fish recruitment monitoring program, were shown by two-way ANOVA to differ significantly among years (1996-2001, 2006-2013), seasons (summer, autumn and spring) and the interaction between these two factors ($P \leq 0.001$; Table 3.1).

Table 3.1: Two-way crossed ANOVA of Whitebait densities in samples collected from the nearshore waters at Becher Point by DoF during summer, autumn and spring in 1996-2001 and 2006-2013. df=degrees of freedom; MS=mean square. Significant differences (*P* <0.05) are in bold.

	df	MS	F	*P*
Year	13	**0.714**	**2.672**	**0.001**
Season	2	**4.286**	**16.050**	**<0.001**
Year * Season	26	**0.894**	**3.349**	**<0.001**
Residual	358	0.267		

Plots of the (back-transformed) marginal mean Whitebait densities[3] in each year and season revealed that values fluctuated widely among both of these factors. Mean catches were typically far higher in spring than summer and especially autumn, where they were negligible (<1 fish 500 m^{-2}; Fig. 3.1). Moreover, during spring, catches were far greater in several years in the 1996-2001 period (peaking at ~26 fish 500 m^{-2} in 2000) than in the 2006-13 period (0-1.7 fish 500 m^{-2}; Fig. 3.1).

Similar interannual patterns in mean Whitebait density also occurred at Pinnaroo Point between 1998 and 2012 (using data from October-December only). One-way ANOVA detected significant differences between years (*P*=0.027; Table 3.2), which were mainly driven by the typically higher mean catches in the 1998-2001 period (~2.2-24.2 fish 500 m^{-2}, peaking in 2000) than in the 2005-2012 period (0-2.9 fish 500 m^{-2}; Fig. 3.2).

[3] Note that these (and all other) back-transformed marginal mean values differ substantially from the true arithmetic mean values, and should not be considered as interchangeable.

Table 3.2: One-way ANOVA of Whitebait densities in samples collected from the nearshore waters at Pinnaroo Point by DoF during October-December in 1998-2001, 2005-2010 and 2012. df=degrees of freedom; MS=mean square. Significant differences (*P* <0.05) are in bold.

	df	**MS**	**F**	***P***
Year	10	**1.798**	**2.145**	**0.027**
Residual	100	0.838		

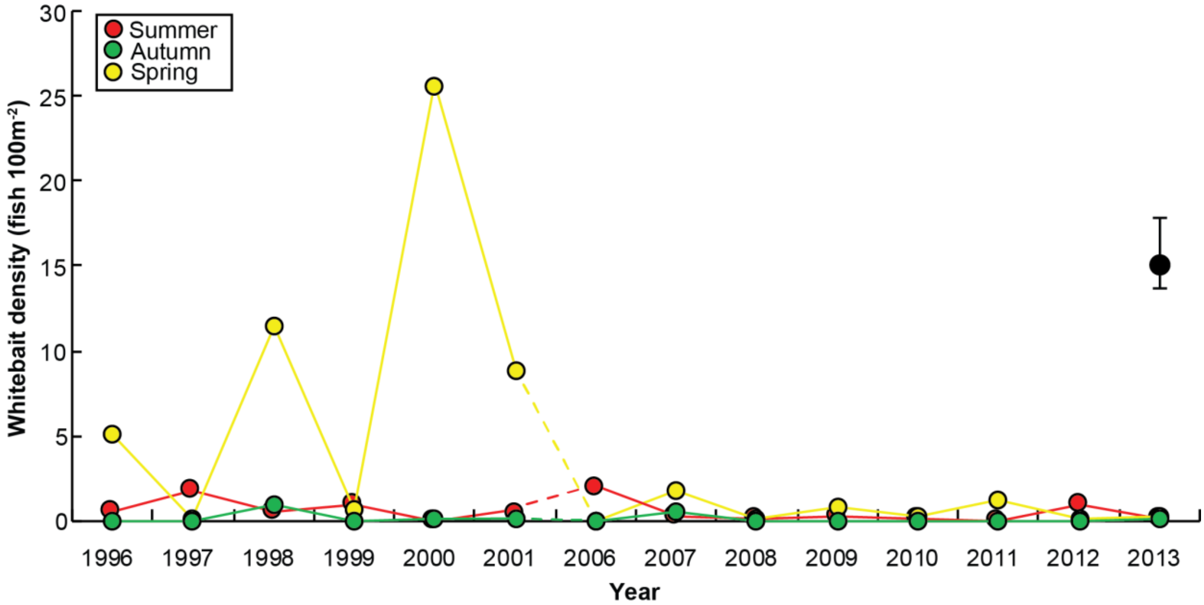


Fig. 3.1: Marginal mean densities of Whitebait (back-transformed) in samples collected from the nearshore waters at Becher Point by DoF during summer, autumn and spring in 1996-2001 and 2006-2013. For clarity, the average ± 95% confidence intervals have been presented.

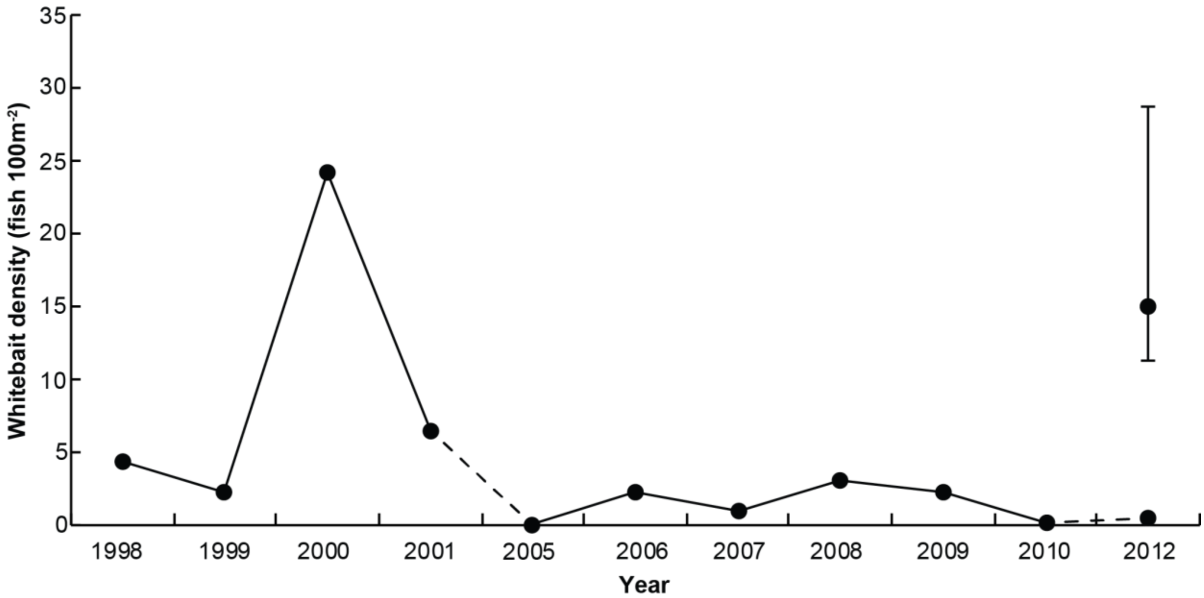


Fig. 3.2: Marginal mean densities of Whitebait (back-transformed) in samples collected from the nearshore waters at Pinnaroo Point by DoF during October-December in 1998-2001, 2005-2010 and 2012. For clarity, the average ± 95% confidence intervals have been presented.

3.1.2 Interannual trends in the nearshore fish community at Becher Point (2007-13)

- *Broad interannual trends in fish species abundances*

The mean densities of each fish species caught in the nearshore waters at Becher Point during the DoF monitoring program between 2007 and 2013 are provided for each year in Appendix 1. A total of 72 species and 30,748 fish (following conversion of the catches in each sample to fish 500 m^{-2}) were recorded over this period.

Total species richness ranged between 44 in 2011 and 30 in 2008, with the highest of these values being mainly due to several species that were recorded only in that year (*e.g.* Goldenline Whiting *Sillago analis*, Western Australian Salmon *Arripis truttaceus*, Black Bream *Acanthopagrus butcheri* and Elongate Hardyhead *Atherinosoma elongata*), but typically in very low numbers. In contrast, the lowest overall mean density of fish was recorded in 2011 (75 fish), which was less than a third of the highest value recorded in 2010 (332 fish). These comparatively high densities were mainly attributable to large catches of Blue Sprat *Spratelloides robustus* and Common Hardyhead *Atherinomorus vaigiensis* (~95% of the total number of fish), both of which are small, highly-schooling species (Appendix 1).

Blue sprat was by far the most abundant species in each year, comprising ~45-77% of the annual catch. Southern School Whiting *Sillago bassensis*, Blowfish *Torquigener pleurogramma*, and Common Hardyhead were also relatively abundant (*i.e.* ≥ 5% of the catch) in at least two years between 2007 and 2013, whereas the remaining abundant species varied between individual years (highlighted in Appendix 1). The only year in which Whitebait was comparatively abundant was 2007 (~12% of the catch).

Further description of the species which contributed most to significant interannual differences in the fish faunas at Becher Point is provided for the shade plot analyses outlined below.

- *Interannual differences in mean species richness and density*

The mean number of species was shown by two-way ANOVA to differ significantly among years (2007-2013), seasons and the interaction term ($P \leq 0.01$; Table 3.3). Figure 3.3a shows that the overarching cause of this interaction was the wide variability in values among both of the above factors, with few consistent trends being evident. The only exception was that mean values during spring were the lowest in five of the seven years, reaching a minimum of

2.5-2.7 species in 2008 and 2010. The highest mean values were recorded in 2008 and 2011 during summer and autumn, respectively (~9 species; Fig. 3.3a).

Table 3.3: Two-way ANOVA of mean species richness and density of fish in samples collected from the nearshore waters at Becher Point by DoF during summer, autumn and spring in 2007-13. df=degrees of freedom; MS=mean square. Significant differences (*P* <0.05) are in bold.

		Mean number of species			Mean density		
	df	**MS**	**F**	***P***	**MS**	**F**	***P***
Year	6	**0.850**	**2.882**	**0.010**	0.757	2.109	0.054
Season	2	**4.580**	**15.521**	**<0.001**	**6.814**	**18.994**	**<0.001**
Year * Season	12	**1.129**	**3.826**	**<0.001**	**0.741**	**2.065**	**0.021**
Residual	182	0.295			0.359		

Mean density, however, only bordered on significance for the year main effect, but did exhibit a significant interaction between year and season, in addition to significant seasonal differences (*P* ≤0.021; Table 3.3). When the marginal mean annual densities were plotted separately for each season, it was apparent that the main cause of the interaction was the considerable interannual variability during autumn (particularly for 2007-10), whereas values in summer and spring remained relatively consistent across years (Fig. 3.3b). In all years, mean densities were the lowest in spring, with values of only 10-20 fish 500m^{-2} in five of the seven years. The highest mean densities were recorded in 2008 and 2010 during autumn (345-397 fish 500m^{-2}).

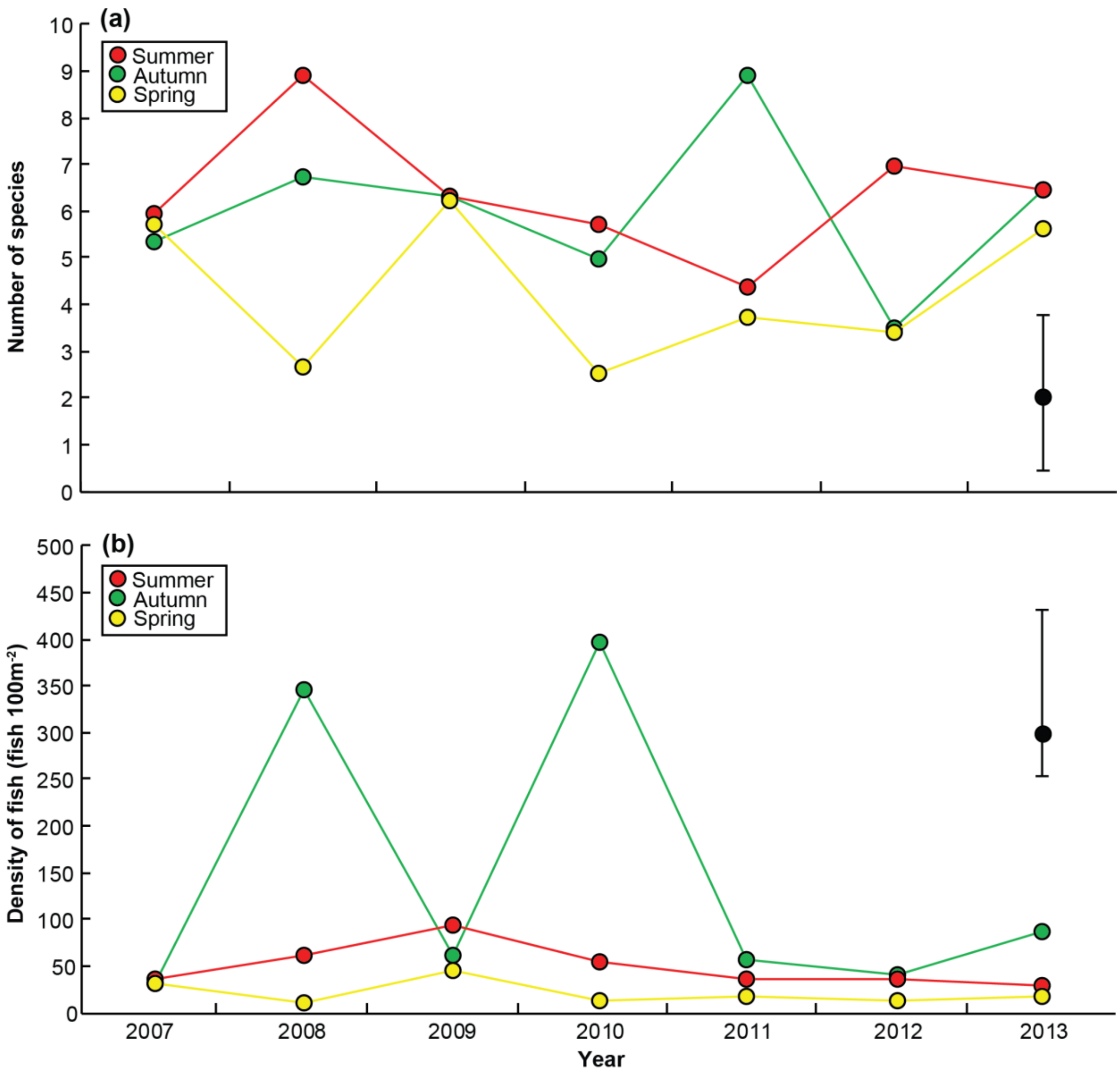


Fig. 3.3: Back-transformed marginal mean values of the (a) number of fish species and (b) density of fish in samples collected from the nearshore waters at Becher Point by DoF during summer, autumn and spring in 2007-13. For clarity, the average ± 95% confidence intervals have been presented.

- *Interannual differences in fish assemblage composition*

The species composition of the nearshore fish assemblage at Becher Point differed significantly among years, seasons and the year*season interaction (*P*=0.001). Year exerted the least influence, as demonstrated by its far lower components of variation value compared to those of other model terms, whereas the interaction and season main effect were similarly important (Table 3.4).

Table 3.4: Two-way PERMANOVA of the species composition of the fish assemblage in samples collected in the nearshore waters at Becher Point by DoF during summer, autumn and spring in 2007-13. df=degrees of freedom; MS=mean square; COV=components of variation. Significant differences (*P* <0.05) are in bold.

	df	MS	Pseudo-F	P	COV
Year	6	**9043.4**	**3.1189**	**0.001**	**14.894**
Season	2	**31864.0**	**10.989**	**0.001**	**21.254**
Year * Season	12	**6712.9**	**2.3152**	**0.001**	**20.097**
Residual	182	2899.5			53.847

Given the importance of the year*season interaction, further investigation of interannual differences using ANOSIM was then undertaken separately for each individual season. The results of these analyses are given in Appendix 2.

In general, while significant interannual differences in fish composition were detected in each season (Global *P*=0.001 in all cases), the overall extents of those differences were low (Global R=0.187-0.282), and several comparisons between pairs of years were insignificant (Appendix 2). The greatest overall differences occurred in autumn, which were driven largely by the comparative distinctness of the fish assemblage in 2010 compared to those in most other years (R >0.4 in most cases), and especially 2011 (R=0.65). The 2011 fish faunas were also relatively distinct from those in 2007 and 2008 in this season. The greatest interannual differences in summer were detected for 2007 *vs* 2011 and 2009 *vs* 2013 (R=0.342-0.356), while those in spring were between 2007 and 2010 (R=0.370). Few other notable interannual trends were evident (Appendix 2).

The MDS ordination plots shown in Fig. 3.4 illustrate the above interannual patterns. Note that, for clarity, these plots have been constructed from the yearly averages in each season, whereas the above ANOSIM tests were undertaken on the replicate data. The distinctiveness of the fish faunas in 2010 during autumn is reflected by the point for this year lying to the far left of the plot, and on the opposite side from 2011 from which it was most different (Fig. 3.4b). Similarly, the points representing 2007 and 2011 in summer occupied opposite sides of the plot in Fig. 3.4a, as did those for 2007 and 2010 in spring (Fig. 3.4c).

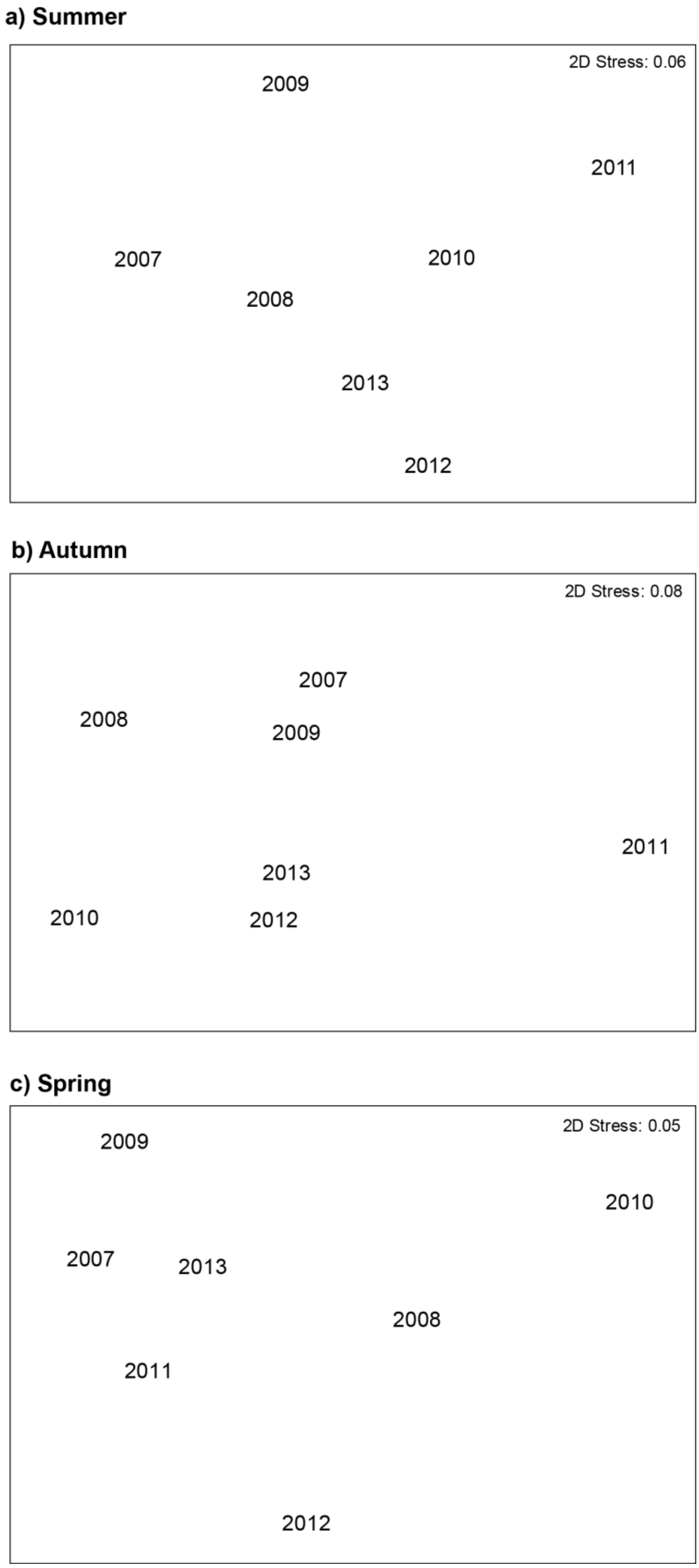


Fig. 3.4: MDS ordination plots constructed from the species composition of the nearshore fish assemblages, averaged for each year, in samples collected at Becher Point by DoF during (a) summer, (b) autumn and (c) spring in 2007-13.

The shade plot shown in Fig. 3.5, in which the (pretreated[4]) abundances of species comprising ≥10% to the total in any year*season combination are depicted as grey-scale shading (white=absent; black=most abundant), demonstrates that the distinctness of the 2010 fish fauna in autumn was due mainly to large catches of Common Hardyhead and Blue sprat and only small to moderate catches of a few other species. In contrast, the distinctiveness of the fish faunas during 2011 in this season were driven mainly by moderately high catches of several weed-associated species (*e.g.* Leatherjacket sp. [Monocanthidae], Cobbler *Cnidoglanis macrocephalus*, Blue weed whiting *Haletta semifasciata*, Gobbleguts *Ostorhinchus rueppellii* and Western Striped Grunter *Pelates octolineatus*) that were, in almost all cases, either not recorded or recorded in notably lower abundances in all other year*season combinations. During summer, differences in the abundance of Blowfish were among the main reasons for the largest interannual differences detected in that season, while the largest interannual differences in spring (2007 *vs* 2010) were driven mainly depauperate catches in the latter year dominated by Yelloweye Mull*et aldrichetta forsteri*, compared to relatively speciose catches in the former year that were dominated by Sandfish *Lesueurina platycephala*. Few other obvious interannual trends in species composition were apparent, though further detail on the individual species most responsible for distinguishing each year and season can be obtained from Fig. 3.5.

The above shade plot also highlights the prevalence of several species that consistently dominated the fish assemblages across most years in two or all seasons, such as Western School Whiting *Sillago vittata*, Southern School Whiting, Yellowfin Whiting *Sillago schomburgkii*, Blowfish and Sandfish in most seasons, and Blue Sprat in autumn and summer (Fig. 3.5).

3.1.3 Interannual relationships between nearshore fish and environmental characteristics

The results of the BIOENV and/or DISTLM analyses used to determine whether there were significant correlations between the above interannual trends in Whitebait densities or fish faunal composition at Becher Point, and those in a suite of environmental characteristics, are summarised in Table 3.5.

[4] Note that the comparative dominance of species in Fig. 3.5 differs to some extent from that reflected by the mean species densities in Appendix 1, given that the former is based on pretreated data (and thus has downweighted the influence of highly inconsistent species - see subsection 2.2.2) while the latter is based on raw data.

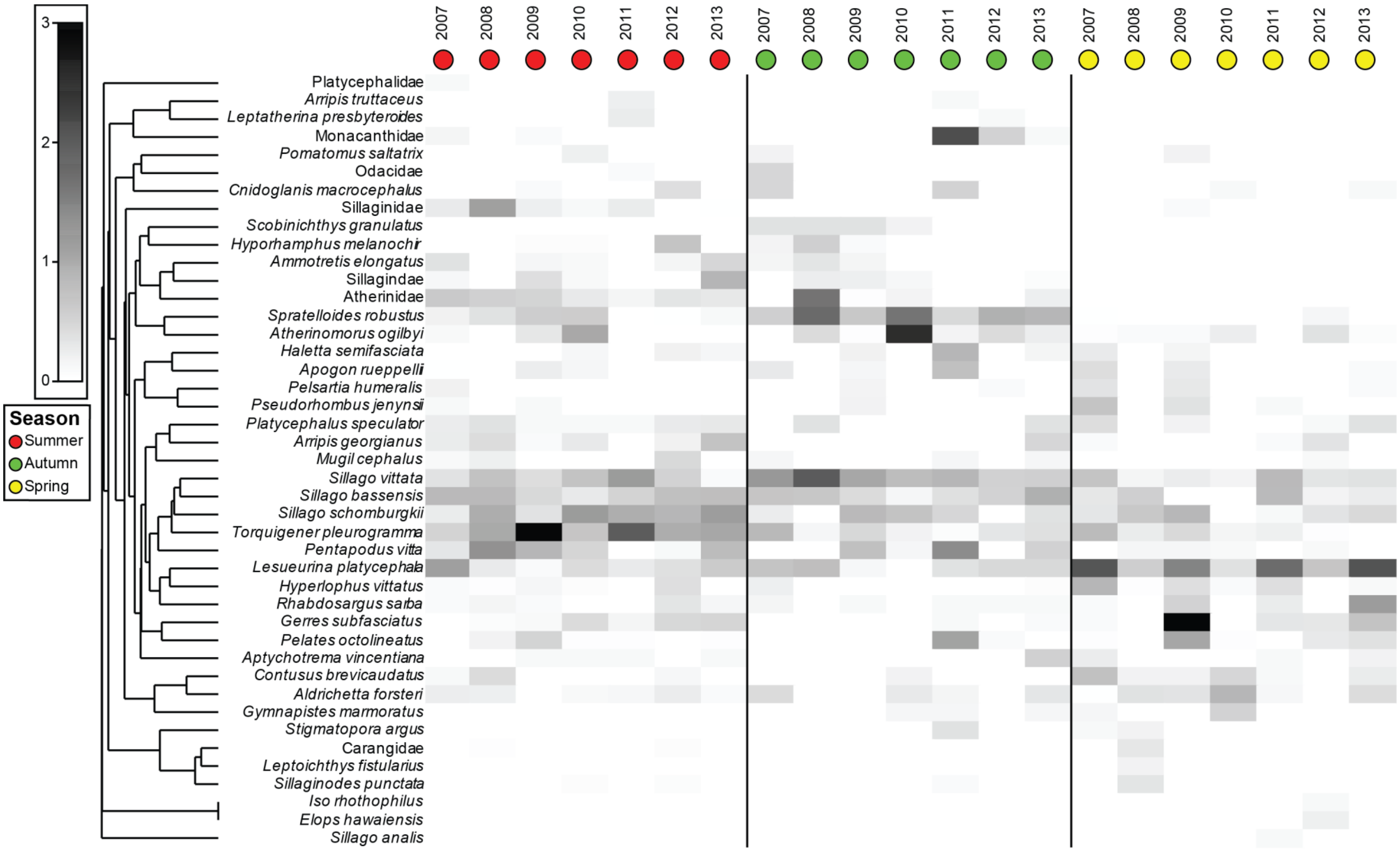


Fig. 3.5: Shade plot illustrating the (pretreated) abundances of the most prevalent fish species recorded at Becher Point by DoF during summer, autumn and spring in 2007-13 (*i.e.* those accounting for >10% of the average abundance in any year*season combination), with shading intensity being proportional to abundance. Samples have been ordered by year for each season, and species are ordered by a hierarchical cluster analysis of their mutual associations across samples.

Table 3.5: Results of the statistical matching procedures (BIOENV and DISTLM) used to determine any significant interannual relationships between the Whitebait densities (1996-2001, 2006-2013) or fish assemblage composition (2007-13) in the nearshore waters at Becher Point and a suite of environmental variables (see Table 2.4) for which no time lag, a one year lag and a two year lag had been introduced. Note that DISTLM analyses were only able to be carried out for the Whitebait data, and had to employ a reduced set of environmental variables (see Table 2.4). Significant results (P <0.05) are in bold, and include the subset of environmental variables responsible for the 'best' match.

		Predictor data (environmental data)					
		No lag		1 yr lag		2 yr lag	
		BIOENV	*DISTLM*	*BIOENV*	*DISTLM*	*BIOENV*	*DISTLM*
Response data (fish)	**Whitebait only**						
	Summer	P=0.59; ρ=0.322	P=0.065; R^2=0.267	P=0.32; ρ=0.428	P=0.064; R^2=0.26	P=0.69; ρ=0.322	P=0.149; R^2=0.173
	Autumn	P=0.76; ρ=0.328	P=0.115; R^2=0.209	P=0.64; ρ=0.381	P=0.156; R^2=0.159	P=0.51; ρ=0.444	**P=0.03; R^2=0.321** ***Total rainfall***
	Spring	P=0.95; ρ=0.247	**P=0.04; R^2=0.464** ***E <10 km/h; mean wave height***	P=0.34; ρ=0.468	**P=<0.05; R^2=0.539** ***E<10; E 20-30 km/h***	P=0.90; ρ=0.266	P=0.07; R^2=0.227
	Full fish assemblage						
	Summer	P=0.09; ρ=0.783	Insufficient samples	P=0.17; ρ=0.723	Insufficient samples	P=0.39; ρ=0.637	Insufficient samples
	Autumn	P=0.11; ρ=0.827	Insufficient samples	P=0.07; ρ=0.819	Insufficient samples	P=0.79; ρ=0.581	Insufficient samples
	Spring	P=0.71; ρ=0.631	Insufficient samples	P=0.95; ρ=0.484	Insufficient samples	P=0.74; ρ=0.601	Insufficient samples

Significant interannual matches were detected between Whitebait densities (in spring or autumn) and select environmental variables containing no time lag, a one year lag or a two year lag, but only when the regression-based DISTLM routine was used. The proportion of the interannual variability in Whitebait that was 'explained' by the selected variables was moderate (R^2=0.321-0.539), with the greatest detected for the relationship between spring Whitebait catches and local easterly winds (at speeds of both <10 and 20-30 km/h) after a one-year lag was introduced. The modelled (or 'fitted') interannual relationships between these response and predictor variables are illustrated by the dbRDA ordination plots in Fig. 3.6, in which dbRDA axis 1 (the 'y axis') captured 100% of the fitted variation in the underlying model in all cases. The above R^2 values are also provided on dbRDA axis 1. To aid interpretation of the plots, the magnitude of the selected environmental variables is also superimposed on each year as circles of proportionate sizes. Thus, years in which higher spring Whitebait catches were recorded (*e.g.* 1996, 1998, 2000, 2001; top right of the plots) typically had a greater number of days, both in the same year and the previous year, in which only light (<10 km/h) easterly winds were blowing (Figs 3.6a, c). The opposite was generally true for moderate to strong (20-30 km/h) easterly winds in the previous year, although the relationship was not as clear (Fig. 3.6d).

Higher spring Whitebait catches also showed a tendency to be associated with greater wave heights in the same year (Fig. 3.6b), although there were several instances where this relationship was inconsistent (*e.g.* relatively low catches were recorded in 2009, yet this year had a similarly high average wave height as in 2000 when the highest catches were recorded). Lastly, years in which greater autumn Whitebait densities were recorded (*e.g.* 1998, 2007; top right of the plot) were often correlated with higher rainfall in the previous two years (Fig. 3.6e).

No significant interannual matches were detected between the full fish assemblage from 2007-13 and any combination of environmental variables in any season or lag state (Table 3.5). Only BIOENV, however, could be used to explore these relationships (see subsection 2.2.2), and even then the lack of significant matches despite obtaining high correlation coefficient (ρ) values in several cases, is indicative of the comparative lack of statistical power (*i.e.* number of years) in these tests.

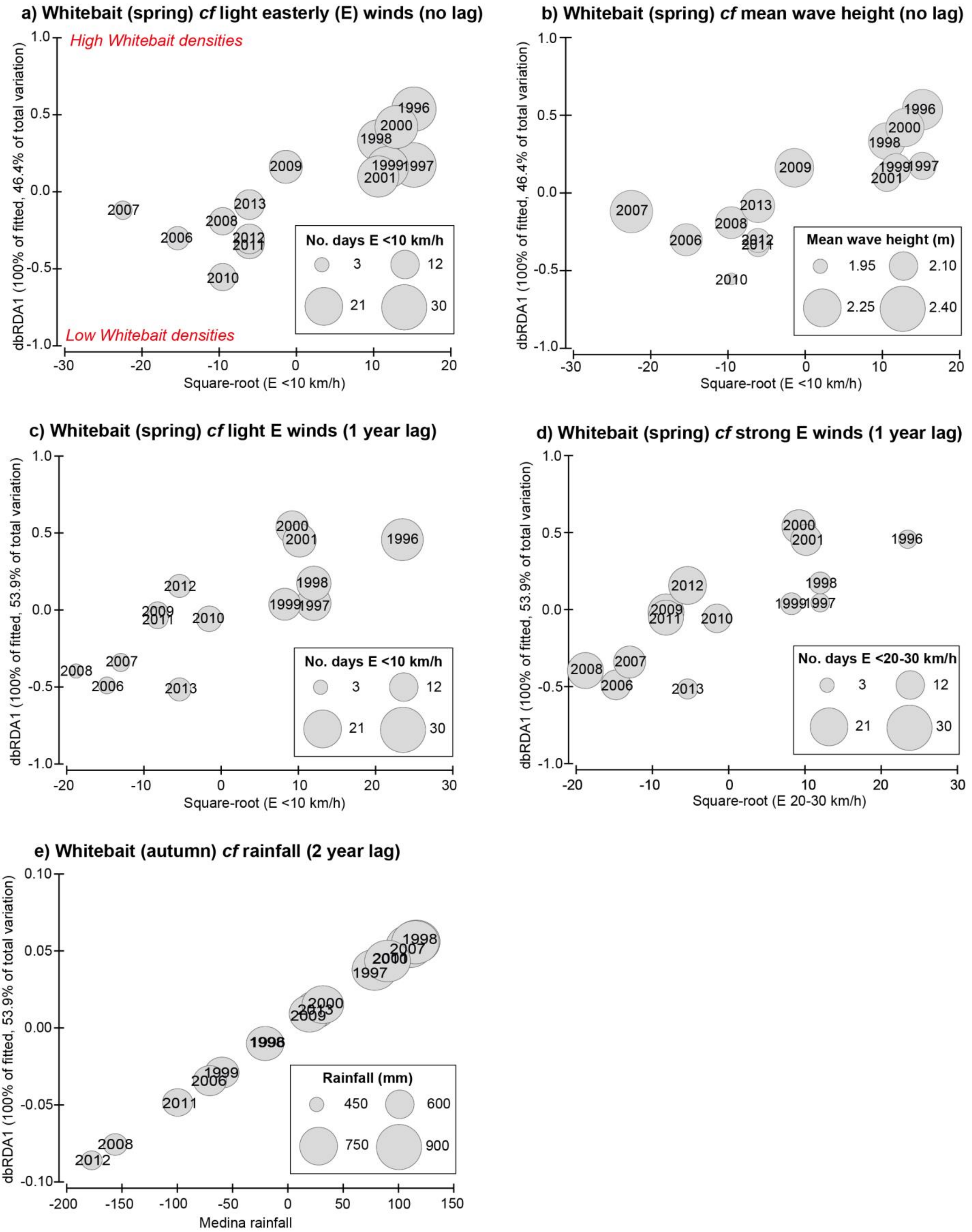


Fig. 3.6: dbRDA ordination plots depicting the DISTLM fitted models for significant interannual relationships between Whitebait densities recorded at Becher Point by DoF (in specified seasons) and selected environmental variables (in specified lag states). The (unpretreated) magnitudes of the selected environmental variables are also overlaid on each year as circles of proportionate sizes.

3.2 Objective 2: Interannual relationships between penguin biology and penguin prey and environmental variables

3.2.1 Interannual trends in penguin breeding performance and survival

Interannual trends in Little Penguin breeding performance (1986-2011) and survival (1986-2008) on Penguin Island are summarised in Fig. 3.7a and b, respectively.

The MDS ordination plot in Fig. 3.7a, which represented the interannual differences in the collective suite of six reproduction parameters, showed that the greatest differences occurred between years such as 1986, 1994, 1999 and 2011 towards the far left of the plot, and years such as 1991, 2006 and 2009 on the far right. The first group of years had the poorest breeding performance for multiple parameters (*e.g.* smallest proportion of eggs laid, smallest percentage of eggs that hatched or fledged, lowest fledging mass and/or smallest number of chicks per pair) while the second group had among the best. A gradational trend from poor to good breeding performance was thus evident moving from left to right across the plot.

Little Penguin survival was lowest in 1989, 1997 and 1998 (~60%) and highest in 2008, followed by 1986, 1987 and 2000 (~90-100%; Fig. 3.7b).

3.2.2 Interannual relationships between penguin biology and prey/environmental characteristics

Tables 3.6-3.8 provide the results of the BIOENV and DISTLM analyses used to explore any significant relationships between the above interannual trends in penguin biology and those in (i) the abundance of penguin prey (fish) species in both the nearshore waters at Becher Point (Table 3.6) and the commercial catches in the broader coastal region (Table 3.7), and (ii) a suite of environmental parameters (Table 3.8). Each of these relationships were explored separately following the inclusion of no time lag, a one year lag and a two year lag in the above fish and environmental data sets, and also for each sampling season for the nearshore fish data.

Note that, due to disparities in the years for which data were available across each of the above response (penguin reproduction and survival) and predictor (nearshore fish, commercial fish and environmental) data sets (see Table 2.1), the years able to be included in each of the correlation analyses often differed. The particular interannual sets employed in each case are given in the captions for Tables 3.6-3.8.

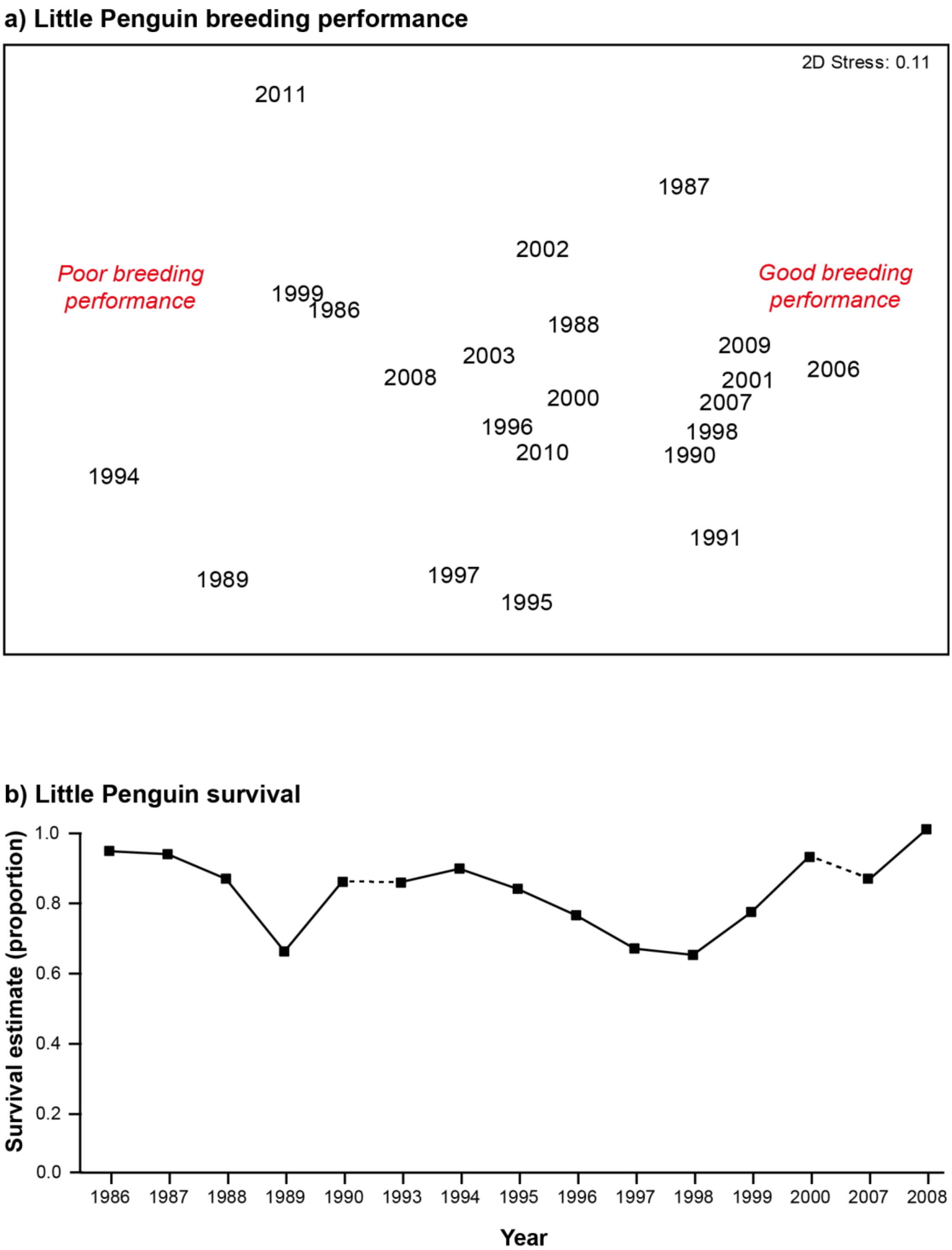


Fig. 3.7: (a) MDS ordination plot derived from the suite of Little Penguin breeding performance parameters recorded in each sampling year from 1986-2011; (b) Little Penguin survival estimates in each sampling year from 1986-2008, expressed as a proportion of the total number of penguins monitored in nestboxes on Penguin Island.

Table 3.6: Results of the statistical matching procedures (BIOENV and DISTLM) used to determine any significant interannual relationships between Little Penguin breeding performance and survival ('response data') and a suite of penguin prey species in the nearshore waters at Becher Point ('predictor data'; see Table 2.5). These relationships were explored periodically from 1996-2011 for breeding performance and 1996-2008 for survival (see Table 2.1 for further details). Significant results (*P*<0.05) are in bold, and include the subset of fish species responsible for the 'best' match.

			Response data (Penguin biology)	
			Breeding performance	**Survival**
Predictor data (Penguin prey species, nearshore waters)	Summer			
	No lag	*BIOENV*	P=0.19; ρ=0.326	P=0.32; ρ=0.314
		DISTLM	P=1; R^2=0	P=1; R^2=0
	1 yr lag	*BIOENV*	P=0.87; ρ= -0.007	P=0.65; ρ=0.05
		DISTLM	P=1; R^2=0	Insufficient samples
	2 yr lag	*BIOENV*	P=0.83; ρ=0.011	Insufficient samples
		DISTLM	P=1; R^2=0	Insufficient samples
	Autumn			
	No lag	*BIOENV*	P=0.07; ρ=0.397	P=0.66; ρ=0.100
		DISTLM	P=1; R^2=0	***P*=0.011; R^2=0.654 Blue Sprat**
	1 yr lag	*BIOENV*	P=0.55; ρ=0.114	P=0.38; ρ=0.416
		DISTLM	P=1; R^2=0	Insufficient samples
	2 yr lag	*BIOENV*	P=0.35; ρ=0.268	Insufficient samples
		DISTLM	P=1; R^2=0	Insufficient samples
	Spring			
	No lag	*BIOENV*	P=0.41; ρ=0.246	P=0.17; ρ=0.519
		DISTLM	P=0.450; R^2=0.07	***P*=0.015; R^2=0.708 *Southern Garfish***
	1 yr lag	*BIOENV*	P=0.91; ρ=-0.003	P=0.16; ρ=0.624
		DISTLM	P=0.267; R^2=0.124	Insufficient samples
	2 yr lag	*BIOENV*	P=0.46; ρ=0.261	Insufficient samples
		DISTLM	P=0.294; R^2=0.133	Insufficient samples

Table 3.7: Results of the statistical matching procedures (BIOENV and DISTLM) used to determine any significant interannual relationships between Little Penguin breeding performance and survival ('response data') and a suite of penguin prey species in the commercial catches of nearby waters ('predictor data'; see Table 2.5). These relationships were explored periodically from 1986-2011 for breeding performance and 1986-2008 for survival (see Table 2.1 for further details). Significant results (P<0.05) are in bold, and include the subset of fish species responsible for the 'best' match.

			Response data (Penguin biology)	
			Breeding performance	**Survival**
Predictor data (Penguin prey species, commercial catches)	No lag	*BIOENV*	P=0.81; ρ=0.072	P=0.68; ρ=0.100
		DISTLM	***P*=0.008; R²=0.185** ***Australian Anchovy***	P=0.07; R^2=0.237
	1 yr lag	*BIOENV*	P=0.27; ρ=0.177	P=0.23; ρ=0.268
		DISTLM	P=0.263; R^2=0.060	***P*=0.034; R²=0.312** ***Southern Garfish***
	2 yr lag	*BIOENV*	P=0.80; ρ=0.065	P=0.35; ρ=0.209
		DISTLM	P=0.300; R^2=0.056	***P*<0.028; R²=0.579** ***Australian Anchovy, Southern Garfish***

Table 3.8: Results of the statistical matching procedures (BIOENV and DISTLM) used to determine any significant interannual relationships between Little Penguin breeding performance and survival ('response data') and a suite of environmental variables ('predictor data'; see Table 2.5). These relationships were explored periodically from 1988-2011 for breeding performance and 1988-2008 for survival (see Table 2.1 for further details). Note that all DISTLM analyses necessarily used a reduced environmental data set (Table 2.6) and those involving survival were undertaken in two separate runs (see subsection 2.3.2). Significant results (P <0.05) are in bold, and include the subset of environmental variables responsible for the 'best' match.

			Response data (Penguin biology)	
			Breeding performance	**Survival**
Predictor data (Environmental data)	No lag	*BIOENV*	***P*=0.02; ρ=0.529** ***Reynolds WS SST-April; Reynolds SST-Jun; E <10; W <10; W 20-30 km/h***	P=0.77; ρ=0.315
		DISTLM	***P*=<0.05; R²=0.376** ***Reynolds WS SST-Autumn; S <10 km/h***	***P*<0.05; R²=0.509-0.651** ***Days >33°C; W <10 km/h; S 20-30; N 20-30 km/h***
	1 yr lag	*BIOENV*	P=0.60; ρ=0.306	P=0.31; ρ=0.494
		DISTLM	***P*=<0.05; R²=0.298** ***Reynolds WS SST-Autumn; Reynolds WS SST-Winter***	P=0.054-0.07; R^2=0.327-0.329

			Response data (Penguin biology)	
			Breeding performance	**Survival**
	2 yr lag	*BIOENV*	P=0.37; ρ=0.386	**P=0.01; ρ=0.768** ***N 20-30; E <10; SW <10 km/h; Reynolds WS SST-April***
		DISTLM	**P=0.04; R^2=0.161** ***Reynolds SST-Winter***	**P=0.024; R^2=0.650** ***E <10 km/h; Rainfall (May-Aug)***

Very few significant interannual relationships were detected between either of the penguin biological attributes and the abundance of penguin prey species in the nearshore waters at Becher Point (Table 3.6). The only exceptions were for penguin survival and the abundances, in the same year, of Blue Sprat (in autumn) and Southern Garfish (in spring), for which DISTLM detected a significant (P<0.015) and high correlation (R^2=0.654-0.708).

These significant relationships are illustrated by the dbRDA ordination plots in Fig. 3.8, in which dbRDA axis 1 again captured 100% of the fitted model variation in all cases, and the proportion of total variation in the response data ‘explained’ by that axis (*i.e.* the R^2 value) is also given. Years in which penguin survival was high (*e.g.* 2008) were linked with comparatively large average Blue Sprat abundances (945 fish), while those in which survival was low (*e.g.* 1997 and 1998) had very small or no catches of this baitfish species (Fig. 3.8a). The opposite was true, however, for Southern Garfish, although it is noteworthy that even the largest average catches of this species in spring were very small (<1 fish; Fig. 3.8b).

Correlations between the penguin biological attributes and the abundance of prey species in commercial fish catches also revealed few significant results (Table 3.7). DISTLM detected weak interannual relationships between penguin breeding performance and the abundance of Australian Anchovy in the same year which, as illustrated by the dbRDA ordination plot in Fig. 3.8f, typically reflected an inverse relationship, with years in which reproduction was poor (*e.g.* 1994; bottom right) being associated with the highest Australian Anchovy catches. However, some years in which breeding performance was relatively good (*e.g.* 1987) also had relatively high Australian Anchovy catches, demonstrating the imperfect nature of the modelled relationship resulting from unexplained variability. DISTLM also detected moderate correlations between penguin survival and (i) Southern Garfish abundance when a one year lag was introduced, and (ii) Australian Anchovy and Southern Garfish abundances when a two year lag was imposed (Table 3.7). Each of these correlations was also shown by dbRDA to

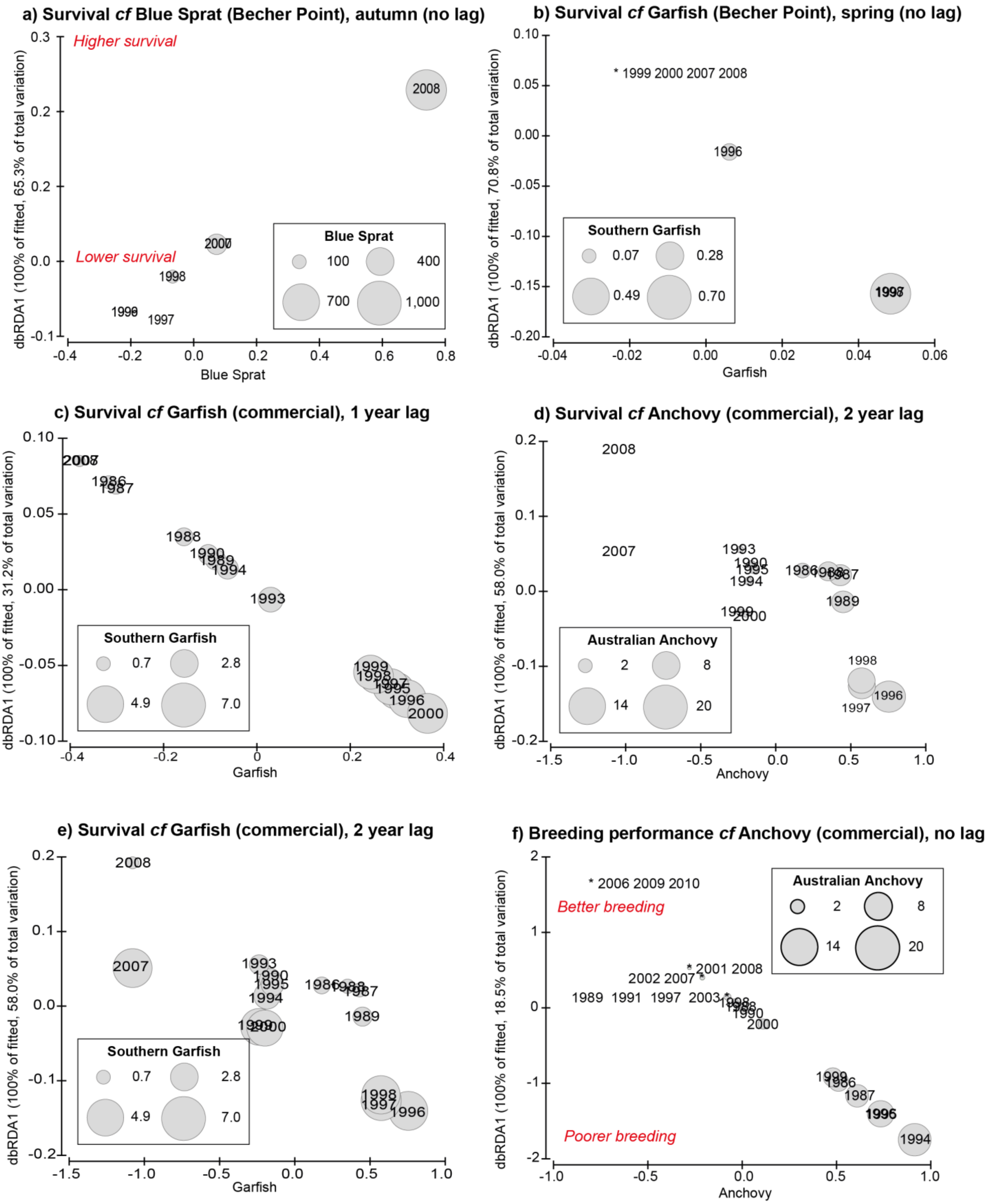


Fig. 3.8: dbRDA ordination plots depicting the DISTLM fitted models for significant interannual relationships between Little Penguin survival (a-e) or breeding performance (f) and abundances of select penguin prey species in the nearshore waters at Becher Point or in commercial fish catches (in specified seasons and/or lag states). The (unpretreated) magnitudes of the selected prey species are also overlaid on each year as circles of proportionate sizes. * denote years with the same value, but that have had their labels spaced out for clarity.

generally reflect an inverse relationship (Fig. 3.8c, d and e, respectively), but again there were several cases in which the modelled relationships were not consistent. In Fig. 3.8c for example, despite the relatively high survival in 2000, this year was fitted at the bottom right of the plot next to 1995, 1996 and 1997 in which survival was relatively low, and all of these years had higher Southern Garfish catches.

Lastly, significant correlations were commonly detected between interannual trends in penguin biology and those in various environmental characteristics (Table 3.8). DISTLM identified significant relationships between penguin breeding performance and select environmental variables, which explained a moderate amount of interannual variability in the former data when no time lag was imposed on the latter (R^2=0.376), and a small amount when one-two year lags were introduced (R^2=0.161-0.298). BIOENV also detected significant and moderate matches (ρ=0.529) between breeding performance and subsets of environmental variables, but only when no time lag was included. In all of the above cases, sea surface temperatures in April (or autumn) and/or June (or winter) were always among the variables selected, with the remainder including various local wind variables (Table 3.8). Accompanying ordination plots illustrating each of these significant relationships are provided in Appendix 3.

In general, better breeding performance (*e.g.* that in 1991, 2001, 2006 and 2009) was clearly associated with lower April (or autumn) water temperatures in Warnbro Sound during the same year, while the opposite was true for poorer breeding performance (*e.g.* that in 1989, 1994, 1999 and 2011; *e.g.* Appendix 3a, f). When a one-year lag was introduced, however, better breeding performance tended to be linked with higher autumn water temperatures in Warnbro Sound (Appendix 3h), although this relationship was less obvious than when no lag was imposed. Interannual trends between penguin reproduction and June (or winter) water temperatures (either in Warnbro Sound or the broader 32-33°S region, and irrespective of lag state) were also not as clear, but 1994, in which breeding performance was amongst the poorest recorded, also had by far the lowest June temperatures (Appendix 3b). The dbRDA plot in Appendix 3j also suggests a positive relationship between breeding performance and winter water temperatures in the previous two years, though there were several inconsistencies (*e.g.* 2006, which had among the best reproductive success, was linked with a lower mean winter temperature). Most of the selected wind variables also tended to reflect more localised rather than holistic interannual trends in penguin reproduction, although better breeding performance was often associated with more frequent moderate to strong westerly winds in the same year (Appendix 3e).

DISTLM detected significant and moderate interannual relationships between penguin survival and particular subsets of environmental variables when either no time lag or a two year lag was imposed on the latter data (R^2=0.509-0.650). BIOENV further demonstrated significant and high interannual correlations between penguin survival and select environmental variables following the inclusion of a two year lag (ρ=0.768). Local wind variables were amongst those selected in all of the above cases, while air temperature, sea surface temperature in Warnbro Sound and rainfall were also implicated (Table 3.8).

The MDS or dbRDA ordination plots depicting the interannual relationships between penguin survival and the selected predictor variables are provided in Appendix 4. A relatively clear inverse relationship was apparent between survival and the number of days exceeding 33 °C (over December-January) in the same year (Appendix 4a). A clear but positive relationship was also detected between survival and the frequency of moderate to strong southerly winds in the same year (Appendix 4c). Thus, several of the years in which survival was the lowest formed a distinct group that had no days under these wind conditions, in contrast to all other years and especially 2008 when survival was highest. While not as marked, a similar relationship was also demonstrated for moderate to strong northerly winds in the same year (Appendix 4d). Higher survival also tended to be associated with a range of environmental conditions in the previous two years, including less frequent light easterly winds (Appendix 4f, i), more frequent light south-westerly winds (Appendix 4g) and lower Warnbro Sound sea surface temperatures in April (Appendix 4h).

3.3 Objective 3: Impact of the boat ramp on Whitebait abundance and the broader fish community at Becher Point

3.3.1 Spatial and temporal trends in Whitebait density and fish faunal characteristics around the Becher Point boat ramp from 2011-13

A total of 31,517 fish representing 57 species were recorded at the five nearshore sites sampled around Becher Point, including near the boat ramp, from 2011-13 during the current study (Table 3.9). Five species, namely Whitebait, Southern School Whiting, Blue Sprat, Sandfish and the Common Hardyhead were relatively abundant (*i.e.* each represented >5% of the catch), and together comprised ~81% of all fish caught. While these species were always amongst the most abundant in each year, their mean densities and percentage contributions differed substantially between years. For example, the mean densities of Whitebait increased progressively from 5.4-30.1 fish 100 m^{-2} from 2011-13, and those of Blue Sprat increased from <5-54 fish 100 m^{-2} over the same period (Table 3.9). These two species were largely responsible for the notably higher overall mean densities in 2013 than either of the previous two years. In contrast, the mean densities of Sandfish remained relatively constant across all years (*i.e.* ~3-5 fish 100 m^{-2}) and, although it did not occur in high numbers, this resident species was by far the most consistently-occurring, and was present in ~76-79% of samples in each year (Table 3.10). Southern School Whiting, Whitebait and Blowfish were also recorded consistently in all or most years, occurring in 20-42.5% of samples (Table 3.10).

Table 3.9: Mean densities (M; number of fish 100m^{-2}) and percentage contributions to the total catch (%) of the fish species recorded around the Becher Point area between August and January in 2011, 2012 and 2013. Abundant species (*i.e.* those representing ≥5% of the total catch in any or all years) are highlighted in grey.

		Total		2011		2012		2013	
Species name	**Common name**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**
Hyperlophus vittatus	Whitebait	19.03	25.21	5.44	10.81	16.36	39.42	30.06	26.54
Sillago bassensis	Southern School Whiting	17.01	22.53	19.85	39.47	7.63	18.38	7.71	6.81
Spratelloides robustus	Blue Sprat	15.42	20.43	4.78	9.51	3.27	7.87	54.07	47.74
Lesueurina platycephala	Sandfish	5.34	7.07	5.09	10.11	2.67	6.44	4.65	4.10
Atherinomorus vaigiensis	Common Hardyhead	4.08	5.40	4.00	7.96	1.28	3.08	5.59	4.93
Torquigener pleurogramma	Blowfish	3.59	4.76	0.87	1.73	4.76	11.47	0.96	0.84
Sillaginidae sp.	Whiting	1.85	2.45	1.86	3.70	0.27	0.66	3.37	2.97
Aldrichetta forsteri	Yelloweye Mullet	1.67	2.21	0.98	1.96	1.10	2.65	2.28	2.02
Sillago vittata	Western School Whiting	1.10	1.46	1.26	2.51	0.47	1.14	0.63	0.56
Sillago burrus	Western Trumpeter Whiting	0.97	1.29	1.74	3.46	0.04	0.10		
Craterocephalus mugiloides	Spotted Hardyhead	0.76	1.01	1.18	2.34			0.63	0.55
Sillago schomburgkii	Yellowfin Whiting	0.73	0.97	0.17	0.34	0.51	1.23	1.62	1.43
Gerres subfasciatus	Common Silverbiddy	0.62	0.82	0.09	0.17	0.77	1.85	0.49	0.43
Pelsartia humeralis	Sea Trumpeter	0.61	0.80	0.73	1.46	0.27	0.66	0.21	0.18
Pelates octolineatus	Western Striped Grunter	0.40	0.53	0.04	0.07	0.60	1.45	0.06	0.05
Enoplosus armatus	Old Wife	0.29	0.39	0.11	0.23	0.37	0.88	0.01	0.01
Gymnapistes marmoratus	Soldier	0.20	0.26	0.37	0.73				
Haletta semifasciata	Blue Weed Whiting	0.19	0.25	0.32	0.64	0.01	0.02	0.03	0.03
Paraplagusia bilineata	Lemon Tongue Sole	0.18	0.24	0.07	0.14	0.17	0.42	0.17	0.15
Rhabdosargus sarba	Tarwhine	0.15	0.20	0.25	0.50	0.02	0.05	0.01	0.01
Cnidoglanis macrocephalus	Cobbler	0.15	0.20	0.23	0.46	0.03	0.07	0.04	0.03
Ammotretis rostratus	Longsnout Flounder	0.14	0.19	0.12	0.24	0.11	0.26	0.04	0.03
Ammotretis elongatus	Elongate Flounder	0.11	0.14			0.17	0.42	0.01	0.01
Platycephalus speculator	Southern Bluespotted Flathead	0.10	0.14	0.03	0.06	0.13	0.31	0.04	0.04
Leptatherina presbyteroides	Silverfish	0.09	0.12	0.04	0.09	0.11	0.26		
Ostorhinchus rueppellii	Gobbleguts	0.08	0.11	0.15	0.30				
Contusus brevicaudus	Prickly Toadfish	0.08	0.11	0.04	0.09	0.09	0.22		
Neoodax balteatus	Little Weed Whiting	0.07	0.09	0.11	0.23	0.01	0.02		
Pempheris analis	Bronze Bullseye	0.06	0.08					0.32	0.28
Fistularia commersonii	Bluespotted Cornetfish	0.06	0.08	0.11	0.23				
Pentapodus vitta	Western Butterfish	0.06	0.07			0.08	0.19	0.04	0.03
Etrumeus teres	Maray	0.04	0.06			0.07	0.17		
Cristiceps australis	Crested Weedfish	0.04	0.06	0.06	0.11	0.01	0.03	0.01	0.01
Monacanthidae sp.	Leatherjacket	0.02	0.03	0.04	0.09				
Acanthaluteres brownii	Spinytail Leatherjacke	0.02	0.03	0.01	0.01	0.02	0.05	0.01	0.01
Pugnaso curtirostris	Pug-nosed pipefish	0.02	0.02			0.02	0.05	0.02	0.02
Monacanthus chinensis	Fanbelly Leatherjacket	0.02	0.02	0.03	0.06				
Repomucenus calcaratus	Spotted Dragonet	0.02	0.02	0.03	0.06				
Pempheris klunzingeri	Rough Bullseye	0.01	0.02					0.07	0.06
Arripis georgianus	Australian Herring	0.01	0.02	0.01	0.03	0.01	0.02	0.01	0.01
Pseudorhombus jenynsii	Small-tooth Flounder	0.01	0.02	0.01	0.03	0.01	0.02		
Pseudocalliurichthys goodladi	Longspine Dragonet	0.01	0.02			0.01	0.03	0.01	0.01
Engraulis australis	Australian Anchovy	0.01	0.01			0.01	0.03	0.01	0.01
Hyporhamphus melanochir	Southern Garfish	0.01	0.01					0.05	0.04
Histiogamphelus cristatus	Rhino Pipefish	0.01	0.01	0.01	0.01	0.01	0.02		
Mugil cephalus	Sea Mullet	0.01	0.01			0.01	0.02	0.01	0.01
Scobinichthys granulatus	Rough Leatherjacket	<0.01	0.01			0.01	0.02		
Scorpis georgiana	Banded Sweep	<0.01	0.01			0.01	0.02		
Acanthopagrus butcheri	Black Bream	<0.01	0.01	0.01	0.01				
Epinephelides armatus	Breaksea Cod	<0.01	0.01	0.01	0.01				
Myliobatis australis	Southern Eagle Ray	<0.01	0.01	0.01	0.01				
Schuettea woodwardi	Western Pomfred	<0.01	0.01	0.01	0.01				
Dasyatis brevicaudata	Smooth Stingray	<0.01	<0.01					0.01	0.01
Platycephalus laevigatus	Rock Flathead	<0.01	<0.01					0.01	0.01
Pseudocaranx dentex	Silver Trevally	<0.01	<0.01					0.01	0.01
Siphonognathus attenuatus	Slender Weed Whiting	<0.01	<0.01					0.01	0.01
Upeneichthys vlamingii	Bluespotted Goatfish	<0.01	<0.01					0.01	0.01
Number of species		**57**		**40**		**38**		**38**	
Overall mean density		**76**		**50**		**41**		**113**	

Table 3.10: Number of samples in which each fish species collected around the Becher Point area between August and January 2011-13 was recorded (#) and percentage frequency of occurrence (%). Consistently recorded species (*i.e.* those in ≥20% of samples) are highlighted in grey.

		Total		2011		2012		2013	
Species name	**Common name**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Lesueurina platycephala	Sandfish	281	78.06	91	75.83	95	79.17	95	79.17
Sillago bassensis	Southern School Whiting	133	36.94	36	30.00	51	42.50	46	38.33
Hyperlophus vittatus	Whitebait	85	23.61	31	25.83	22	18.33	32	26.67
Torquigener pleurogramma	Blowfish	78	21.67	26	21.67	24	20.00	28	23.33
Gerres subfasciatus	Common Silverbiddy	62	17.22	8	6.67	31	25.83	23	19.17
Spratelloides robustus	Blue Sprat	48	13.33	5	4.17	14	11.67	29	24.17
Aldrichetta forsteri	Yelloweye Mullet	46	12.78	8	6.67	16	13.33	22	18.33
Sillago vittata	Western School Whiting	44	12.22	13	10.83	17	14.17	14	11.67
Paraplagusia bilineata	Lemon Tongue Sole	39	10.83	9	7.50	17	14.17	13	10.83
Atherinomorus vaigiensis	Common Hardyhead	38	10.56	12	10.00	10	8.33	16	13.33
Ammotretis rostratus	Longsnout Flounder	32	8.89	14	11.67	14	11.67	4	3.33
Sillago schomburgkii	Yellowfin Whiting	31	8.61	13	10.83	17	14.17	1	0.83
Platycephalus speculator	Southern Bluespotted Flathead	22	6.11	4	3.33	15	12.50	3	2.50
Pelsartia humeralis	Sea Trumpeter	20	5.56	9	7.50	2	1.67	9	7.50
Pelates octolineatus	Western Striped Grunter	17	4.72	3	2.50	11	9.17	3	2.50
Sillago burrus	Western Trumpeter Whiting	15	4.17	14	11.67	1	0.83		
Ammotretis elongatus	Elongate Flounder	10	2.78			9	7.50	1	0.83
Cnidoglanis macrocephalus	Cobbler	10	2.78	5	4.17	1	0.83	4	3.33
Contusus brevicaudus	Prickly Toadfish	10	2.78	2	1.67	8	6.67		
Enoplosus armatus	Old Wife	10	2.78	5	4.17	3	2.50	2	1.67
Haletta semifasciata	Blue Weed Whiting	8	2.22	6	5.00	1	0.83	1	0.83
Rhabdosargus sarba	Tarwhine	8	2.22	4	3.33	3	2.50	1	0.83
Craterocephalus mugiloides	Spotted Hardyhead	7	1.94	1	0.83			6	5.00
Pentapodus vitta	Western Butterfish	7	1.94			5	4.17	2	1.67
Acanthaluteres brownii	Spinytail Leatherjacke	6	1.67	1	0.83	3	2.50	2	1.67
Cristiceps australis	Crested Weedfish	6	1.67	3	2.50	2	1.67	1	0.83
Gymnapistes marmoratus	Soldier	6	1.67	6	5.00				
Pugnaso curtirostris	Pug-nosed pipefish	6	1.67			3	2.50	3	2.50
Neoodax balteatus	Little Weed Whiting	5	1.39	4	3.33	1	0.83		
Sillaginidae	Whiting	4	1.11	1	0.83	1	0.83	2	1.67
Arripis georgianus	Australian Herring	3	0.83	1	0.83	1	0.83	1	0.83
Leptatherina presbyteroides	Silverfish	3	0.83	2	1.67	1	0.83		
Mugil cephalus	Sea Mullet	3	0.83			1	0.83	2	1.67
Ostorhinchus rueppellii	Gobbleguts	3	0.83	3	2.50				
Pseudocalliurichthys goodladi	Longspine Dragonet	3	0.83			2	1.67	1	0.83
Pseudorhombus jenynsii	Small-tooth Flounder	3	0.83	2	1.67	1	0.83		
Repomucenus calcaratus	Spotted Dragonet	3	0.83	3	2.50				
Engraulis australis	Australian Anchovy	2	0.56			1	0.83	1	0.83
Histiogamphelus cristatus	Rhino Pipefish	2	0.56	1	0.83	1	0.83		
Hyporhamphus melanochir	Southern Garfish	2	0.56					2	1.67
Monacanthidae	Leatherjacket	2	0.56	2	1.67				
Pempheris analis	Bronze Bullseye	2	0.56					2	1.67
Pempheris klunzingeri	Rough Bullseye	2	0.56					2	1.67
Acanthopagrus butcheri	Black Bream	1	0.28	1	0.83				
Dasyatis brevicaudata	Smooth Stingray	1	0.28					1	0.83
Epinephelides armatus	Breaksea Cod	1	0.28	1	0.83				
Etrumeus teres	Maray	1	0.28			1	0.83		
Fistularia commersonii	Bluespotted Cornetfish	1	0.28	1	0.83				
Monacanthus chinensis	Fanbelly Leatherjacket	1	0.28	1	0.83				
Myliobatis australis	Southern Eagle Ray	1	0.28	1	0.83				
Platycephalus laevigatus	Rock Flathead	1	0.28					1	0.83
Pseudocaranx dentex	Silver Trevally	1	0.28					1	0.83
Schuettea woodwardi	Western Pomfred	1	0.28	1	0.83				
Scobinichthys granulatus	Rough Leatherjacket	1	0.28			1	0.83		
Scorpis georgiana	Banded Sweep	1	0.28			1	0.83		
Siphonognathus attenuatus	Slender Weed Whiting	1	0.28					1	0.83
Upeneichthys vlamingii	Bluespotted Goatfish	1	0.28					1	0.83

Three-way crossed ANOVA showed that the mean density of Whitebait differed significantly among months and all interaction terms except month*site (Table 3.11). A plot of the (back-transformed) marginal mean values for each site, month and year showed that Whitebait densities were low (< 4 fish 100 m^{-2}) throughout all sampling months in 2011, but were notably higher for select sites and months in 2012 and 2013 (Fig. 3.9). The largest catch was recorded at Becher Point in October 2012 (~51 fish 100 m^{-2}), followed by those at Boat Ramp North and Comet Bay in October and September 2013, respectively (38 and 23 fish 100 m^{-2}). The lack of a consistent trend in Whitebait density among sites, months and years, however, is reflected by the significant interaction among all of these factors.

Table 3.11: Three-way ANOVA of the mean density of Whitebait in samples collected from five sites in the nearshore waters at Becher Point in August-January 2011-13. df = degrees of freedom; MS=mean square. Significant differences (*P* <0.05) are in bold.

	df	MS	F	*P*
Year	2	0.84	0.62	0.527
Month	5	**4.81**	**3.56**	**0.005**
Site	4	1.92	1.42	0.231
Year*Month	10	**3.50**	**2.59**	**0.009**
Year*Site	8	**2.28**	**1.69**	**0.080**
Month*Site	20	2.00	1.48	0.076
Year*Month*Site	40	**3.68**	**2.73**	**0.001**
Residual	270	1.35		

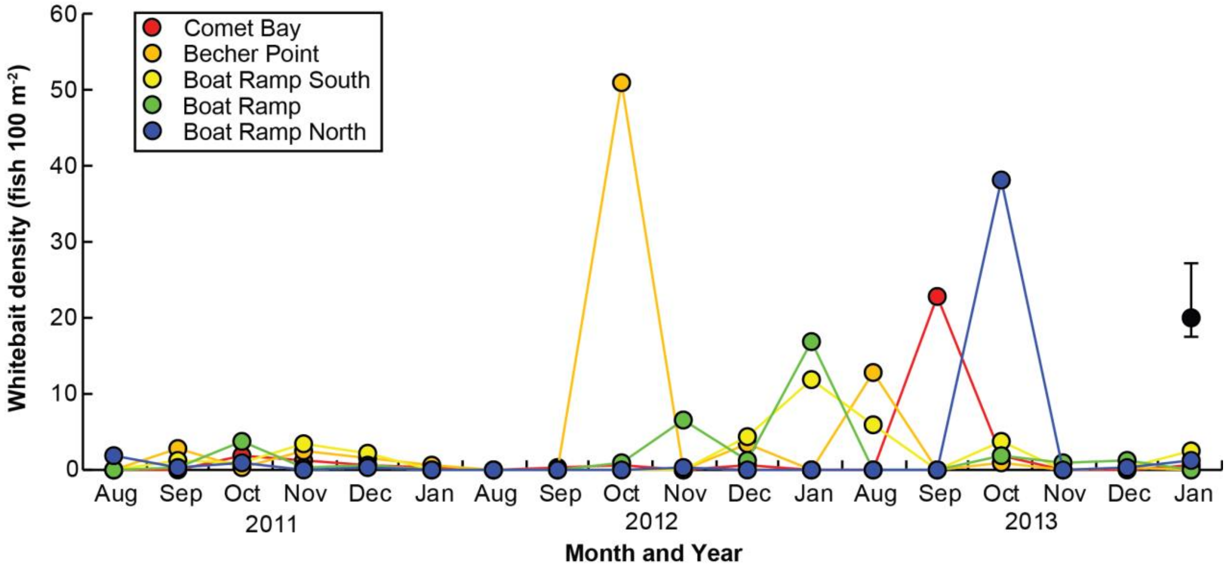


Fig. 3.9: Marginal mean densities of Whitebait (back-transformed) in samples collected from five sites in the nearshore waters around Becher Point between August and January 2011-13. For clarity, the average ± 95% confidence intervals have been presented.

The mean number of fish species and density of fish recorded in the Becher Point region differed significantly among all model terms in the three-way ANOVA, except for the month main effect and the month*site interaction, respectively (Table 3.12). In general, the marginal mean number of species tended to increase from a minima in August (0.8-2 species) to a maxima in November/December (up to 7) before falling again in January (Fig. 3.10a). Becher Point was usually amongst the most speciose of sites, and Boat Ramp North was often among the least speciose. However, changes in the rank orders of sites among months and years led to several of the significant interactions detected for this dependent variable (Fig. 3.10a).

The mean density of fish was notably lower in 2011 and 2012 (always <100 fish 100 m^{-2}) than in 2013, where it exceeded 100 fish 100 m^{-2} at several sites in the later part of the year, reaching a maxima of ~290 fish 100 m^{-2} at Boat Ramp North in October (Fig. 3.10b). Notably high values were also recorded at the Boat Ramp, Boat Ramp South and Comet Bay in December 2013 or January 2014. The substantial inconsistency in density trends among sites, months and years, however, reflects the numerous interactions detected for this variable (Fig. 3.10b).

Table 3.12: Three-way ANOVA of the mean number of species and density of fish in samples collected from five nearshore sites at Becher Point in August-January 2011-13. df = degrees of freedom; MS = mean square. Significant differences (P < 0.05) are in bold.

		Mean number of species			**Mean density**		
	df	**MS**	**F**	***P***	**MS**	**F**	***P***
Year	2	0.42	2.34	0.103	**7.91**	**5.18**	**0.007**
Month	5	**7.69**	**42.79**	**0.001**	**27.14**	**17.75**	**0.001**
Site	4	**0.66**	**3.66**	**0.007**	**4.14**	**2.71**	**0.039**
Year*Month	10	**1.17**	**6.50**	**0.001**	**4.76**	**3.12**	**0.001**
Year*Site	8	**0.55**	**3.04**	**0.007**	**3.23**	**2.11**	**0.041**
Month*Site	20	**0.41**	**2.29**	**0.005**	1.36	0.89	0.609
Year*Month*Site	40	**0.31**	**1.72**	**0.008**	**3.69**	**2.42**	**0.001**
Residual	270	0.18			1.53		

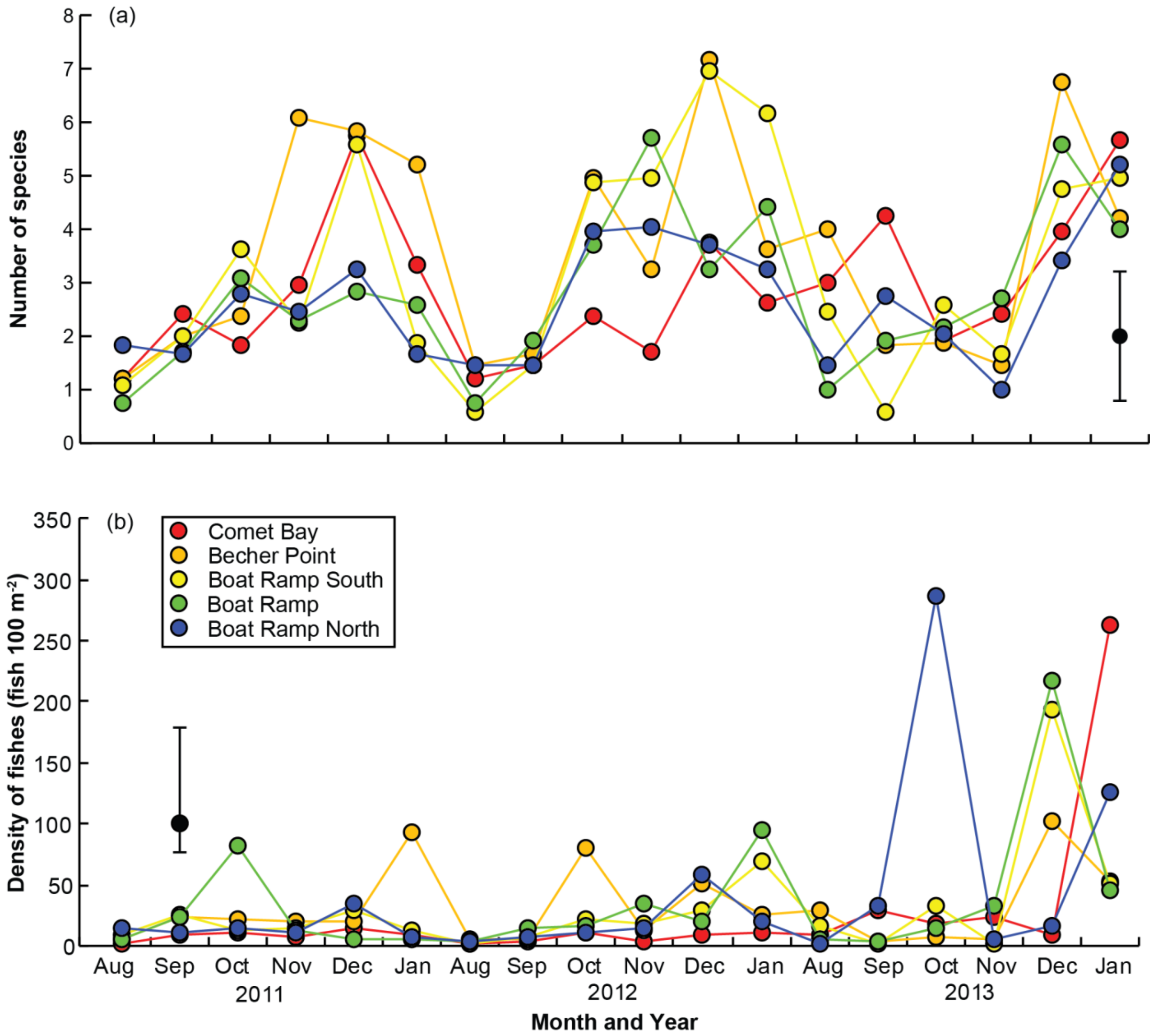


Fig. 3.10: Back-transformed marginal mean values of the (a) number of fish species and (b) density of fish (individuals 100 m^{-2}) in samples collected from five sites in the nearshore waters around Becher Point between August and January 2011-13. For clarity, the average ± 95% confidence intervals have been presented.

3.3.2 Spatial and temporal trends in the nearshore fish faunal composition around the Becher Point boat ramp from 2011-13

Three-way PERMANOVA showed that the species composition of the broader fish assemblage at Becher Point from 2011-13 differed significantly among years, months and sites and all interactions between these factors (Table 3.13). The components of variation values showed, however, that the three-way interaction exerted the greatest influence (Table 3.13). Given this, further investigations of fish assemblage trends using ANOSIM were undertaken within individual strata of select factors to investigate the influence of the remaining factor(s). Further detail on the particular tests used in each case is given below.

Table 3.13: Three-way PERMANOVA on the fish species composition in samples collected at five nearshore sites at Becher Point in August-January 2011-13. df = degrees of freedom; MS=mean square; COV=components of variation. Significant differences (P < 0.05) are in bold.

	df	MS	Pseudo-*F*	*P*	COV
Year	2	**5410**	**5.05**	**0.001**	**36.15**
Month	5	**11347**	**10.59**	**0.001**	**171.25**
Site	4	**4927**	**4.60**	**0.001**	**53.54**
Year*Month	10	**4374**	**4.08**	**0.001**	**165.11**
Year*Site	8	**2457**	**2.29**	**0.001**	**57.71**
Month*Site	20	**1980**	**1.85**	**0.001**	**75.67**
Year*Month*Site	40	**1804**	**1.68**	**0.001**	**183.06**
Residual	270	1072			1071.8

Firstly, spatial (site) differences in fish faunal composition were explored, within each month, by subjecting the data to a two-way crossed site x year ANOSIM test and focussing on the site component. Significant site differences were detected in each of the six months (P=0.001-0.002), but the overall extent of those differences was low to moderate (Global R=0.118-0.328), with the greatest occurring in December (Appendix 5). In each month, the greatest pairwise site differences always involved Comet Bay, indicating that the fish fauna at this site was comparatively distinct. This was particularly pronounced in December, where moderately high R statistic values were recorded for comparisons between Comet Bay and all other sites (R=0.552-0.628) except Boat Ramp North (R=0.368; Appendix 5e). In contrast, the fish composition at the Boat Ramp often did not differ significantly from those at most other sites (see grey highlighted values in Appendix 5).

The above trends are illustrated on the MDS ordination plots in Fig. 3.11, where at least two of the samples representing Comet Bay tended to lay towards one side of the plot in several months (*e.g.* Fig. 3.11a, c, e and f). In contrast, samples representing most other sites were widely dispersed and/or intermingled, reflecting the low and/or insignificant differences in their fish faunal compositions. The shade plot in Fig. 3.12 showed that the comparative distinctness of the Comet Bay fish faunas was due to the greater prevalence of select species in each month, such as the Blowfish in August and September, Solider *Gymnapistes marmoratus*, Tarwhine *Rhabdosargus sarba* and Whitebait in September, and the Lemon Tongue Sole

Paraplagusia bilineata in all months except November (Fig. 3.12). The fish fauna during December at this site contained particularly high and consistent catches of the latter species, in addition to greater catches of another flatfish, the Longsnout Flounder *Ammotretis rostratus*, and the bottom-dwelling Sandfish *L. platycephala*. The similarities in the fish faunas at the remaining sites reflected the fact that they were all largely dominated by Sandfish in all months, and shared similar abundances of several other characteristic species in one or more months, *e.g.* Yelloweye Mullet *A. forsteri* (October), Western School Whiting *S. vittata* (December and January), Common Silverbiddy *Gerres subfasciatus* and Southern School Whiting *S. bassensis* (October-January; Fig. 3.12).

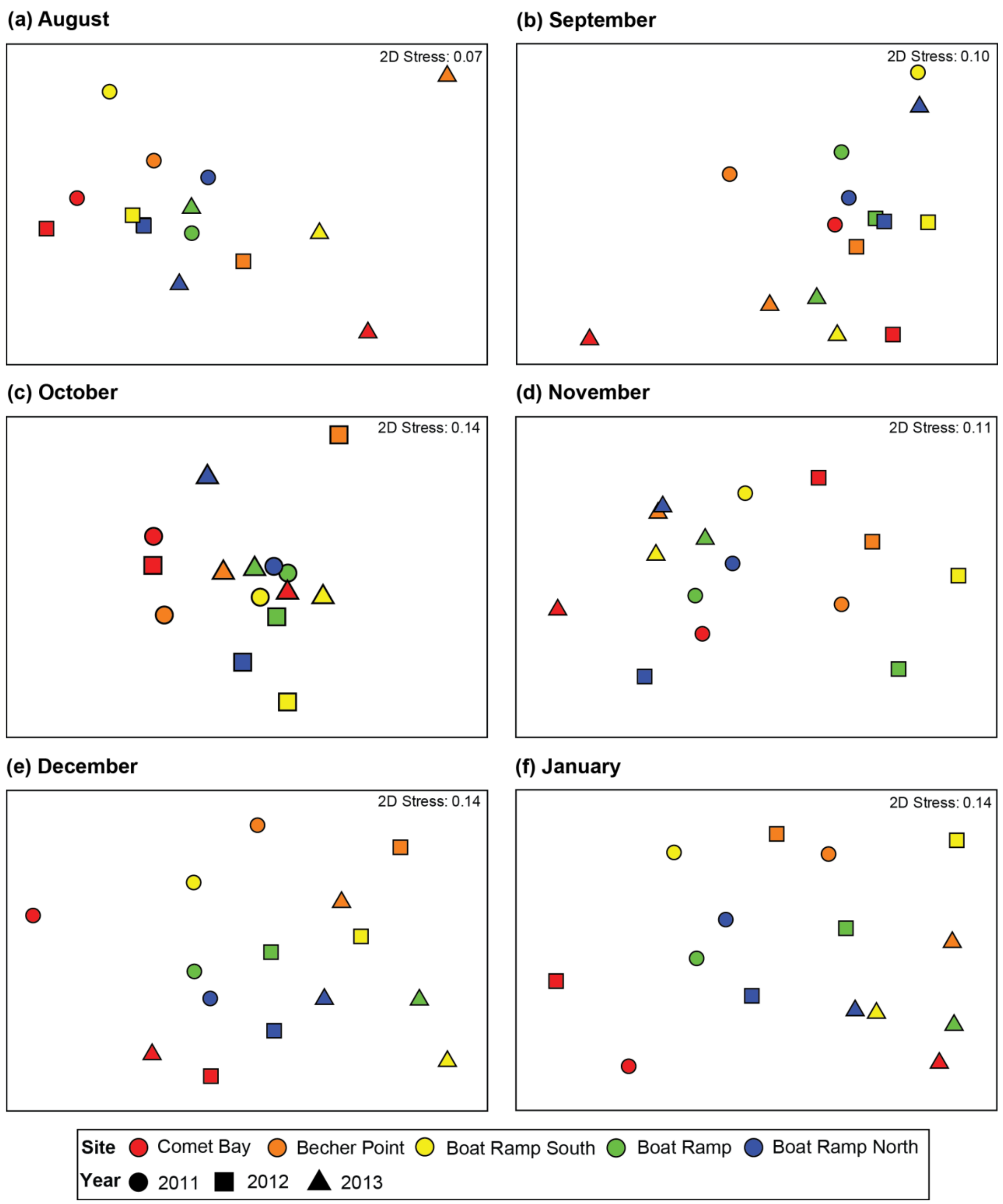


Fig. 3.11: MDS ordination plots derived from the average fish species composition data recorded at nearshore sites around Becher Point in 2011-13, undertaken separately for each sampling month.

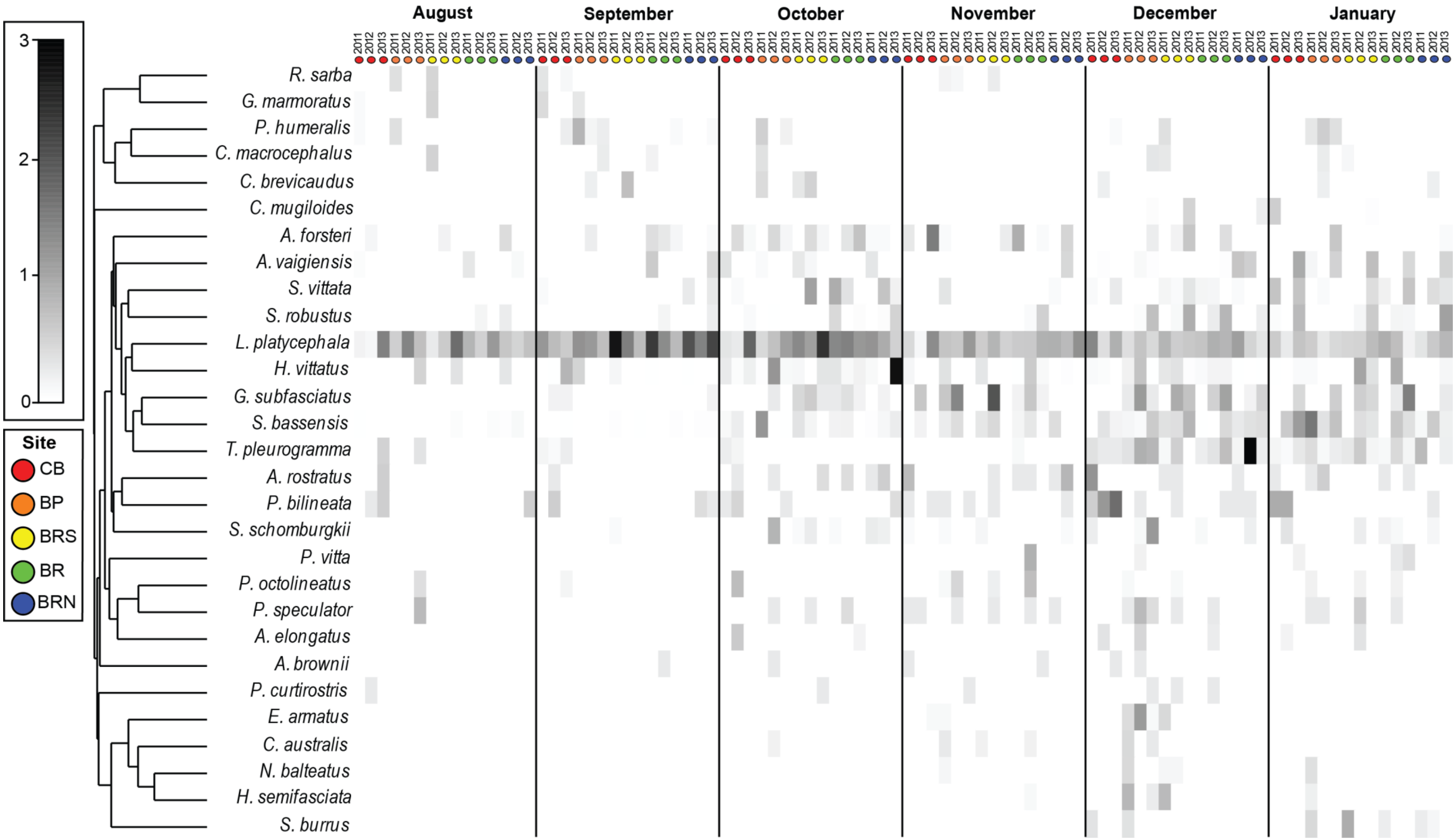


Fig. 3.12: Shade plot illustrating the (pretreated) abundances of the most prevalent fish species recorded at nearshore sites around Becher Point in 2011-13 (*i.e.* those recorded in ≥ 5 samples), presented separately for each sampling month. Shading intensity is proportional to fish abundance. Samples have been ordered by site then year within each month, and species are ordered by a hierarchical cluster analysis of their mutual associations across samples.

Secondly, temporal (monthly and yearly) differences in fish faunal composition around Becher Point were examined using one-way ANOSIM to compare all months in each year, undertaken separately for each site (Appendix 6). Monthly differences in fish assemblages were, in general, notably greater in 2012 and/or 2013 (maximum Global R=0.719 and 0.599, respectively) than 2011 (maximum Global R=0.356), during which many of the pairwise month comparisons at most sites were not significant (*e.g.* Boat Ramp 2011, where no significant differences were found; Appendix 6d). During 2012 and/or 2013, monthly differences were typically greatest at the Boat Ramp South, Becher Point and Comet Bay sites, with many of the pairwise comparisons being moderately high (R> 0.5) to high (R>0.75), especially for the former site in 2012. The particular months which were most distinct varied considerably between sites and years, however, thus contributing to the substantial three-way interaction detected by PERMANOVA (Appendix 6; Table 3.13).

The MDS plots in Fig. 3.13 illustrate that, at several sites, there was a very broad tendency for fish composition to change progressively from the winter/early spring months (August and/or September; left half of the plots) to the early to mid-summer months (December and January; right half of the plots). However, there were several instances in which this progression was not evenly spaced, more applicable to some years and/or sites than others, or did not hold true. Thus, whereas a relatively even shift from winter to summer months occurred at Boat Ramp South in 2012, this was less applicable in 2013 and especially 2011, in which the August and January samples lay closest together (Fig. 3.13c). Moreover, at Comet Bay, only the samples from December and January tended to separate from the remaining, intermingled months (Fig. 3.13a). At Becher Point, while nearly all August-September samples formed a tight group on the left of the plot, those for the remaining months and years were relatively dispersed, although all December-January samples did tend towards the right side of the plot (Fig. 3.13b).

The shade plot summarising monthly trends in the abundance of key species in each year (presented separately for each site) is shown in Fig. 3.14. The species most responsible for driving only the largest of the above trends are described below, although further detail can be obtained from Fig. 3.14. In general, the number of prevalent species increased from winter to summer months, and particularly at the Becher Point, Boat Ramp South and Boat Ramp sites. Moreover, the resident Sandfish, which made notable contributions to the fish fauna at all sites in most months and years, showed a general tendency to decline from winter/spring to summer. With reference to individual sites that exhibited the greatest monthly differences, those at Boat Ramp South in 2012 reflected an increase in the number of prevalent species from just two in

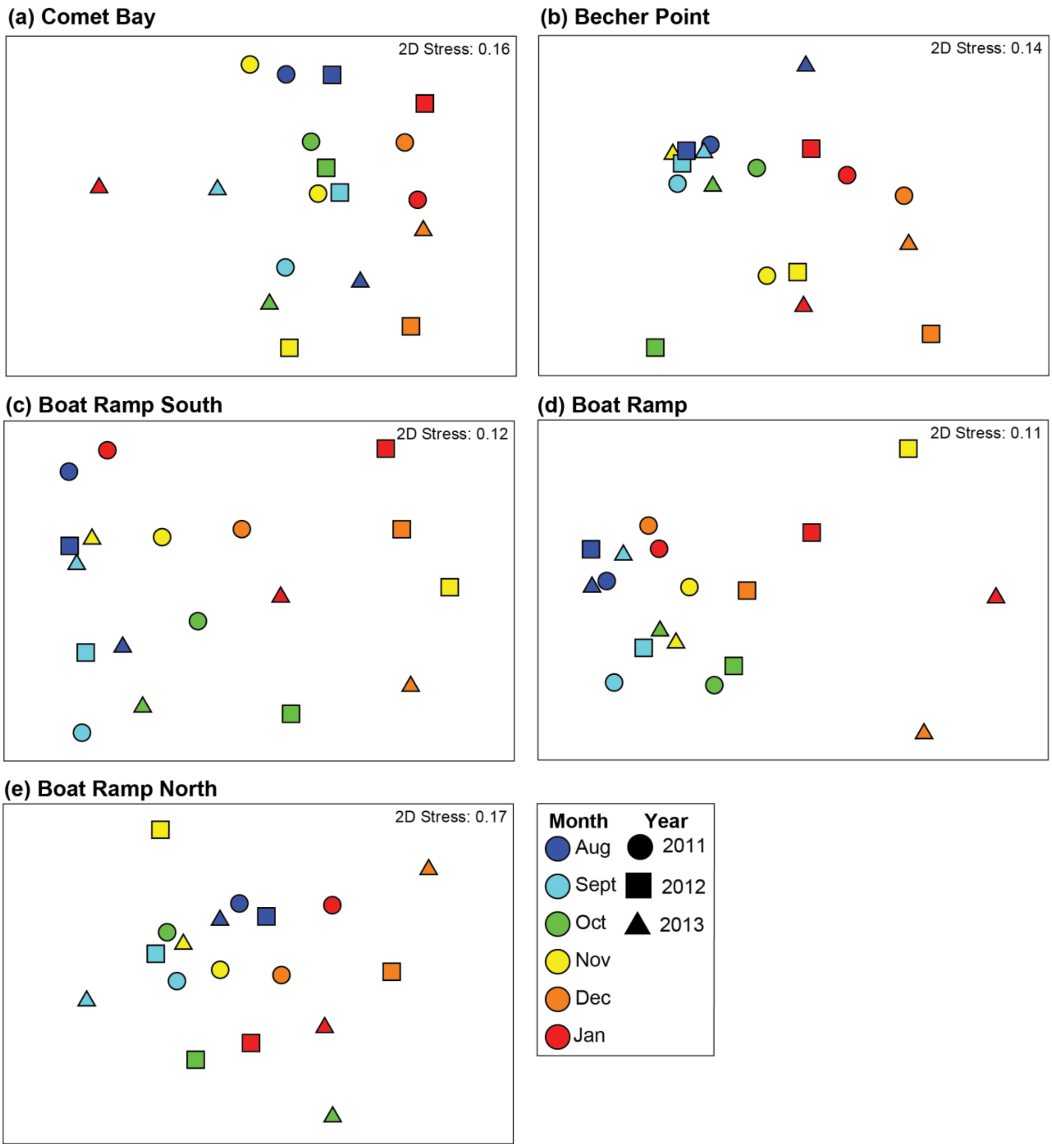


Fig. 3.13: MDS ordination plots derived from the average fish species composition data recorded in each sampling month at Becher Point in 2011-13, undertaken separately for each site.

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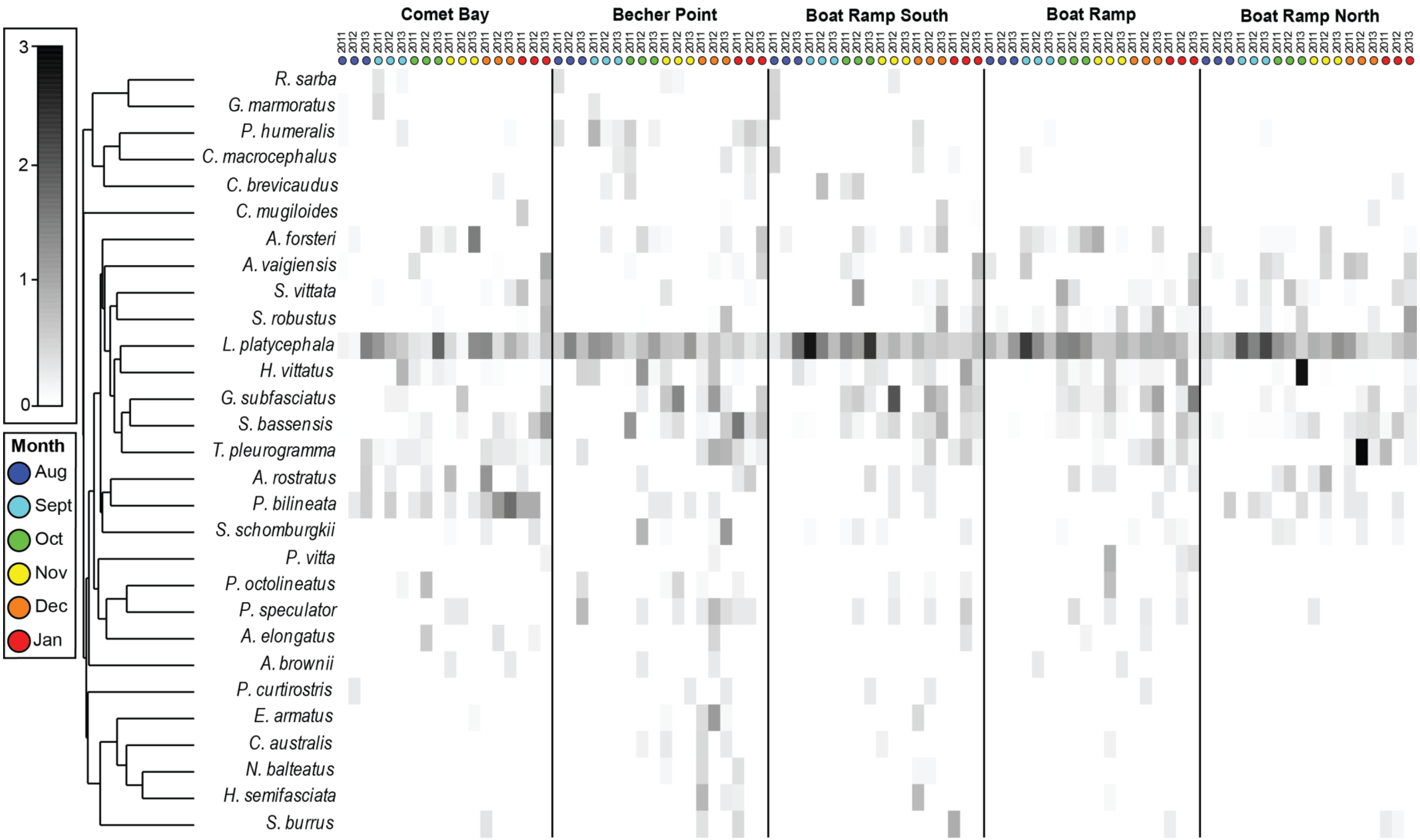


Fig. 3.14: Shade plot illustrating the (pretreated) abundances of the most prevalent fish species recorded in each sampling month in 2011-13 around Becher Point (*i.e.* those recorded in ≥ 5 samples), presented separately for each site. Shading intensity is proportional to fish abundance. Samples have been ordered by month then year within each site, and species are ordered by a hierarchical cluster analysis of their mutual associations across samples.

August and September (Sandfish, Yelloweye Mullet and/or Prickly Toadfish *Contusus brevicaudus*) to several in subsequent months, in addition to a progressive shift in the type of species. Thus, the October assemblages were characterised not only by these three species but also Western School Whiting and Common Silverbiddy, while the latter, Sandfish and Southern School Whiting predominated in November and others such as Whitebait and Blowfish also made notable contributions in December-January (Fig. 3.14). At Comet Bay, the relative distinctiveness of the summer samples largely reflected an emerging prevalence of species such as Common Hardyhead, Western and Southern School Whiting, Blue Sprat and Lemon Tongue Sole that were either absent or far less abundant in the preceding months, while the broad winter to summer shifts at Becher Point similarly reflected an increase in several species (*e.g.* Southern School Whiting, Common Silverbiddy, Blowfish and Southern Bluespotted Flathead *Platycephalus speculator*; Fig. 3.14).

3.3.3 Inter-period trends in Whitebait density and fish faunal characteristics prior to and following boat ramp construction

Collation of the comparable fish assemblage data recorded prior to (1997, 2000-01) and following (2011-13) construction of the Becher Point boat ramp revealed that a total of 54,933 fish and 45 species were recorded over these two periods (Table 3.17). Whitebait and Blue Sprat were particularly abundant and together represented ~91% of the overall catch. However, the mean densities and percentage contributions of both of these species have declined markedly from the pre- to post-boat ramp periods, in which they were often one to two orders of magnitude lower. Accordingly, the overall mean densities of fish exhibited similar trends over these two periods, whereas the total number of species remained relatively constant (16-19 species), with the exception of comparatively species-rich faunas in 2011 (23 species) and especially 2000 (28 species). Whereas the fish assemblages in the pre-boat ramp years were dominated almost exclusively by the above two clupeid species, those in the post-boat ramp years contained several other comparatively abundant species (*i.e.* those representing ≥ 5% of the total catch). These included, for example, various whiting species (*e.g.* Southern School Whiting in 2012 and 2013 and Western Trumpeter *Sillago burrus* and School Whiting in 2011) and atherinid species (*e.g.* Common Hardyhead in 2013 and Spotted Hardyhead *Craterocephalus mugiloides* in 2011).

Table 3.17: Mean densities (M; number of fish 100 m^{-2}) and percentage contributions (%) of the fish species recorded at the Becher Point and Comet Bay sites prior to (1997, 2000-01) and following (2011-13) construction of the boat ramp. Abundant species (*i.e.* those representing ≥ 5% of the catch) are highlighted in grey.

				Pre-boat ramp						Post-boat ramp					
		Total		1997		2000		2001		2011		2012		2013	
Species name	**Common name**	M	%	M	%	M	%	M	%	M	%	M	%	M	%
Hyperlophus vittatus	Whitebait	183.79	53.53	714.32	51.03	152.87	66.06	340.73	59.18	2.48	10.70	23.74	54.36	5.06	5.02
Spratelloides robustus	Blue Sprat	129.93	37.84	663.70	47.41	35.52	15.35	209.09	36.32	0.50	2.17	0.90	2.06	55.78	55.33
Atherinomorus vaigiensis	Common Hardyhead	5.45	1.59	3.26	0.23	19.00	8.21	8.26	1.43	0.11	0.47			12.72	12.61
Sillago bassensis	Southern School Whiting	3.84	1.12	2.92	0.21	0.68	0.29	3.20	0.56	0.83	3.57	13.51	30.92	16.31	16.17
Lesueurina platycephala	Sandfish	3.58	1.04	3.07	0.22	9.45	4.08	5.14	0.89	1.22	5.27	1.29	2.96	4.74	4.70
Aldrichetta forsteri	Yelloweye Mullet	1.78	0.52	1.53	0.11	5.06	2.19	2.05	0.36	0.50	2.17	0.29	0.66	4.13	4.10
Leptatherina presbyteroides	Silverfish	1.74	0.51	5.41	0.39	4.42	1.91					0.54	1.23		
Craterocephalus mugiloides	Spotted Hardyhead	1.20	0.35							5.89	25.43			0.04	0.04
Sillago burrus	Western Trumpeter Whiting	1.09	0.32							5.24	22.64				
Sillago vittata	Western School Whiting	1.08	0.31			2.16	0.93	1.19	0.21	1.83	7.91			0.93	0.93
Sillago schomburgkii	Yellowfin Whiting	0.73	0.21	3.30	0.24	0.04	0.02	0.14	0.02	0.14	0.62	0.40	0.90		
Gerres subfasciatus	Common Silverbiddy	0.64	0.19	0.29	0.02	0.14	0.06	0.86	0.15			1.44	3.29	0.22	0.21
Engraulis australis	Australian Anchovy	0.61	0.18			0.22	0.09	2.30	0.40					0.04	0.04
Rhabdosargus sarba	Tarwhine	0.61	0.18	0.10	0.01	0.18	0.08	1.62	0.28	0.57	2.48	0.07	0.16		
Mugil cephalus	Sea Mullet	0.45	0.13	1.39	0.10			0.54	0.09						
Torquigener pleurogramma	Blowfish	0.42	0.12	0.14	0.01			0.25	0.04	0.29	1.24	0.72	1.64	0.57	0.57
Gymnapistes marmoratus	Soldier	0.39	0.11			0.07	0.03			1.19	5.12				
Cnidoglanis macrocephalus	Cobbler	0.37	0.11			0.50	0.22			0.61	2.64				
Paraplagusia bilineata	Lemon Tongue Sole	0.32	0.09	0.05	0.00	0.18	0.08	0.22	0.04	0.18	0.78	0.22	0.49	0.11	0.11
Fistularia commersonii	Bluespotted Cornetfish	0.27	0.08							0.57	2.48				
Ostorhinchus rueppellii	Gobbleguts	0.27	0.08							0.57	2.48				
Pelsartia humeralis	Sea Trumpeter	0.27	0.08	0.10	0.01	0.43	0.19			0.04	0.16				
Platycephalus speculator	Southern Bluespotted Flathead	0.22	0.06			0.04	0.02	0.04	0.01	0.04	0.16	0.14	0.33		
Ammotretis rostratus	Longsnout Flounder	0.21	0.06							0.18	0.78	0.04	0.08	0.07	0.07
Pelates octolineatus	Western Striped Grunter	0.21	0.06			0.04	0.02					0.18	0.41		
0Ammotretis elongatus	Elongate Flounder	0.21	0.06	0.10	0.01							0.11	0.25		
Arripis georgianus	Australian Herring	0.20	0.06	0.14	0.01	0.04	0.02								
Pseudorhombus jenynsii	Small-tooth Flounder	0.20	0.06			0.07	0.03	0.04	0.01			0.04	0.08		
Urolophus mucosus	Western Shovelnose Stingaree	0.19	0.06			0.07	0.03	0.04	0.01						
Repomucenus calcaratus	Spotted Dragonet	0.19	0.06							0.11	0.47				
Enoplosus armatus	Old Wife	0.19	0.05			0.04	0.02	0.04	0.01					0.04	0.04
Pseudocalliurichthys goodladi	Longspine Dragonet	0.19	0.05			0.04	0.02					0.04	0.08		

		Total		Pre-boat ramp						Post-boat ramp					
				1997		2000		2001		2011		2012		2013	
Species name	**Common name**	M	%	M	%	M	%	M	%	M	%	M	%	M	%
Arripis truttaceus	Western Australian Salmon	0.18	0.05	0.05	0.00										
Scorpis aequipinnis	Sea Sweep	0.18	0.05	0.05	0.00										
Gonorynchus greyi	Beaked Salmon	0.18	0.05			0.04	0.02								
Pugnaso curtirostris	Pug-nosed pipefish	0.18	0.05									0.04	0.08		
Platycephalidae sp.	Flathead sp.	0.18	0.05			0.04	0.02								
Sillaginidae	Whiting sp.	0.18	0.05					0.04	0.01						
Haletta semifasciata	Blue Weed Whiting	0.18	0.05			0.04	0.02								
Cristiceps australis	Crested Weedfish	0.18	0.05							0.04	0.16				
Acanthaluteres brownii	Spinytail Leatherjacket	0.18	0.05							0.04	0.16				
Scobinichthys granulatus	Rough Leatherjacket	0.18	0.05			0.04	0.02								
Contusus brevicaudus	Prickly Toadfish	0.18	0.05			0.04	0.02								
Pseudocaranx dentex	Silver Trevally	0.17	0.05											0.04	0.04
Pentapodus vitta	Western Butterfish	0.17	0.05											0.04	0.04
Number of species		**46**		**18**		**28**		**19**		**23**		**18**		**16**	
Overall mean density		**343.33**		**1399.90**		**231.43**		**575.75**		**23.17**		**43.68**		**100.83**	

Table 3.18: Number of samples in which each fish species at the Becher Point and Comet Bay sites prior to (1997, 2000-01) and following (2011-13) construction of the boat ramp was recorded (#) and their percentage frequency of occurrence (%). Consistently recorded species (*i.e.* those in ≥20% of samples) are highlighted in grey.

				Pre-boat ramp						**Post-boat ramp**					
		Total		**1997**		**2000**		**2001**		**2011**		**2012**		**2013**	
Species name	**Common name**	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Lesueurina platycephala	Sandfish	101	73.19	11	61.11	21	87.50	23	95.83	12	50.00	12	50.00	22	91.67
Sillago bassensis	Southern School Whiting	49	35.51	8	44.44	7	29.17	8	33.33	6	25.00	12	50.00	8	33.33
Hyperlophus vittatus	Whitebait	44	31.88	10	55.56	11	45.83	10	41.67	4	16.67	2	8.33	7	29.17
Spratelloides robustus	Blue Sprat	28	20.29	6	33.33	9	37.50	6	25.00	1	4.17	2	8.33	4	16.67
Aldrichetta forsteri	Yelloweye Mullet	28	20.29	4	22.22	8	33.33	6	25.00	1	4.17	3	12.50	6	25.00
Torquigener pleurogramma	Blowfish	25	18.12	3	16.67			5	20.83	4	16.67	4	16.67	9	37.50
Sillago schomburgkii	Yellowfin Whiting	20	14.49	9	50.00	1	4.17	3	12.50	2	8.33	5	20.83		
Gerres subfasciatus	Common Silverbiddy	20	14.49	2	11.11	3	12.50	2	8.33			9	37.50	4	16.67
Atherinomorus vaigiensis	Common Hardyhead	20	14.49	1	5.56	4	16.67	3	12.50	4	16.67	5	20.83	3	12.50
Sillago vittata	Western School Whiting	18	13.04	3	16.67	6	25.00	1	4.17	1	4.17			7	29.17
Paraplagusia bilineata	Lemon Tongue Sole	18	13.04			5	20.83	7	29.17	1	4.17			5	20.83
Rhabdosargus sarba	Tarwhine	8	5.80	2	11.11	2	8.33	1	4.17	1	4.17	2	8.33		
Platycephalus speculator	Southern Bluespotted Flathead	7	5.07			1	4.17	1	4.17	1	4.17	4	16.67		
Engraulis australis	Australian Anchovy	6	4.35			2	8.33	3	12.50					1	4.17
Ammotretis rostratus	Longsnout Flounder	6	4.35							3	12.50	1	4.17	2	8.33
Ammotretis elongatus	Elongate Flounder	5	3.62	2	11.11							3	12.50		
Lepatherina presbyteroides	Silverfish	4	2.90	2	11.11	1	4.17					1	4.17		
Pelates octolineatus	Western Striped Grunter	4	2.90			1	4.17					3	12.50		
Pelsartia humeralis	Sea Trumpeter	4	2.90	1	5.56	2	8.33			1	4.17				
Arripis georgianus	Australian Herring	4	2.90	3	16.67	1	4.17								
Pseudorhombus jenynsii	Small-tooth Flounder	4	2.90			2	8.33	1	4.17			1	4.17		
Cnidoglanis macrocephalus	Cobbler	3	2.17			1	4.17			2	8.33				
Gymnapistes marmoratus	Soldier	3	2.17			1	4.17			2	8.33				
Sillago burrus	Western Trumpeter Whiting	3	2.17							3	12.50				
Enoplosus armatus	Old Wife	3	2.17			1	4.17	1	4.17					1	4.17
Urolophus mucosus	Western Shovelnose Stingaree	2	1.45			1	4.17	1	4.17						
Craterocephalus mugiloides	Spotted Hardyhead	2	1.45							1	4.17			1	4.17
Mugil cephalus	Sea Mullet	2	1.45	1	5.56			1	4.17						
Pseudocalliurichthys goodladi	Longspine Dragonet	2	1.45			1	4.17					1	4.17		
Repomucenus calcaratus	Spotted Dragonet	2	1.45							2	8.33				
Gonorynchus greyi	Beaked Salmon	1	0.72			1	4.17								
Fistularia commersonii	Bluespotted Cornetfish	1	0.72							1	4.17				

				Pre-boat ramp						Post-boat ramp					
		Total		1997		2000		2001		2011		2012		2013	
Species name	**Common name**	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Pugnaso curtirostris	Pug-nosed pipefish	1	0.72									1	4.17		
Platycephalidae sp.	Flathead sp.	1	0.72			1	4.17								
Ostorhinchus rueppellii	Gobbleguts	1	0.72							1	4.17				
Sillaginodes maculate	Whiting sp.	1	0.72					1	4.17						
Pseudocaranx dentex	Silver Trevally	1	0.72											1	4.17
Arripis truttaceus	Western Australian Salmon	1	0.72	1	5.56										
Pentapodus vitta	Western Butterfish	1	0.72											1	4.17
Haletta semifasciata	Blue Weed Whiting	1	0.72			1	4.17								
Cristiceps australis	Crested Weedfish	1	0.72							1	4.17				
Acanthaluteres brownii	Spinytail Leatherjacket	1	0.72							1	4.17				
Scobinichthys granulatus	Rough Leatherjacket	1	0.72			1	4.17								
Contusus brevicaudus	Prickly Toadfish	1	0.72			1	4.17								
Scorpis aequipinnis	Sea Sweep	1	0.72	1	5.56										

Sandfish was the most consistently recorded species in each year, occurring in at least 50% of samples and up to 96% of samples (Table 3.18). Southern School Whiting was also caught regularly in all years, while Whitebait, Blue Sprat and Yelloweye Mullet were caught consistently only in the pre-boat ramp years (except for 2013 in the case of the former and latter species). Other species which were regularly caught in any individual year are highlighted in (Table 3.18).

Four-way ANOVA showed that the mean density of Whitebait differed significantly between the pre- and post-boat ramp periods, and that the period*season interaction, along with various other interactions involving year nested within period, were significant (Table 3.19). For this and all other tests in this subsection, the following focuses on interpreting the 'period' component, since each of the other factors (for the post boat-ramp data) are explored in subsections 3.3.1-3.3.2.

Plots of the (back-transformed) marginal mean Whitebait densities in each period and season showed that far higher values were recorded in spring prior to than following construction of the boat ramp (49 *vs* 0.5 fish 100 m^{-2}; Fig. 3.15).

Table 3.19: Four-way ANOVA of the mean Whitebait densities in samples collected from the nearshore waters around Becher Point in each sampling season in 1997, 2000-01 (pre-boat ramp period) and 2011-13 (post-boat ramp period). df = degrees of freedom; MS = mean square. Significant differences ($P < 0.05$) are in bold.

	df	MS	F	*P*
Period	1	**63.07**	**46.31**	**0.017**
Season	2	31.01	4.14	0.068
Site	1	17.78	1.81	0.232
Year (Period)	4	1.36	0.62	0.672
Period*Season	2	**43.14**	**5.75**	**0.027**
Period*Site	1	0.19	0.02	0.835
Season*Site	2	0.82	0.16	0.850
Year (Period)*Season	8	**7.54**	**3.44**	**0.001**
Year (Period)*Site	4	**9.86**	**4.50**	**0.004**
Period*Season*Site	2	3.45	0.66	0.535
Year (Period)*Season*Site	8	**5.26**	**2.40**	**0.016**
Residual	102	2.19		

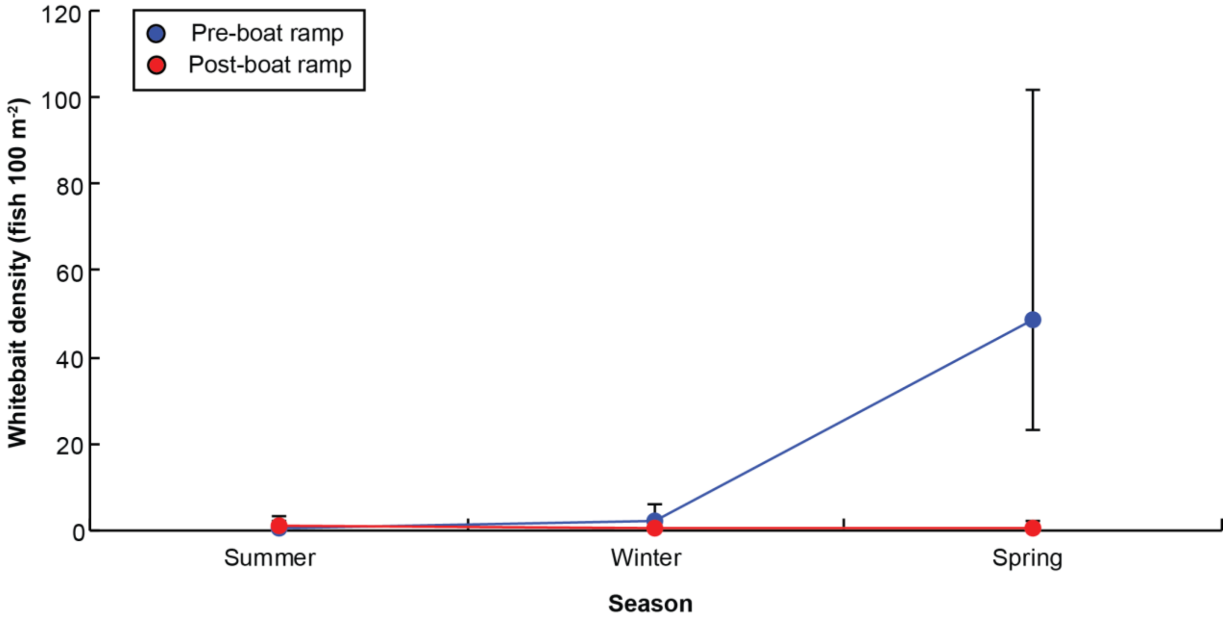


Fig. 3.15: Back-transformed marginal mean Whitebait densities (± 95% confidence intervals) in samples collected in the pre- and post-boat ramp periods in each sampling season at Becher Point.

The mean number of fish species only differed significantly among seasons, and not for any term involving period (Table 3.20). As such, no further exploration of these data was undertaken. In contrast, the mean density of fish differed significantly among periods and various other terms, including seasons, years and the interaction between year (period)* site (Table 3.20). Marginal mean fish densities in the pre-boat ramp period were far higher than those in the post-boat ramp period, *i.e.* 65 *vs* 11 fish 100 m^{-2}.

Table 3.20: Four-way ANOVA of the mean number of species and density of fish in samples collected from the nearshore waters around Becher Point in each sampling season in 1997, 2000-01 (pre-boat ramp period) and 2011-13 (post-boat ramp period). df = degrees of freedom; MS = mean square. Significant differences ($P < 0.05$) are in bold.

		Mean number of species			Mean density		
	df	**MS**	**F**	***P***	**MS**	**F**	***P***
Period	1	2.99	6.94	0.105	**99.98**	**19.07**	**0.037**
Season	2	**3.53**	**5.09**	**0.045**	**26.41**	**6.40**	**0.030**
Site	1	0.24	0.41	0.578	15.74	1.04	0.371
Year (Period)	4	0.43	0.56	0.839	**5.27**	**2.51**	**0.047**
Period*Season	2	0.52	0.75	0.522	7.19	1.74	0.228
Period*Site	1	0.18	0.30	0.623	4.26	0.28	0.610
Season*Site	2	0.23	0.77	0.465	1.57	0.49	0.643
Year (Period)*Season	8	0.70	2.39	0.121	4.14	1.97	0.070
Year (Period)*Site	4	0.59	2.03	0.180	**15.16**	**7.23**	**0.001**
Period*Season*Site	2	0.03	0.10	0.916	2.87	0.89	0.469
Year (Period)*Season*Site	8	0.29	1.74	0.111	3.25	1.55	0.147
Residual	102	0.17			2.10		

Lastly, PERMANOVA did not detect any significant inter-period differences in the species composition of the fish assemblage, either for the main effect or for any term involving period (Table 3.21). Thus, no further examination of these data was undertaken.

Table 3.21: Four-way PERMANOVA on the species composition of the fish assemblages in samples collected from the nearshore waters around Becher Point in each sampling season in 1997, 2000-01 (pre-boat ramp period) and 2011-13 (post-boat ramp period). df = degrees of freedom; MS = mean square. Significant differences ($P < 0.05$) are in bold.

	df	**MS**	**Pseudo-*F***	***P***	**COV**
Period	1	7259.6	1.58	0.133	39.1
Season	2	**10599.0**	**3.10**	**0.004**	**157.8**
Site	1	3997.9	1.37	0.269	15.8
Year (Period)	4	**4620.9**	**4.31**	**0.001**	**155.0**
Period*Season	2	3850.8	1.13	0.368	18.9
Period*Site	1	4625.3	1.58	0.211	50.0
Season*Site	2	2424.8	1.35	0.217	27.6
Year (Period)*Season	8	**3439.8**	**3.21**	**0.001**	**310.2**
Year (Period)*Site	4	**2934.1**	**2.74**	**0.001**	**162.7**
Period*Season*Site	2	1654.3	0.92	0.535	-12.5
Year (Period)*Season*Site	8	**1802.4**	**1.68**	**0.001**	**191.6**
Residual	102	1071.0			1071.0

4. Discussion

4.1 Objective 1: Interannual trends in Whitebait abundance and the broader fish community at Becher Point since the mid-1990s, and relationships with environmental variables

4.1.1 Interannual trends in Whitebait density at Becher Point (including comparisons with Pinnaroo Point) since the 1990s

Whitebait abundances in the nearshore shallow waters at Becher Point, as recorded in samples collected by the DoF using a 61 m long beach seine net, have declined markedly between 1996-2001 and 2006-2013. These trends were particularly apparent in spring, which is when large numbers of larval and juvenile Whitebait typically recruit into the shallow coastal and estuarine waters along the lower west coast of Australia following the peak spawning period in winter (Gaughan *et al.* 1996b; Valesini *et al.* 1998; 2004b). Thus, while there was often considerable variability in the catches between consecutive years (which is frequently observed for highly schooling and patchily distributed species such as Whitebait), marginal mean densities in the earlier period often exceeded ~9 fish 500 m^{-2} (raw arithmetic mean of ~39 fish 500 m^{-2}) and reached a maximum of ~26 fish 500 m^{-2} (raw mean of 575 fish 500 m^{-2}) in spring 2000, whereas they rarely exceeded 1 fish 500 m^{-2} (raw mean of 10 fish 500 m^{-2}) in the later period. Valesini *et al.* (2004a) also recorded large numbers of juvenile Whitebait at Becher Point in spring 2000 (raw mean of 11,126 fish 500 m^{-2}) using a very similar seine net that to that employed by DoF. The large difference in the catches between these two studies further highlights the patchiness of occurrence of this species.

Similar interannual patterns in Whitebait densities were also observed at Pinnaroo Point ~80 km to the north of Becher Point, another known Whitebait nursery along the metropolitan coast (Valesini *et al.* 2004a, Smith *et al.* 2008). Thus, during the spring and early summer period, notably higher catches were recorded during 1998-2001 (marginal mean densities typically >5 fish 500 m^{-2}, peaking at ~24 fish 500 m^{-2} in 2000) than for any year sampled from 2005-12 (always <3 fish 500 m^{-2}). The parity in interannual differences in Whitebait abundance across these two sites suggests that the main drivers of these trends are factors operating at a regional scale rather than a highly localised scale exclusive to the Becher Point area.

Smith *et al.* (2008) also identified similar patterns in the annual recruitment of Whitebait at various metropolitan coastal sites from 1995-2008.

Although interannual variations in the commercial catches of adult Whitebait along the lower west coast of Australia have been positively linked with the strength of the Leeuwin Current in the previous one-two years (*e.g.* Gaughan *et al.* 1996a, Lenanton *et al.* 1991; 2009, Caputi *et al.* 2010), no such significant relationships were detected in the current study for juvenile Whitebait in the nearshore waters at Becher Point. Significant, moderate and positive relationships were, however, detected with the frequency of light (<10 km/h) easterly winds (when either no lag or a one year lag was introduced), mean inshore wave heights (no time lag) and rainfall (two-year lag). Inverse relationships were also detected with more frequent strong easterlies following a one year lag. While it is important to reiterate that such correlations do not necessarily reflect a direct causal relationship, there are several potential mechanisms by which these factors could be influencing the recruitment success of Whitebait at shallow coastal nurseries such as Becher Point. For example, given that Whitebait eggs and larvae are pelagic and are spawned in surface waters mainly within 5 km of the coast (Gaughan *et al.* 1996b), it is feasible that more frequent strong easterly winds could transport them further offshore, and thus reduce their ability to successfully recruit into suitable nearshore nursery habitats. Gaughan (2007) has likewise implicated the influence of coastal (northerly) winds in the inshore-offshore distribution of the pelagic eggs and larvae of Australian Sardine along the south-western Australian coast. Additionally, stronger wave activity could promote the inshore transport of Whitebait eggs and larvae, and/or create better feeding conditions for their zooplanktivorous larvae and juveniles. Thus, several workers have detected greater abundances of zooplankton in more exposed coastal environments (*e.g.* see review by McLachlan 1983), attributing such findings to the greater suspension and availability of nutrients to support phytoplankton growth. Indeed, in a study of the zooplankton assemblages at several sites along the Perth metropolitan coast (including Becher Point), Valesini *et al.* (2004b) showed that overall densities were an order of magnitude higher at the most exposed than least exposed site. Zooplankton densities at Becher Point were only slightly less than at the most exposed site, which probably also contributes to its suite of favourable attributes as a Whitebait nursery (see below). Lastly, Gaughan *et al.* (1996a) also detected a significant positive relationship between commercial Whitebait catches in the Warnbro Sound region and rainfall, but their correlation was obtained with rainfall from the same year rather than the previous two years as in the current study. Higher rainfall could be associated with greater productivity (and thus food availability) in coastal waters through greater nutrient runoff, either directly from the land or increased flushing of the nearby Swan and Peel-Harvey estuaries. Greater river flow resulting from increased rainfall could also flush larval/juvenile Whitebait from estuarine to coastal nursery environments. However, the relevance of a two year lag on these potential mechanisms is unclear.

It is of interest to note that more recent examination of the relationships between commercial Whitebait catches and Leeuwin Current strength along the lower west Australian coast has revealed that, while a positive correlation still exists, it is now weaker since the original 1977-94 database has been updated to include observations from 1995-2007 (Lenanton *et al.* 2009). While the cause of this finding is unknown, the latter authors cite the importance of "as yet unquantifiable factors", and suggest the emerging relevance of aspects such as the northward flowing Capes Current and more localised wind stress. The significant correlations detected in the current study between nearshore Whitebait abundance and various local wind, wave and rainfall attributes thus contribute to unravelling these more complex relationships.

There are various attributes of Becher Point that are likely to contribute to its importance as a nursery for juvenile Whitebait (and other fish species), several of which are also shared by the other known coastal nursery sites for this species along the lower west coast of WA, *i.e.* Pinnaroo Point, the coastal waters just outside the Mandurah entrance channel of the Peel-Harvey Estuary, and Koombana Bay. Firstly, all of these coastal sites have north to north-westerly aspects, which would increase the likelihood of Whitebait eggs and larvae being transported to them during winter when the alongshore coastal currents in the region are southward-flowing (Masselink and Pattiaratchi 2001) and Whitebait spawning activity is typically at its peak (Gaughan *et al.* 1996b). Secondly, the concentrations of Whitebait eggs along the lower west coast of WA are greatest in more sheltered coastal embayments such as Warnbro Sound and Koombana Bay (reflecting either a greater tendency for adults to form spawning aggregations in these areas or a reduced tendency for eggs to be dispersed; Gaughan *et al.* 1996b), and the prominence of the cuspate foreland at Becher Point and highly indented morphology of the latter bay would further increase their likelihood of receiving and retaining eggs and larvae. Thirdly, all of these sites have substantial seagrass/macroaglae beds nearby, and tend to accumulate wracks of detached weed, particularly during winter when greater wave activity dislodges and transports this plant material. For example, Valesini *et al.* (2004b) recorded up to ~38,000 L of detached weed along a 50 m beach transect at Becher Point during individual sampling occasions in 2000-01. Such accumulations in the shallows would not only attract higher concentrations of zooplankton and thus provide a key food source for Whitebait larvae, but also provide shelter from piscivorous fish and birds. The nearshore waters at Becher Point also commonly have a 'milky' characteristic (F. Valesini, pers. obs.), which may be caused through the regular suspension of fine sediment particles by the complex hydrodynamic-sediment interactions that occur at this cuspate foreland (Sanderson and Eliot 1996). It is likely that this characteristic provides further refuge for juvenile Whitebait.

4.1.2 Interannual trends in the nearshore fish community at Becher Point (2007-13)

Few obvious interannual trends were detected in the mean species richness, density or species composition of the fish assemblage in samples collected at Becher Point by the DoF between 2007 and 2013. Thus, while significant interannual differences were identified in each of these three attributes, the extent of those differences was small and typically reflected year-to-year variability rather than any notable trends indicative of a major shift over that period. For example, although the fish faunas in autumn 2010 and 2011 were relatively distinct from those in several other years in this season, this was driven mainly by a larger than normal dominance of the schooling Common Hardyhead and Blue Sprat in the first of these years and the prevalence of several weed-associated species in the second year. Indeed, seasonal trends were notably more evident, with the lowest mean number of species and densities generally occurring in spring. Valesini *et al.* (2004b) also detected lower numbers of nearshore fish species and densities along the lower west Australian coast during spring than in summer and autumn in 2000-01. These seasonal differences reflect, to a large extent, species differences in the timing of spawning and the nearshore recruitment of their juveniles.

Fish catches in each year were dominated by Blue Sprat (~45-77% of the total number of fish) which, like Whitebait, is a small schooling clupeid that uses Becher Point as a nursery, with large numbers of its juveniles typically occurring in December-January and also into autumn (Valesini *et al.* 1998; 2004a). This species was only caught in low numbers and/or inconsistently in spring of all years (see Fig. 3.5), undoubtedly contributing to the significantly lower overall mean densities in that season. Other commonly-occurring species in each year, which tended to be relatively consistent across most seasons, included Southern School, Western School and Yellowfin Whiting, Blowfish and Sandfish. The first two of these species use shallow nearshore waters as nurseries then migrate further offshore as they mature (Hyndes *et al.* 1996; 1997), while the latter three remain in nearshore waters throughout their life (Hyndes *et al.* 1996; 1997; Potter *et al.* 1988).

The relatively modest interannual differences in fish species composition from 2007-13 were not significantly related to any of those in the suite of environmental variables examined. However, the potential to investigate any such relationships was compromised by the relatively small number of samples (years) able to be included in the analyses, given that the full fish assemblage was not recorded consistently in the preceding years of the DoF fish monitoring program at Becher Point (*i.e.* 1996-2001, 2006). Thus, species considered to be of 'low priority' (presumably those which do not support fisheries in south-western Australia, though the exact suite is unknown) were either excluded or patchily recorded in this period (Smith *et al.* 2008). Given the small sample to variable ratio in the above analyses (*i.e.* seven samples to at least 12 environmental variables; see Table 2.4), the regression-based DISTLM routine could not be used to reliably investigate potential fish faunal–environmental relationships, and the analyses that could be undertaken with the non-parametric BIOENV routine (which is not impacted by the sample to variable ratio; Anderson *et al.* 2008) were, like any statistical test, compromised by the small sample size and thus statistical power.

In an attempt to enable the full suite of DoF monitoring years to be included and thus provide some further insights into any interannual relationships between the Becher Point fish fauna and environmental conditions, the fish data were restricted to those fishery species known to be recorded consistently over the full monitoring period (*i.e.* Whitebait, Blue Sprat, Tailor *Pomatomus saltatrix*, Australian Herring, Western Australian Salmon, King George Whiting *Sillaginodes punctata*, Yellowfin whiting, Sea Mullet and Yelloweye mullet; Smith *et al.* 2008) and select analyses undertaken. These analyses have not been presented in the Results given that they deviate from the primary objectives of this study, but the main findings are summarised below for their potential relevance to the interannual trends observed in the Whitebait data alone.

The shade plot shown in Fig. 4.1 demonstrates that, in addition to Whitebait, several other species in the restricted suite showed a tendency to decline in abundance from earlier (1996-2001/06) to later (2006/07-2013) years in one or more seasons, *e.g.* Yellowfin Whiting in autumn and spring, Yelloweye Mullet in summer and spring, Australian Herring in all seasons and, to a lesser extent, Tailor and King George Whiting. In contrast, while the abundances of

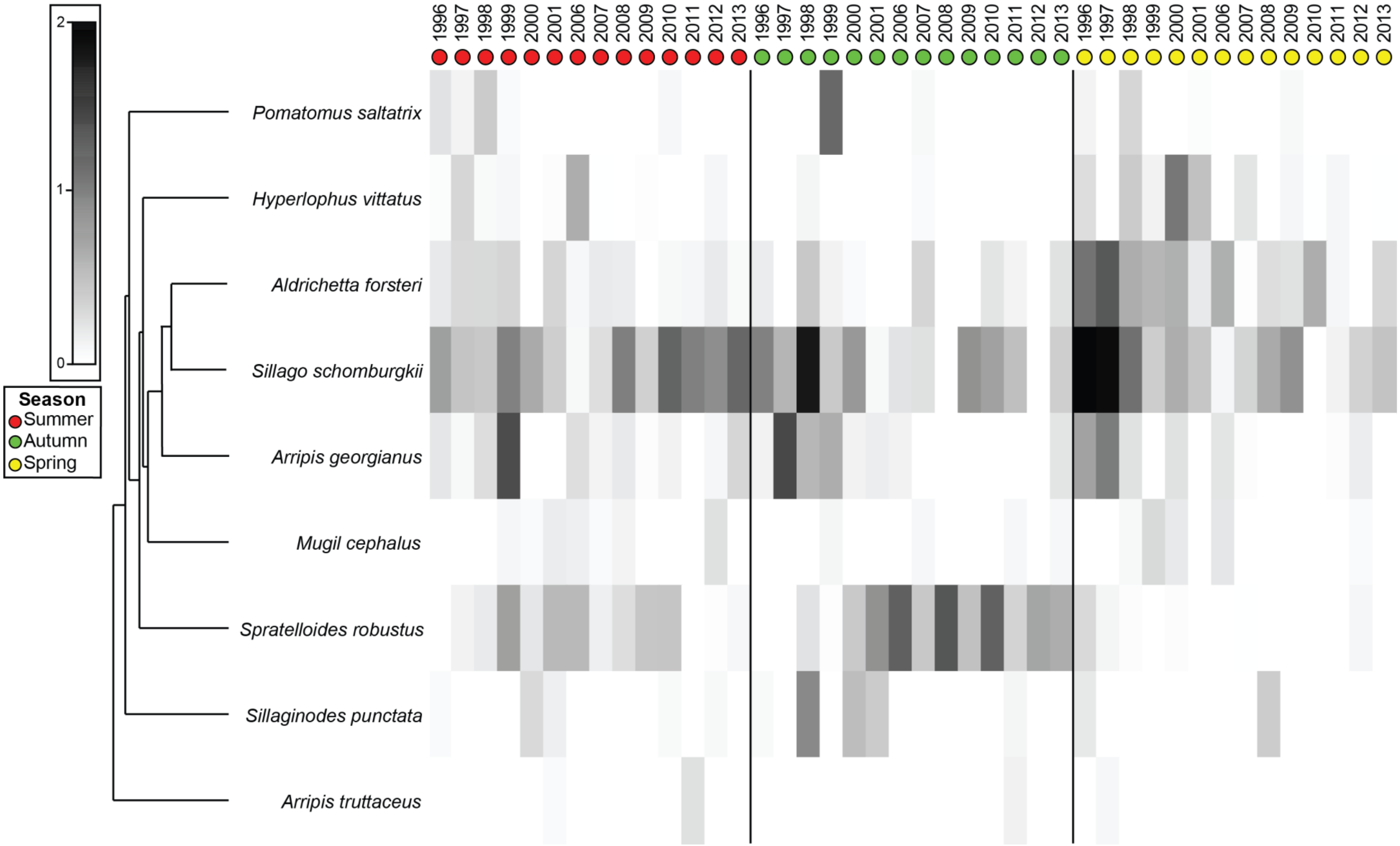


Fig. 4.1: Shade plot illustrating the (pretreated) abundances of the most prevalent fishery species recorded at Becher Point by DoF during summer, autumn and spring in 1996-2001 and 2006-2013 (*i.e.* those accounting for >10% of the average abundance in any year*season combination), with shading intensity being proportional to abundance. Samples have been ordered by year for each season, and species are ordered by a hierarchical cluster analysis of their mutual associations across samples.

other species such as Blue Sprat have varied between years, they have exhibited less of a tendency to change progressively over time. Smith *et al.* (2008) have likewise shown a tendency for juvenile Yelloweye Mullet, Australian Herring *Arripis georgianus* and Tailor to decline from earlier to later years (over the 1996-2008 period) at various other sites along the south-western Australian coast.

The above interannual differences in the restricted fish assemblage were shown to be significant in a year x season PERMANOVA test (*P*=0.001 for all model terms) and indeed more important than seasonal differences. When DISTLM and BIOENV were used to test for any interannual relationships between these fish data and the suite of environmental variables, significant and small-moderately high correlations were obtained in several cases, which are summarised in Table 4.1. Corresponding dbRDA or MDS ordination plots that illustrate some of the clearest of these relationships are provided in Fig. 4.2.

In general, the above fish faunal differences from earlier to later years, particularly in autumn and/or spring, tended to be most clearly associated with more frequent light (<10 km/h) easterly and southerly winds, and more frequent strong (20-30 km/h) westerly winds in the earlier than later years across various lag states (Fig. 4.2d, e and f, respectively). It is relevant that, like Whitebait, all of the species that showed the greatest tendencies to decline have pelagic eggs and use nearshore zones as nurseries, and are thus similarly susceptible to the impacts of coastal wind conditions that may promote egg/larval transport inshore to suitable nursery habitats, or disperse them further offshore or alongshore. It is also relevant that Blue Sprat, which showed the least tendency to change progressively in abundance from earlier to later years, has demersal eggs (Rogers and Ward 2007), and would thus be less susceptible to the effects of coastal wind conditions on recruitment success. It should be emphasised, however, that more detailed investigations of the above relationships are required to better determine their veracity, including focussing on wind conditions at specific times of year (rather than across the full year as done here) to better match with the peak spawning and recruitment times of individual species.

Interannual trends in the restricted suite of fish species during summer at Becher Point were significantly linked with Leeuwin Current strength (as reflected by mean sea level height at Fremantle) and also summer/winter sea surface temperatures in the same year. Years in which the Leeuwin Current was the weakest (*e.g.* 1997, 1998, 2001, 2006, 2007 and 2009) also had among the lowest temperatures in both of the above seasons (Fig. 4.2a, b, c). While Yellowfin

Table 4.1: Results of the statistical matching procedures (BIOENV and DISTLM) used to determine any significant interannual relationships between the restricted suite of fishery species (1996-2001, 2006-2013) in the nearshore waters at Becher Point and a suite of environmental variables (see Table 2.4) for which no time lag, a one year lag and a two year lag had been introduced. Note that DISTLM analyses had to employ a reduced set of environmental variables (see Table 2.4). Significant results (P<0.05) are in bold, and include the subset of environmental variables responsible for the 'best' match.

		Predictor data (environmental data)					
		No lag		**1 yr lag**		**2 yr lag**	
		BIOENV	*DISTLM*	*BIOENV*	*DISTLM*	*BIOENV*	*DISTLM*
Response data (restricted fish assemblage)	Summer	***P*=0.01; ρ=0.615** ***N <10, N 20-30; W <10 km/h; Reynolds SST summer; winter***	***P*=0.001; R^2=0.484** ***FSL; N<10 km/h***	*P*=0.36; ρ=0.401	***P*=0.019; R^2=0.180** ***Mean wave ht***	*P*=0.90; ρ=0.261	*P*=0.191; R^2=0.108
	Autumn	*P*=0.45; ρ=0.394	***P*=0.004; R^2=0.279** ***E <10 km/h***	*P*=0.43; ρ=0.393	***P*=0.003; R^2=0.304** ***E 20-30 km/h***	***P*=0.01; ρ=0.609** ***N 20-30; E <10; S <10; SW 20-30; W 20-30 km/h***	***P*=0.003; R^2=0.336** ***S <10 km/h***
	Spring	*P*=0.64; ρ=0.305	*P*=0.065; R^2=0.149	*P*=0.24; ρ=0.416	***P*=0.015; R^2=0.192** ***W <20-30 km/h***	***P*=0.04; ρ=0.506** ***SW <10; W 20-30 km/h***	***P*=0.002; R^2=0.286** ***W 20-30 km/h***

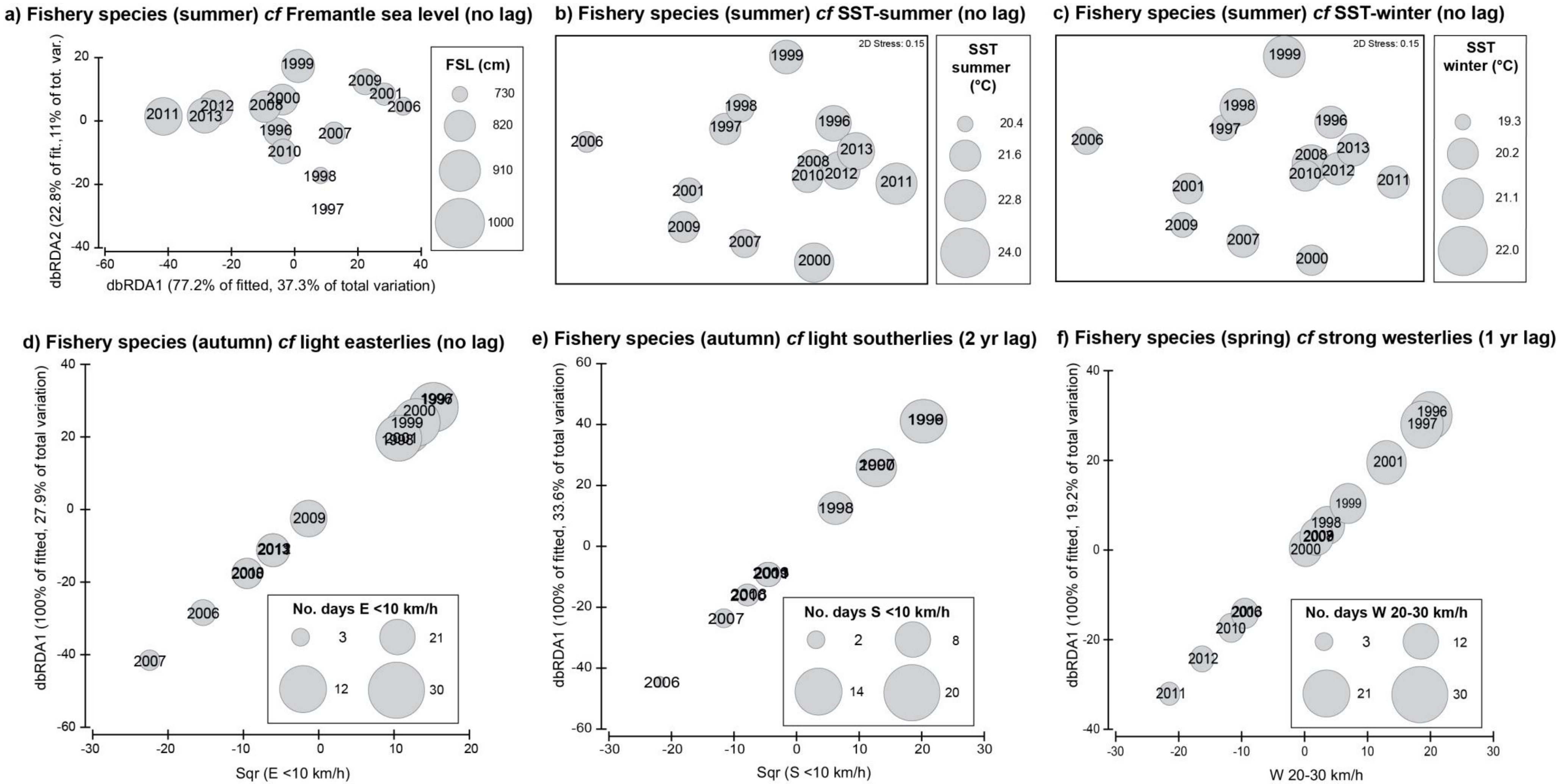


Fig. 4.2: MDS or dbRDA ordination plots depicting the significant interannual relationships between the suite of fishery species collected by DoF at Becher Point in 1996-2001 and 2006-2013 (in specified seasons) and environmental variables (in specified seasons and/or lag states) selected by the BIOENV or DISTLM routines. The (unpretreated) magnitudes of the selected environmental variables are also overlaid on each year as circles of proportionate sizes.

Whiting tended to be less abundant in each of the above years during summer, the abundances of several other species showed mixed responses, *e.g.* although Whitebait catches in two of the above years were the greatest of any recorded over the 1996-2013 monitoring period, it was recorded only in low numbers or not at all in the remainder. More detailed assessments of the complex relationships between several of the fish species in the restricted suite and the larger-scale impacts of the Leeuwin Current along the WA coast are given in Lenanton *et al.* (2009) and Caputi *et al.* (2010). Lastly, it is noteworthy that one of the most distinct fish faunal compositions during summer occurred in 2011 (*i.e.* lying to the far right of the plot in Fig. 4.2b), which was attributable to very low or no catches of most species except Yellowfin whiting (Fig. 4.1), and coincided with the highest average summer sea surface temperatures recorded over the 1996-2013 period (23.14 °C). These high temperatures reflect the 'marine heatwave' that occurred along WA's west coast towards the end of 2010 and peaked in March 2011, with sea surface temperatures reaching up to 5 °C higher than average (Feng *et al.* 2013; Pearce and Feng, 2013).

4.2 Objective 2: Interannual relationships between penguin biology and penguin prey and environmental variables

Interannual trends in both the survival estimates and breeding performance of Little Penguins on Penguin Island during 1986-2008 and 1986-2011, respectively, were significantly correlated with the abundances of select penguin prey (fish) species and/or a range of environmental variables. The following discussion focuses on those predictor variables which showed the clearest relationships with the penguin response attributes.

Penguin survival, which ranged from ~60% (1989, 1997 and 1998) to ~90-100% (1986, 1987, 2000 and 2008), was positively correlated in the same year with Blue Sprat abundances at Becher Point in autumn, and more frequent strong southerly and northerly winds. It was also inversely related in the same year to the number of hot (> 33 °C) days in December-January. Following the introduction of a one to two year lag into the environmental data, higher penguin survival was most clearly related to lower April sea surface temperatures in Warnbro Sound, less frequent light easterly winds and more frequent light south-westerly winds. The extent of any significant lagged relationships with prey abundances at Becher Point are unknown, however, given that there were an insufficient number of common years between the penguin survival and fish data sets to enable reliable statistical testing.

Penguin breeding performance, which was generally poorest in 1986, 1994, 1999 and 2011 and among the best in 1991, 2006 and 2009, was also shown to be inversely related to April (autumn) sea surface temperatures in Warnbro Sound, but in the same year rather than following a lag effect. Other relatively clear significant correlations included a positive relationship with strong westerly winds, also in the same year.

The first of the above relationships corresponds not only with the fact that Blue Sprat is a key food source for Little Penguins (Murray *et al.* 2011), but also with the life-cycle characteristics of this fish species. Thus, while the majority of Blue Sprat in the shallows at Becher Point are juveniles (and thus smaller than the one to two year old fish typically eaten by Little Penguins; Klomp and Wooller 1988; Bradley *et al.* 1997), the fast growth rate and short life span (~eight months) of this species in southern Australian waters (Rogers and Ward 2007) means that this same cohort of fish would move slightly offshore as they mature later in the same year, and thus into areas where Little Penguins spend more time foraging. In contrast, the other penguin prey species examined (*i.e.* Whitebait, Australian Sardine, Australian Anchovy and Southern Garfish) don’t reach maturity until they are close to or more than one year old, and thus any relationships between their nearshore abundances at Becher Point and penguin survival would not be expected in the same year. While these ‘lagged’ relationships could not be explored statistically (see above), some evidence of a positive correlation between nearshore Whitebait abundance at Becher Point (in the previous year) and penguin survival is provided by the combined findings of this study and the companion study by Cannell (2013). Thus, the latter author found that penguin population sizes, calculated using mark-recapture techniques in 2007, 2008, 2010 and 2011, were notably higher in the first two years (1413-1695) than the latter two (690-964). Moreover, whereas Whitebait comprised 56% of penguin diets in 2010, this prey type was absent in 2011. These findings mainly correspond with a one-year lag in Whitebait abundances at Becher Point, *i.e.* comparatively high to moderate catches in 2006 and 2007, low catches in 2009 and none in 2010 (see Fig. 4.1).

The inverse relationship between penguin survival and hot summer days in the same year concurs with previous findings of Ropert-Coudert *et al.* (2004) and Cannell *et al.* (2012). However, the mechanisms underlying the positive relationships with more frequent strong southerly and, to a lesser extent, northerly winds are less clear. These wind conditions could potentially have a direct effect on penguin survival through pathways such as terrestrial cooling, or indirect effects such as through impacts on prey availability. On the latter point, persistent southerly winds during summer are known to drive the Capes Current that flows northwards along the lower west Australian coast (Pearce and Pattiaratchi 1999), and which has been implicated in variability in coastal fish assemblages in the region (*e.g.* Muhling *et al.* 2008). More detailed examination of wind conditions at different times of the year and its relationships with both penguin survival and fish faunal characteristics in the region would be required to further ascertain the nature of these relationships. This is also the case for the varying relationships between penguin survival and select local wind conditions following a two year lag.

Higher sea surface temperatures in Warnbro Sound during April (autumn) were shown to not only negatively impact penguin survival (lagged two years) but also breeding performance in the same year. The latter findings correspond with those of Cannell *et al.* (2012), who suggested that these warmer water temperatures may cause local fish stocks to emigrate from the region, which would in turn increase the length of time penguins spent foraging and/or reduce meal sizes brought back to the chicks. However, no significant matches were detected in the current study between interannual trends in breeding performance and those in penguin prey composition at Becher Point in any season or lag state, and only weak (and inverse) relationships were found between breeding performance and commercial Australian Anchovy catches in the same year (see below). Direct interannual relationships between Warnbro Sound sea surface temperatures and the Becher Point fish fauna could not be explored as the former data was not available over the full fish monitoring period, although some evidence of reduced fish abundances under higher than average sea surface temperatures was detected in the restricted suite of fishery species at Becher Point during the ‘marine heatwave’ conditions of 2010/11 (see subsection 4.1.2).

As for the relationships between penguin survival and select wind conditions described above, the actual mechanism(s) by which more frequent strong westerly winds might positively influence penguin breeding performance in the same year could be many and varied. It may be relevant, however, that more frequent strong westerly winds were also positively associated with greater abundances of various fishery species in the nearshore waters at Becher Point in autumn and spring (see subsection 4.1.2).

Lastly, although significant interannual relationships were occasionally detected between penguin biology and the commercial catches of select penguin prey species in the region, these relationships were generally inverse. It is less likely that these findings represent a true biological relationship and more likely that they are a spurious outcome resulting from several issues with the representativeness of this commercial fish data set, including the following.

1. Given the small number of commercial bait fishers operating in the region of interest, it was not possible to carry out a more detailed spatial examination of penguin-fish relationships in the waters where Little Penguins typically feed (*i.e.* fishing block 3215; see Fig. 2.3), as this contravened the DoF's confidentiality policy around commercial catch reporting (see subsection 2.3.1) on too many occasions. The necessary inclusion of catch data to the north and south of this fishing block could thus have impacted the ability to detect any real correlations between penguin response and prey availability.
2. The CPUE data for the schooling baitfish species preyed upon by Little Penguins is not a particularly reliable representation of their abundance in the region of interest, due to several factors outlined below and described further by Gaughan *et al.* (1996a).
    i. The best measure of 'effort' in baitfish fisheries is the amount of productive fishing time. This includes both time spent searching for schools (usually the major component) and making the catch. However, the only measure of effort available to this study was the number of fishing vessels.
    ii. The baitfish fisheries include different gear types (*i.e.* beach seines, haul nets and purse seines), which further complicates estimates of fishing effort and thus the representativeness of the CPUE data. For example, unlike fishers using beach seines in nearshore shallow waters, those using purse seines in deeper waters may be able to detect large schools of fish using sonar.
    iii. Effort tends to follow catch, with perceived declines in catch resulting in a decrease in effort. It is thus possible that a low CPUE does not actually reflect low fish abundance, but is simply an artefact of low effort.
    iv. Only a small number of commercial fishers have operated in the region of interest over the last decade or so, *i.e.* typically <4 vessels/year, compared to an average of 8-17 vessels/year from the mid-1970s to early 2000s. The likelihood of obtaining CPUE data that is representative of true fish abundance in the region is thus now far lower than previously.

4.3 Objective 3: Impact of the boat ramp on Whitebait abundance and the broader fish community at Becher Point

4.3.1 Spatial and temporal trends in Whitebait density and fish faunal characteristics around the Becher Point boat ramp from 2011-13

Whitebait densities in the nearshore waters around Becher Point, as recorded in samples collected at five sites between August and January in 2011-13 using a 21.5 m seine net, were generally low (often <4 fish 100 m^{-2}, or a raw arithmetic mean <50 fish 100 m^{-2}) with occasional larger catches of ~20-50 fish 100 m^{-2} (raw mean of ~100-770 fish 100 m^{-2}) in 2012 or 2013. Thus, while this species and also Blue Sprat ranked among the most abundant over this period, their catches were episodic, reflecting both the pronounced seasonality in the inshore recruitment of their juveniles (typically peaking in spring and summer, respectively) and their patchy distributions resulting from their highly schooling behaviour (*e.g.* Gaughan *et al.* 1996b; Valesini *et al.* 2004a). The latter was clearly illustrated in the current study where, despite Whitebait ranking as the most abundant species overall, it was only recorded in ~24% of samples (and Blue Sprat in ~13% of samples). This contrasted markedly with the less abundant but highly consistently-occurring Sandfish, which was present in ~78% of samples.

The highest mean densities of Whitebait were found at the Becher Point site, followed by the Boat Ramp North and Comet Bay sites, in September or October of 2012 or 2013. Relatively moderate catches were also recorded at the Boat Ramp site in January 2013. Yet, there was little to no interannual consistency in the above spatial trends, again reinforcing the considerable variability in the occurrence of this species. However, it is relevant that Valesini *et al.* (1998), who also sampled the fish faunas at sites close to the current Becher Point, Boat Ramp South and Comet Bay sites, found that the highest Whitebait densities typically occurred at the first of these locations. These findings suggest that there may be certain environmental or ecological attributes that are more localised to the Becher Point site that are particularly favourable for juvenile Whitebait. These may include its position, not only on the northern side of the Point but closer to the tip of the Point, which could (i) maximise its likelihood of receiving and/or retaining Whitebait eggs or larvae during winter when spawning is at its peak (Gaughan *et al.* 1996a) and the alongshore currents are southward flowing (Masselink and Pattiaratchi 2001), and/or (ii) predispose it to more complex wave-sediment interactions than sites further inside Warnbro Sound or Comet Bay, which may provide larval or juvenile Whitebait with greater refuge (through turbulence) or food (through attracting greater densities of zooplankton). Additionally, detached macrophyte accumulations, which are also likely to provide refuge and attract prey for small Whitebait (Lenanton *et al*., 1982; van der Merwe and McLachlan, 1987), are often greatest at this site (F. Valesini, pers. obs.).

With respect to the species richness and composition of the broader fish assemblage around Becher Point in 2011-13, the greatest differences typically occurred among months rather than sites or years. These monthly trends broadly reflected a shift from late winter/early spring to summer, driven by both an increase in the number of species and, in the case of composition, a progressive shift in the prevalence of different species. Such intra-annual trends are typical of the fish faunas in many coastal areas, including those along the lower west coast of Australia, and reflect (i) differences in the timing of the inshore migration/emigration of species that use nearshore areas as nurseries then move offshore as they increase in size (*e.g.* Gaughan *et al*. 1996a; Hyndes *et al.* 1996; 1999), and (ii) seasonality in the reproductive cycles of resident nearshore species such as the Sandfish, which was clearly shown in the current study to decline in abundance from winter/spring to summer. Similar seasonal trends were also observed in the nearshore fish samples collected at Becher Point by DoF using the 60.5 m seine net (see subsection 3.1.2).

Although the mean density of fish exhibited considerable spatio-temporal variability, the most obvious differences were the notably greater catches in 2013 than 2011-12, which was also reflected by the total density of fish. These trends were at least partly driven by the far greater catches of both Whitebait and Blue Sprat in 2013 than either of the previous two years. The total density of fish recorded by DoF in the nearshore waters at Becher Point over the 2007-13 period was also the lowest in 2011, and it may be relevant that water temperatures in Warnbro Sound in this year peaked at 3.4 °C above the long-term mean for February and March during the so-called 'marine heatwave' along WA's west coast (Pearce and Feng, 2013).

4.3.2. Inter-period trends in Whitebait density and fish faunal characteristics prior to and following boat ramp construction

Examination of the comparable fish faunal data recorded prior to (1997, 2000-01) and following (2011-13) construction of the Becher Point boat ramp in 2010 (*i.e.* that collected using a 21.5 m seine net at a common suite of sites in the same seasons) revealed that far greater mean densities of Whitebait were found in the first of these periods, *i.e.* maximum mean densities of 309 *vs* 12 fish 100 m^{-2}, respectively (raw maximum mean densities of 3953 *vs* 142 fish 100 m^{-2}). While the inability to collect comparable fish data in the year(s) immediately preceding boat ramp construction has compromised understanding of any 'before *vs* after' impacts to some extent (see subsection 2.4.1), a marked decline in Whitebait abundance was also observed between 1996-2001 and 2006-13 at Becher Point and between 1998-2001 and 2005-12 at Pinnaroo Point in samples collected by the DoF using a 61 m seine net (see subsections 3.1.1 and 4.1.1). Thus, the latter two data sets demonstrate that Whitebait densities in the nearshore waters at Becher Point and other areas along the metropolitan coast were comparatively low for at least four years before construction of the ramp. As such, it is less likely that the far lower Whitebait abundances in the post- *vs* pre-boat ramp periods observed in this study are due to any negative impacts of the boat ramp *per se*, but are more likely, as discussed in subsection 4.1.1, to reflect the impacts of other environmental drivers operating at broader regional scales, *e.g.* local wind and wave conditions.

In addition to the above, the relatively small size of the boat ramp and the fact that its central finger jetty is supported by pylons rather than a concrete or rock wall, would mean that its influence on local hydrodynamics, and thus the distribution of pelagic fish larvae/small juveniles, is comparatively minor. Moreover, disturbance effects on juvenile and other fish that regularly inhabit the shallows around Becher Point are reduced by the closing of all nearshore waters between Bridport Point and north Comet Bay to motorised vessels under the management zones of the Shoalwater Islands Marine Park. It is worth noting, however, that negative secondary impacts of the boat ramp on the Becher Point fish fauna could result if macrophyte harvesting at or nearby the ramp was to be undertaken to improve access to the facility. Large wracks of detached macrophytes were observed at the boat ramp on occasions during this study (J. Tweedley, pers. obs,), which precluded boat launching and retrieval. As noted above and in subsection 4.1.1, however, it is likely that the macrophyte wracks which tend to accumulate around Becher Point are an important component of its value as a nursery area to Whitebait and other fish species (*e.g.* Lenanton *et al*., 1982).

The mean density of all fish also exhibited similar trends to Whitebait with respect to pre- *vs* post-boat ramp differences, reflecting the fact that more than half of the total number of fish recoded over these periods was comprised of this species. Together with Blue Sprat, which represented a further 38% of the total fish recorded and also declined markedly from the pre- to post-boat ramp periods, these two clupeid species largely dominated trends in the mean density of fish. In contrast, no significant inter-period differences were detected for the mean number of species and fish assemblage composition.

4.4 Objective 4: Design a cost-effective and robust monitoring regime to enable the abundance of Whitebait around Becher Point to be reliably measured into the future

In view of the findings of this study and those of various others on the fish faunas at Becher Point and/or nearby coastal waters (*e.g.* Valesini *et al.* 1998; 2004a, b; Fairclough *et al.* 1999; Smith *et al.* 2008), the following monitoring regime is proposed for reliably and cost-effectively tracking the abundance and distribution of Whitebait in the Becher Point area into the future (Fig. 4.3). This regime has also been designed to enable Blue Sprat to be monitored, given that this species is also a major prey item for Little Penguins and that large numbers of its juveniles regularly use Becher Point as a nursery area.

Fig. 4.3: Locations of the nearshore sampling sites and a summary of the sampling months for the proposed monitoring regime for Whitebait (WB) and Blue Sprat (BS) in the Becher Point region.

- ***Sampling sites:*** Boat Ramp (32°21’57.71”S 115°43’42.68”E), Becher Point (32°22’09.17”S 115°43’07.64”E) and Comet Bay (32°22’23.84”S 115°42’59.73”E).

These three sites have been selected for one or more of the following reasons.

(i) Comparatively large catches of Whitebait and/or Blue Sprat have been recorded at these localities on a relatively consistent basis, not only in the current study but, at one or both of the latter two sites, also in previous years by Valesini *et al.* (1998;

2004a, b), Fairclough *et al.* (1999) and in the DoF fish recruitment monitoring program (subsections 3.1.1 and 3.1.2; Smith *et al.* 2008).

(ii) Following from the above, historical records of Whitebait and Blue Sprat are most extensive at the Becher Point and Comet Bay sites, thus providing the best available basis for understanding the relative importance of any future shifts in the abundances of these species.

(iii) Continuing to monitor the Boat Ramp site will enable assessment of whether juvenile Whitebait and/or Blue Sprat recruit to this locality in greater numbers in the future (particularly during years of stronger recruitment than the 2011-13 period), or whether numbers remain low and thus may be indicative of disturbance effects at that site. On the latter point, it is noteworthy that Valesini *et al.* (1998) recorded large catches of both of these species near the current Boat Ramp/Boat Ramp South sites during 1996/7.

- ***Sampling times:*** Monthly from September-March on an annual basis.

Although Whitebait along the lower west coast of WA have a protracted spawning period (May-September, typically peaking in June-July; Gaughan *et al.* 1996b), examination of the abundance data recorded at Becher Point in the current study, by DoF during their fish recruitment program (subsection 3.1.1 and Smith *et al.* 2008) and in other previous studies (Valesini *et al.* 1998; 2004a; Fairclough *et al.* 1999), indicates that the greatest and most consistent catches of their juveniles occur in late winter and particularly throughout spring (August to November). The above studies also demonstrate that the densities of juvenile Blue Sprat at Becher Point tend to peak during summer and into autumn (January to March/April). In the interests of capturing the peak juvenile recruitment phases for both of these species and also minimising monitoring resource requirements, a monthly sampling regime from September to March is suggested. Resources permitting, however, an August to April monitoring regime would better capture any variations to these peak recruitment times.

Moreover, given the large annual variations in the strength of recruitment of these species, which are clearly demonstrated by the findings of this study and those of Smith *et al.* (2008), it is recommended that the above monitoring regime be undertaken on a yearly basis.

- ***Sampling method:*** 21.5 m beach seine net.

This small beach seine net has been demonstrated, both in the current study and various others (*e.g.* Ayvazian and Hyndes 1995; Valesini *et al.* 1998; 2004b; Fairclough *et al.* 1999), to be effective at capturing Whitebait, Blue Sprat and many other fish species (particularly those that are smaller-bodied and/or not especially fast swimming) in the nearshore waters at Becher Point and more broadly along the lower west coast of WA. Moreover, the shorter length of this net enables it to be easily and quickly deployed by two people wading out from the shore (rather than requiring a boat and sometimes additional people to set and/or haul the net, as is needed for the 61 m seine), and reduces the sampling impact on the fish fauna given the smaller area it sweeps (*i.e.* 116 vs 592 m^2 for the 21 and 61 m seines, respectively). The smaller mesh size in the bunt (central pocket) of the 21 than 61 m seine (3 vs 8 mm, respectively) also increases its efficiency at catching very small juveniles.

Importantly, the continued use of the 21 m seine at Becher Point will ensure comparability with the current study (and also those in the 1990s and 2000s by Valesini *et al.* 1998; 2004b and Fairclough *et al.* 1999), thus maximising the historical basis against which future monitoring data can be reliably compared.

Although the DoF monitoring program provides a more extensive historical basis (1996-2001, 2006-13) for assessing interannual trends in Whitebait and Blue Sprat at one of the proposed sites (Becher Point), their use of a 61 m seine precludes direct comparison with the data from the current study due to gear bias effects. Thus, Valesini *et al.* (2004b), who used both the 21 and 61 m seines for sampling fish faunas along the lower west coast of WA, demonstrated significant differences in catch composition between these net types. Hallett and Hall (2012) further demonstrated differences in fish catches obtained using 21.5, 41.5 and 133 m seine nets, and developed a statistical standardisation method to reduce gear bias effects on the resultant data. However, while this method provides a major advance in increasing data comparability among net types, some sampling bias issues still remain and can never be fully overcome.

An alternative approach for monitoring Whitebait and Blue Sprat abundances in the region of interest could, of course, be to extend the existing DoF monitoring program at Becher Point, *i.e.* using the 61.5 m seine. While this would provide the benefits of a longer-term and more consistently recorded historical database as outlined above, in addition to potential avenues for sharing monitoring costs across the DoF and DPaW, this approach would increase sampling resource requirements and the impacts on the fish fauna (see above). Moreover, the existing

DoF data encompasses only one of the sites of interest, and does not include any catch data in the immediate vicinity of the boat ramp.

- ***Replication*****:** four (to six) replicates.

A minimum of four replicate samples per site, sampling month and year are required. However, given the extremely patchy occurrence of Whitebait and Blue Sprat, six replicates are suggested to better capture the spatio-temporal variability of these highly schooling species. The extra resource requirements for obtaining these two additional replicates are expected to be small, given that only the above two species are of interest and the time required to record their abundances in the field (and ideally return the catch to the water alive) or, where necessary, in the laboratory, will in most cases be minimal. It should be noted, however, that while larger (>25-30 mm) Whitebait and Blue Sprat are easily distinguishable, smaller fish (*i.e.* post-flexion larvae) of these species are more difficult to discern visually, and will require more detailed examination in the laboratory.

Resources permitting, it would also be beneficial to spread the collection of replicates at each site over two separate sampling occasions within each month to reduce the likelihood of the resultant data being unduly influenced by atypical catches. This approach was adopted in the current study and demonstrated that there were 13 occasions where, at any single site in a given month, relatively large catches of Whitebait and/or Blue Sprat were collected on one of the sampling occasions but not the other, *e.g.* at Boat Ramp North in October 2013, 3,579 Whitebait and 0 Blue Sprat were collected on the first sampling occasion, while 0 Whitebait and 739 Blue Sprat were collected on the second, just one week later.

5. Conclusions

5.1 Objective 1: Interannual trends in Whitebait abundances and the broader fish community at Becher Point since the mid-1990s, and relationships with environmental variables

Whitebait densities in the nearshore waters at Becher Point, as recorded in samples collected by the DoF using a 61 m seine net, have declined markedly between 1996-2001 and 2006-13. These broad interannual trends were also mirrored at Pinnaroo Point ~80 km to the north, indicating that the main drivers of these trends are factors operating at regional scales rather than highly localised scales exclusive to the Becher Point area.

The above interannual trends in Whitebait catches at Becher Point were moderately well ‘explained’ by particular wind, wave and/or rainfall conditions. Thus, the earlier years in which catches were greater often had more frequent light (<10 km/h) easterly winds (with either no lag or a one year lag imposed), less frequent strong (20-30 km/h) easterly winds (one year lag), greater inshore wave heights (no time lag) and higher rainfall (two-year lag). While it is important to reiterate that these conditions do not necessarily have a direct, causative effect on Whitebait abundance, it is feasible that the inshore transport of the pelagic eggs and larvae of this species to suitable coastal nurseries is facilitated under lighter offshore winds and greater inshore wave activity. The latter could also create better feeding conditions for the zooplanktivorous larvae and juveniles of Whitebait.

In contrast, few obvious interannual trends were detected in the mean species richness, density or species composition of the full fish assemblage at Becher Point from 2007-13. The shorter time frame of examination reflected the fact that the abundances of ‘low priority’ (presumably non-fishery) species were not recorded consistently in the DoF nearshore monitoring program prior to 2007. No significant interannual matches were found between this fish data and any environmental variables in any season or lag state, but the ability to detect such relationships was compromised by the relatively small number of years able to be included in these tests.

When the fish assemblage data was restricted to those species known to be consistently recorded over the full (1996-2013) monitoring period (*i.e.* thus enabling longer time scales to be examined), several species in addition to Whitebait tended to decline from earlier (1996-2001/06) to later (2006/07-2013) years in one or more seasons, *e.g.* Yellowfin Whiting, Yelloweye Mullet and Australian Herring. These trends in autumn and spring were most clearly linked (across various lag states) with more frequent light easterlies, light southerlies and strong westerlies in earlier than later years. As all of the above species also have pelagic eggs and use nearshore areas as nurseries, it is feasible that their inshore recruitment success is enhanced under the above wind conditions, although more detailed studies are required to determine the veracity of these linkages. Fish faunal trends in summer were most clearly related to Leeuwin Current strength and summer sea surface temperatures in the same year, with assemblages in the 'marine heatwave' conditions of 2011 being particularly depauperate.

5.2 Objective 2: Interannual relationships between penguin biology and penguin prey and environmental variables

Interannual trends in the breeding performance (1986-2011) and survival (1986-2008) of Little Penguins on Penguin Island were significantly and most clearly linked with penguin prey abundances at Becher Point, air and/or sea surface temperatures and/or local wind conditions.

Trends in survival were, in the same year, positively related with autumn Blue Sprat abundances at Becher Point and more frequent strong southerly and northerly winds, and inversely related to the number of hot (> 33 °C) days in December-January. Following the introduction of a one to two year lag into the environmental data, higher penguin survival was most clearly related to lower April sea surface temperatures in Warnbro Sound, less frequent light easterly winds and more frequent light south-westerly winds. The extent of any significant lagged relationships between survival and prey abundances at Becher Point are unknown, however, as there were an insufficient number of samples to enable reliable statistical testing. Penguin breeding performance was also inversely related to April (autumn) sea surface temperatures in Warnbro Sound (but in the same year) and positively related to strong westerly winds (also in the same year).

The first of the above relationships corresponds not only with the fact that Blue Sprat is a key prey item for Little Penguins, but also with the fast growth and short life span (~eight months) of this fish species. The latter would thus ensure that juveniles in the shallows at Becher Point would grow to a size typically eaten by penguins, and move offshore to the main penguin foraging areas, within the same year. The findings of the current study and the companion study by Cannell (2013) also provide some evidence of a lagged relationship between penguin population size and Whitebait abundances at Becher Point, although these linkages could not be tested statistically. Higher penguin mortality during hot summer days concurs with previous findings of Cannell *et al.* (2012) and Robert-Coudert *et al.* (2004).

The mechanism(s) underlying the relationships between penguin biology and various local wind conditions are less clear, but could include direct pathways such as terrestrial cooling or indirect pathways such as through impacts on prey availability. Some potential drivers of the latter are suggested, though they require further testing.

The negative impacts of higher April (autumn) sea surface temperatures in Warnbro Sound on penguin breeding performance correspond with the findings of Cannell *et al.* (2012), who suggested that such conditions may cause emigration of local fish stocks and thus increase penguin foraging time and/or reduce meal sizes. However, the current study did not find any substantial evidence to support this theory.

Although some significant interannual relationships were occasionally detected between penguin biology and the commercial catches of penguin prey species in the region of interest, these relationships were generally inverse and are likely to be spurious due to several issues with the representativeness of this fish data set.

5.3 Objective 3: Impact of the boat ramp on Whitebait abundance and the broader fish community at Becher Point

There is little evidence from the outcomes of this study to indicate that the boat ramp constructed at Becher Point in 2010 has impacted the abundance of Whitebait or the species richness, density or composition of the broader fish fauna in the nearshore waters of this region. Although far greater numbers of Whitebait were recorded in comparable samples collected using the 21.5 m seine net prior to (1997, 2000-01) than following (2011-13) construction of the boat ramp, these trends are more likely to reflect the impact of broader, regional-scale environmental drivers than highly localised ones exclusive to Becher Point.

Thus, while the inability to collect comparable fish data in the year(s) immediately preceding boat ramp construction has compromised understanding of any ‘before *vs* after’ impacts to some extent, a marked decline in Whitebait abundance was also observed from 1996-2001 to 2006-13 at Becher Point and from 1998-2001 to 2005-12 at Pinnaroo Point (~80 km north) in samples collected by the DoF using a 61 m seine net (see subsection 5.1). Given that the latter datasets show that Whitebait catches were low for at least four consecutive years before construction of the ramp, and that such interannual shifts were relatively well ‘explained’ by various climatic and oceanographic factors (see subsection 5.1), it is less likely that the reduction in Whitebait observed in the current study is due to any negative impacts of the boat ramp *per se*, and more likely to be a result of the above environmental factors.

With respect to the spatio-temporal trends observed in Whitebait and the broader fish fauna at the five sites sampled around Becher Point (including near the boat ramp) between August and January in 2011-13, the most pronounced and/or consistent trends tended to occur among months (with a progression from winter to summer) rather than years or sites. These intra-annual trends reflected differences in the timing of the inshore migration/emigration of species that use this area as a nursery, and the reproductive cycles of resident species. Notably lower densities of Whitebait and fish overall were also recorded in 2011 and/or 2012, which may be related to the impacts of the ‘marine heatwave’ that peaked along WA’s west coast in the first of these years.

5.4 Objective 4: Design a cost-effective and robust monitoring regime to enable the abundance of Whitebait around Becher Point to be reliably measured into the future

The following monitoring regime has been proposed for reliably and cost-effectively tracking the abundance and distribution of Whitebait, and also that of Blue Sprat, in the Becher Point area into the future.

Sampling sites	Boat Ramp, Becher Point and Comet Bay	Sites at which Whitebait and/or Blue Sprat catches are largest, historical records are longest and/or direct assessment of any boat ramp impacts are enabled.
Sampling times	Monthly from September-March on an annual basis	Covers main juvenile recruitment periods for both species and accounts for interannual variability in recruitment strength. Resources permitting, sampling from August-April would better capture any shifts in peak recruitment times.
Sampling method	21.5 m beach seine net	Effective at catching target species; simple and quick to deploy by two people; minimises impact on fish fauna; maintains consistency in gear type with the current study.
Replication	Minimum of four replicates per site, month and year, preferably collected on two separate occasions per site and month	Target species are highly schooling and patchily distributed. This variability would be better accounted for by spreading collection of replicates at each site over two occasions per month and, resources permitting, collecting six instead of four replicates.

6. Appendices

See overleaf.

Appendix 1: Mean density (M; fish 500 m^{-2}) and percentage contribution (%) of each fish species in samples collected in the nearshore waters at Becher point during the DoF monitoring program between 2007 and 2013. Relatively abundant species (*i.e.* those contributing >5% to the overall catch in any year) are highlighted in grey. W.=Western; S.=Southern.

		2007		2008		2009		2010		2011		2012		2013	
Species name	**Common name**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**
Spratelloides robustus	Blue Sprat	59.79	59.11	171.40	77.34	73.76	55.83	243.17	73.26	34.01	45.31	82.83	75.47	72.41	68.62
Hyperlophus vittatus	Whitebait	11.82	11.69	0.09	0.04	3.03	2.30	0.32	0.10	1.26	1.68	2.46	2.24	0.18	0.17
Sillago bassensis	S. School Whiting	4.90	4.85	4.67	2.11	1.32	1.00	0.56	0.17	3.91	5.21	2.68	2.45	5.79	5.49
Aldrichetta forsteri	Yelloweye Mullet	3.81	3.76	3.99	1.80	0.49	0.37	5.17	1.56	1.07	1.43	1.41	1.29	3.61	3.43
Atherinidae	Atherinid	3.54	3.50	13.64	6.15	4.63	3.50	3.48	1.05	1.63	2.18	3.07	2.80	2.79	2.64
Sillago vittata	W. School Whiting	3.38	3.34	4.42	1.99	1.99	1.51	1.85	0.56	10.32	13.75	1.41	1.29	1.07	1.02
Lesueurina platycephala	Sandfish	2.28	2.25	0.56	0.25	1.07	0.81	0.32	0.10	1.45	1.93	0.55	0.50	1.35	1.28
Ostorhinchus rueppellii	Gobbleguts	2.12	2.09			2.05	1.55	0.51	0.15	1.72	2.28			0.09	0.09
Torquigener pleurogramma	Blowfish	1.90	1.88	1.76	0.79	13.26	10.04	1.29	0.39	5.92	7.89	2.32	2.12	1.59	1.51
Sillaginidae	Whiting	1.63	1.62	11.54	5.21	1.65	1.25	0.56	0.17	1.15	1.54			0.06	0.06
Atherinomorus ogilbyi	Common Hardyhead	1.13	1.11	2.70	1.22	5.57	4.22	69.95	21.08	0.67	0.89	6.61	6.02	2.63	2.50
Sillago schomburgkii	Yellowfin Whiting	0.99	0.98	2.06	0.93	2.36	1.79	2.49	0.75	1.93	2.57	1.60	1.46	3.22	3.05
Pelsartia humeralis	Sea Trumpeter	0.67	0.66			0.25	0.19					0.03	0.03	0.03	0.03
Sillagindae sp.	Whiting	0.43	0.42	0.13	0.06	2.36	1.79	0.27	0.08					5.82	5.52
Contusus brevicaudatus	Prickly Toadfish	0.29	0.29	0.17	0.08	0.03	0.02	0.13	0.04	0.03	0.04	0.03	0.03	0.06	0.06
Odacidae	Weed Whiting	0.29	0.29							0.05	0.07				
Cnidoglanis macrocephalus	Cobbler	0.24	0.24			0.03	0.02	0.05	0.02	0.19	0.25	0.22	0.20	0.03	0.03
Pseudorhombus jenynsii	Small-tooth Flounder	0.21	0.21			0.12	0.09			0.03	0.04				
Callionymus goodladi	Longspine Dragonet	0.21	0.21	0.56	0.25	0.25	0.19								
Haletta semifasciata	Blue Weed Whiting	0.19	0.19			0.15	0.12	0.08	0.02	0.40	0.54	0.08	0.08	0.12	0.12
Platycephalus speculator	S. Bluespotted Flathead	0.16	0.16	0.13	0.06	0.06	0.05	0.03	0.01	0.03	0.04	0.08	0.08	0.21	0.20
Arripis georgianus	Australian Herring	0.13	0.13	0.13	0.06	0.03	0.02	0.08	0.02	0.03	0.04	0.28	0.25	0.58	0.55
Ammotretis elongatus	Elongate Flounder	0.13	0.13	0.04	0.02	0.09	0.07	0.03	0.01			0.06	0.05	0.15	0.15
Rhabdosargus sarba	Tarwhine	0.11	0.11	0.09	0.04	0.40	0.30			0.19	0.25	0.22	0.20	0.98	0.93
Hyporhamphus melanochir	Southern Garfish	0.11	0.11	00.26	0.12	0.06	0.05	0.03	0.01			1.27	1.16		
Pentapodus vitta	Western Butterfish	0.08	0.08	0.64	0.29	0.58	0.44	0.21	0.06	0.35	0.46	0.06	0.05	0.61	0.58

		2007		2008		2009		2010		2011		2012		2013	
Species name	**Common name**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**
Gerres subfasciatus	Common Silverbiddy	0.05	0.05	0.04	0.02	13.08	9.90	0.64	0.19	0.67	0.89	0.89	0.81	1.23	1.16
Sillago burrus	W. Trumpeter Whiting	0.05	0.05	0.04	0.02	0.18	0.14			0.16	0.21			0.03	0.03
Mugil cephalus	Sea Mullet	0.05	0.05	0.09	0.04					0.03	0.04	0.22	0.20	0.03	0.03
Gymnapistes marmoratus	Soldier	0.05	0.05					0.32	0.10	0.03	0.04			0.03	0.03
Monacanthidae	Leatherjacket	0.05	0.05			0.03	0.02			1.47	1.96	0.14	0.13	0.03	0.03
Aptychotrema vincentiana	W. Shovelnose Ray	0.05	0.05			0.03	0.02	0.03	0.01	0.05	0.07			0.15	0.15
Dactylopus dactylopus	Finger Dragonet	0.05	0.05	0.09	0.04	0.03	0.02	0.03	0.01	0.11	0.14				
Scobinichthys granulatus	Rough Leatherjacket	0.05	0.05	0.04	0.02	0.06	0.05	0.03	0.01						
Pomatomus saltatrix	Tailor	0.03	0.03			0.03	0.02	0.08	0.02						
Pelates octolineatus	W. Striped Grunter	0.03	0.03	0.26	0.12	2.76	2.09	0.05	0.02	1.29	1.71	0.28	0.25	0.40	0.38
Cristiceps aurantiacus	Yellow Crested Weedfish	0.03	0.03					0.03	0.01			0.03	0.03		
Mullidae	Goatfish	0.03	0.03												
Platycephalidae	Flathead	0.03	0.03												
Stigmatopora argus	Spotted Pipefish	0.03	0.03	0.04	0.02					0.05	0.07				
Carangidae	Jacks			1.46	0.66							0.06	0.05		
Sillaginodes punctata	King George Whiting			0.56	0.25			0.03	0.01	0.03	0.04	0.03	0.03		
Leptoichthys fistularius	Brushtail Pipefish			0.04	0.02										
Paraplagusia bilineata	Lemon Tongue Sole					0.06	0.05								
Pseudocaranx dentex	Silver Trevally					0.06	0.05								
Cristiceps australis	S. Crested Weedfish					0.03	0.02			0.03	0.04	0.08	0.08		
Enoplosus armatus	Old Wife					0.03	0.02								
Leviprora inops	Longhead Flathead					0.03	0.02								
Platycephalus endrachtensis	Yellowtail Flathead					0.03	0.02								
Scorpis georgiana	Banded Sweep					0.03	0.02							0.03	0.03
Upeneichthys vlamingii	Bluespotted Goatfish					0.03	0.02							0.03	0.03
Aracana aurita	Shaw's Cowfish							0.03	0.01	0.05	0.07				
Syngnathidae	Pipefish							0.03	0.01	0.08	0.11			0.06	0.06
Trygonorhina fasciata	Southern Fiddler Ray							0.03	0.01						
Leptatherina presbyteroides	Sliverfish									2.44	3.25	0.36	0.33		
Sillago analis	Goldenline Whiting									1.66	2.21				

		2007		2008		2009		2010		2011		2012		2013	
Species name	**Common name**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**	**M**	**%**
Arripis truttaceus	WA Salmon									0.35	0.46				
Sphyraena novaehollandiae	Snook									0.08	0.11	0.03	0.03		
Acanthopagrus butcheri	Black Bream									0.03	0.04				
Atherinosoma elongata	Elongate Hardyhead									0.03	0.04				
Parupeneus chryserpleuron	Goatfish									0.03	0.04				
Strongylura leiura	Slender Longtom									0.03	0.04				
Urolophidae	Round Stingray									0.03	0.04				
Pseudocaranx wrighti	Skipjack Trevally											0.14	0.13		
Elops hawaiensis	Hawaiian Giant Herring											0.08	0.08		
Siphamia cephalotes	Wood's Siphonfish											0.06	0.05		
Chaetodermis penicilligerus	Prickly Leatherjacket											0.03	0.03		
Iso rhothophilus	Surf Sardine											0.03	0.03		
Tetraodontidae	Pufferfish											0.03	0.03		
Trachurus novaezelandiae	Yellowtail Scad													0.03	0.03
Number of species		**40**		**30**		**41**		**33**		**43**		**36**		**33**	
Total mean density		**101**		**222**		**132**		**332**		**75**		**110**		**106**	

Appendix 2: Results of one-way ANOSIM tests on interannual differences in fish assemblage composition in samples collected from the nearshore waters at Becher point during the DoF monitoring program between 2007 and 2013. Tests were performed separately for each season sampled. Insignificant results are highlighted in grey, while moderately high (0.500-0.750) and high (> 0.750) pairwise R-statistic values are highlighted in yellow and red, respectively.

Summary; *P* = 0.001; Global R = 0.187;

	2007	**2008**	**2009**	**2010**	**2011**	**2012**
2008	0.045					
2009	0.272	0.166				
2010	0.169	0.076	0.171			
2011	0.342	0.235	0.150	0.081		
2012	0.178	0.148	0.311	0.057	0.121	
2013	0.209	0.300	0.356	0.071	0.255	0.161

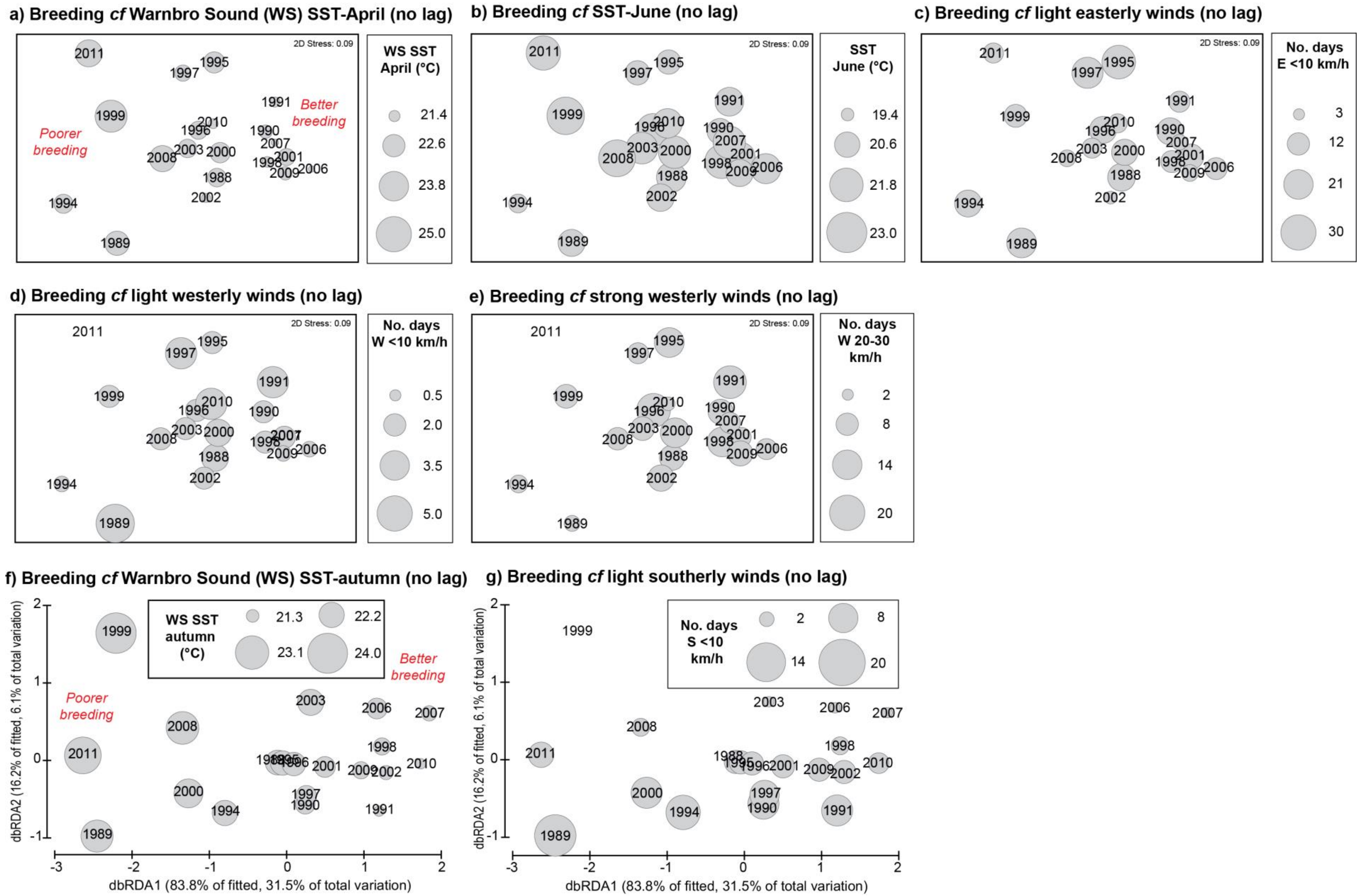
Autumn; *P* = 0.001; Global R =0.282

	2007	**2008**	**2009**	**2010**	**2011**	**2012**
2008	0.022					
2009	0.166	0.256				
2010	0.574	0.493	0.427			
2011	0.446	0.500	0.389	0.650		
2012	0.129	-0.027	0.192	0.249	0.254	
2013	0.109	-0.017	0.172	0.415	0.349	0.052

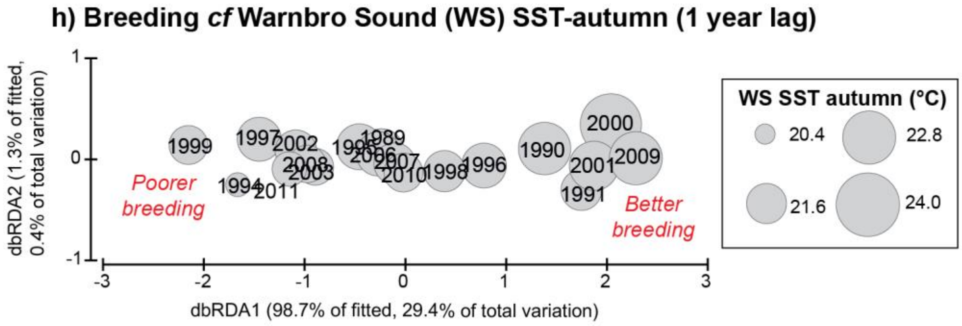
Spring: *P* = 0.001; Global *R*=0.198

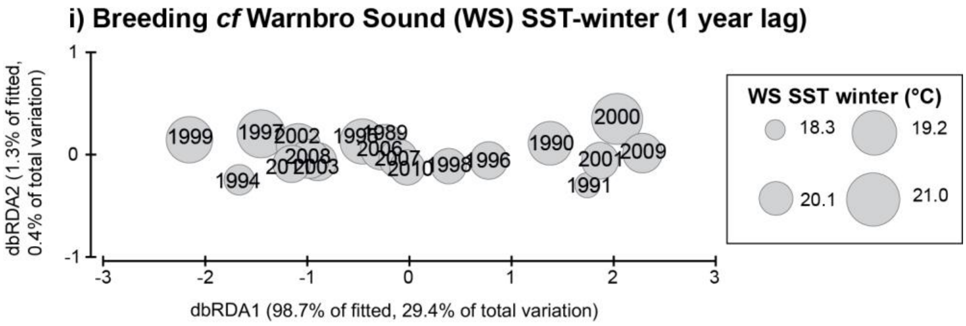
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
2008	0.288					
2009	0.349	0.282				
2010	0.370	0.184	0.295			
2011	0.07	0.206	0.315	0.328		
2012	0.232	0.079	0.087	0.288	0.109	
2013	0.203	0.204	0.092	0.257	0.014	-0.044

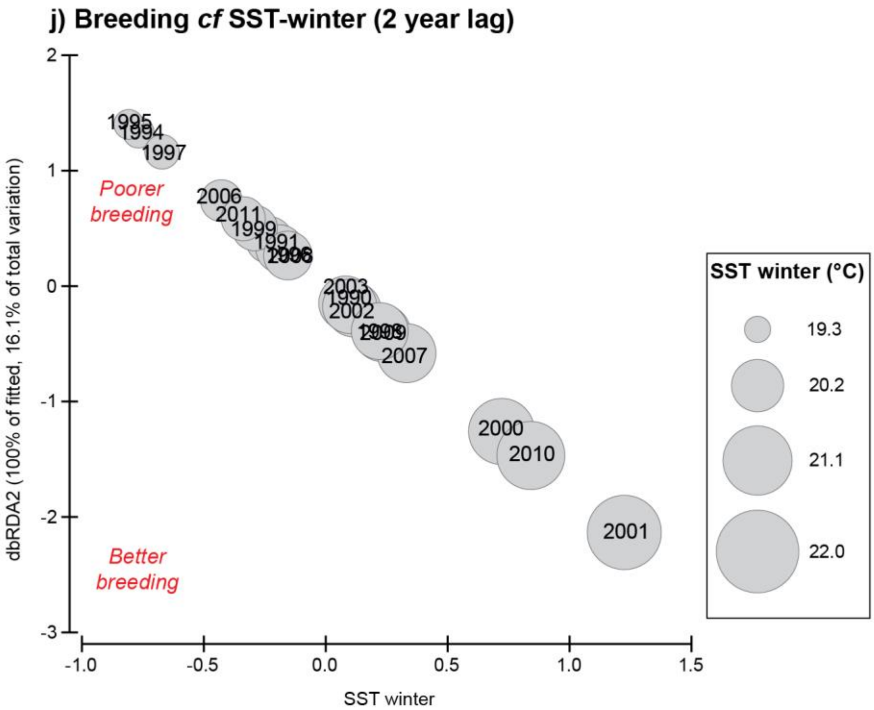
Appendix 3: MDS or dbRDA ordination plots depicting the significant interannual relationships between Little Penguin breeding performance and environmental variables (in specified lag states) selected by the BIOENV or DISTLM routines. The (unpretreated) magnitudes of the selected environmental variables are also overlaid on each year as circles of proportionate sizes.



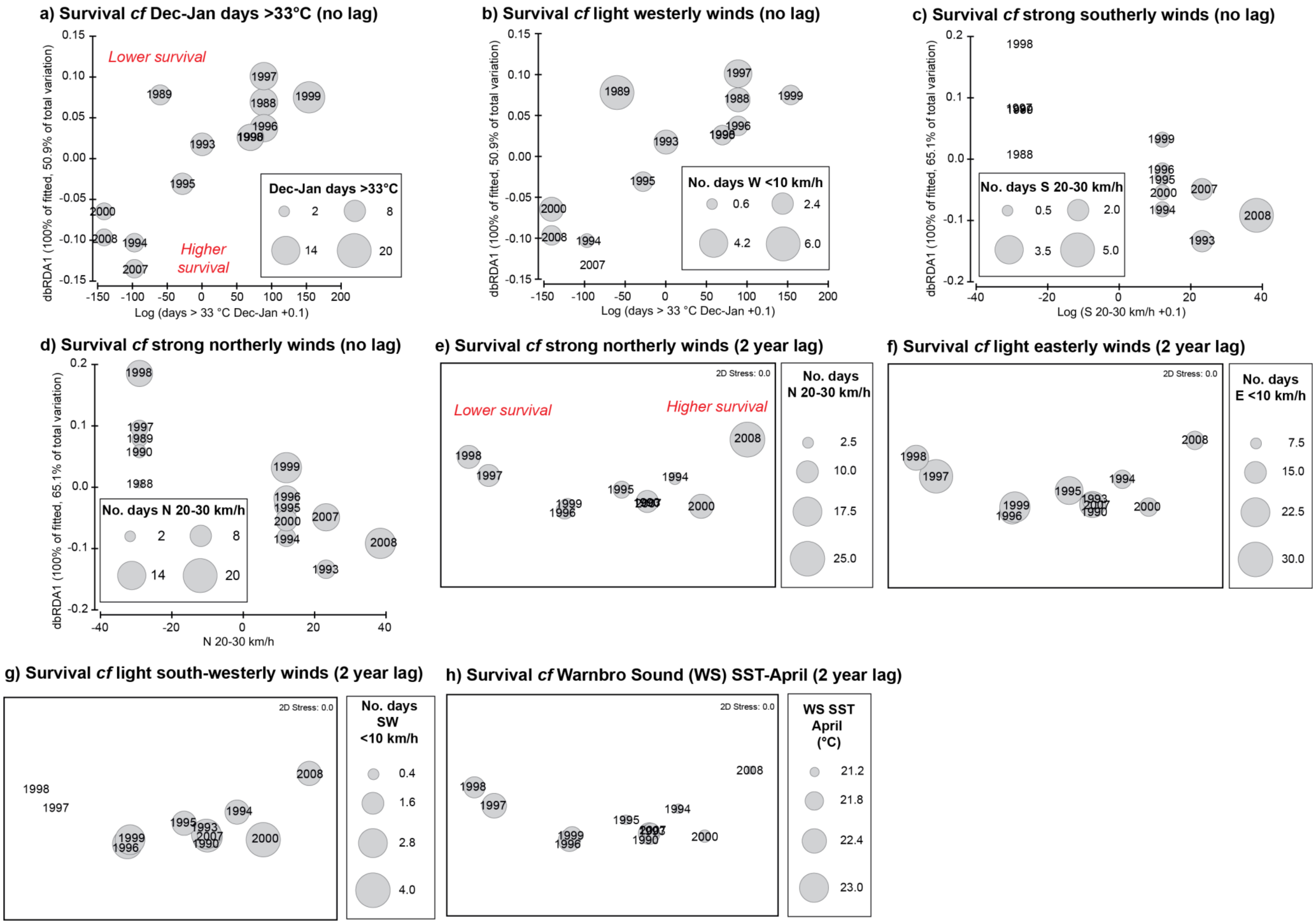
Appendix 3 (continued).





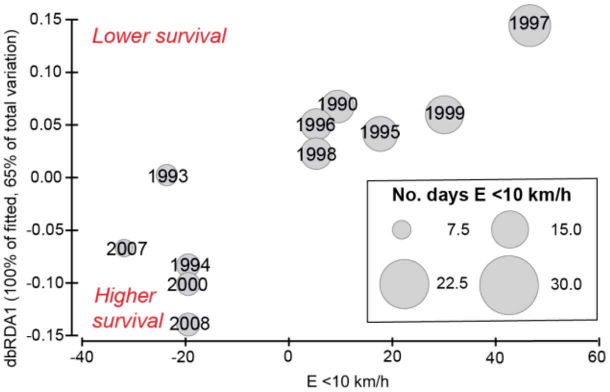


Appendix 4: MDS or dbRDA ordination plots depicting the significant interannual relationships between Little Penguin survival and environmental variables (in specified lag states) selected by the BIOENV or DISTLM routines. The (unpretreated) magnitudes of the selected environmental variables are also overlaid on each year as circles of proportionate sizes.

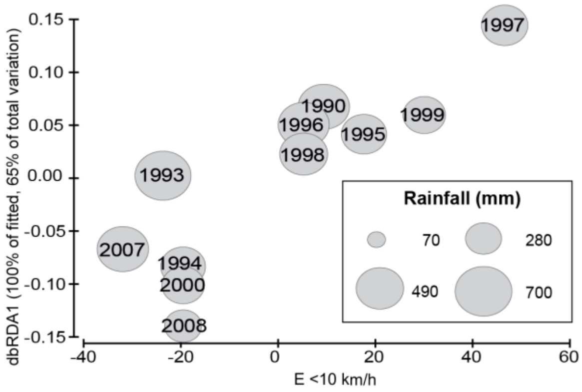


Appendix 4 (continued).

i) Survival *cf* light easterly winds (2 year lag)



j) Survival *cf* rainfall (2 year lag)



Appendix 5: Global and pairwise R-statistic and/or significance level (*P*) values derived from site*year ANOSIM tests of the nearshore fish fauna recorded at sites around Becher Point from 2011-13, undertaken separately for each sampling month. Insignificant results are highlighted in grey, while moderately high (0.500-0.750) and high (> 0.750) pairwise R-statistic values are highlighted in yellow and red, respectively. CB = Comet Bay; BP = Becher Point; BRS = Boat Ramp South; BR = Boat Ramp; BRN = Boat Ramp North.

(a) August
P = 0.001, Global R = 0.179,

	BP	BR	BRN	BRS
BR	0.167			
BRN	0.260	0.049		
BRS	0.163	0.104	0.288	
CB	0.410	0.255	0.375	0.116

(b) September
P = 0.001, Global R = 0.118,

	BP	BR	BRN	BRS
BR	-0.069			
BRN	0.139	0.104		
BRS	0.069	0.080	0.253	
CB	0.108	0.194	0.184	0.382

(c) October
P = 0.001, Global R = 0.166

	BP	BR	BRN	BRS
BR	0.149			
BRN	0.299	0.076		
BRS	0.226	-0.097	0.167	
CB	0.188	0.215	0.333	0.264

(d) November
P = 0.001, Global R = 0.223,

	BP	BR	BRN	BRS
BR	0.056			
BRN	0.285	0.236		
BRS	0.052	0.163	0.375	
CB	0.326	0.170	0.431	0.365

(e) December
P = 0.001, Global R = 0.328

	BP	BR	BRN	BRS
BR	0.299			
BRN	0.292	0.156		
BRS	0.163	0.128	0.240	
CB	0.552	0.608	0.368	0.628

(f) January
P = 0.002, Global R = 0.153

	BP	BR	BRN	BRS
BR	0.222			
BRN	0.097	0.094		
BRS	0.208	-0.073	0.052	
CB	0.278	0.299	0.153	0.288

Appendix 6: Global and pairwise R-statistic and/or significance level (*P*) values derived from one-way ANOSIM tests of the nearshore fish fauna at Becher Point in each sampling month in 2011-13, undertaken separately for each year and site. Insignificant results are highlighted in grey, while moderately high (0.500-0.750) and high (> 0.750) pairwise R statistic values are highlighted in yellow and red, respectively.

(a) Comet Bay

2011: *P* = 0.001, Global R = 0.356

	Aug	Sep	Oct	Nov	Dec
Sep	0.573				
Oct	0.073	0.271			
Nov	0.313	0.260	0.042		
Dec	1.000	0.771	0.698	0.26	
Jan	0.479	0.375	0.135	0.104	0.271

2012: *P* = 0.021, Global R = 0.171

	Aug	Sep	Oct	Nov	Dec
Sep	0.031				
Oct	-0.026	-0.063			
Nov	0.141	0.255	0.042		
Dec	0.365	0.188	-0.052	0.469	
Jan	0.281	0.198	0.063	0.490	-0.01

2013: *P* = 0.001, Global R = 0.559

	Aug	Sep	Oct	Nov	Dec
Sep	0.521				
Oct	0.583	0.521			
Nov	0.813	0.615	0.750		
Dec	0.354	0.396	0.625	0.781	
Jan	0.729	0.688	0.823	0.958	0.708

(b) Becher Point

2011: *P* = 0.006, Global R = 0.210

	Aug	Sep	Oct	Nov	Dec
Sep	-0.021				
Oct	-0.104	0.031			
Nov	0.354	0.375	0.073		
Dec	0.615	0.688	0.240	0.354	
Jan	0.344	0.250	-0.042	0.375	-0.021

2012: *P* = 0.001, Global R = 0.511

	Aug	Sep	Oct	Nov	Dec
Sep	-0.094				
Oct	0.813	0.854			
Nov	0.552	0.615	0.719		
Dec	0.938	0.948	0.615	0.417	
Jan	0.25	0.219	0.583	0.25	0.688

2013: *P* = 0.001, Global R = 0.387

	Aug	Sep	Oct	Nov	Dec
Sep	0.667				
Oct	0.417	-0.094			
Nov	0.667	0.021	-0.083		
Dec	0.375	0.552	0.521	0.583	
Jan	0.958	0.646	0.406	0.677	0.292

(c) Boat Ramp South

2011: *P* = 0.001, Global R = 0.254

	Aug	Sep	Oct	Nov	Dec
Sep	0.448				
Oct	0.240	0.292			
Nov	0.104	0.667	0.010		
Dec	0.260	0.448	0.115	0.24	
Jan	0.063	0.646	0.281	0.167	0.365

2012: *P* = 0.001, Global R = 0.719

	Aug	Sep	Oct	Nov	Dec
Sep	0.365				
Oct	0.792	0.500			
Nov	0.979	1.000	0.802		
Dec	0.969	1.000	0.760	0.479	
Jan	0.906	0.917	0.740	0.646	0.000

2013: *P* = 0.001, Global R = 0.428

	Aug	Sep	Oct	Nov	Dec
Sep	0.417				
Oct	0.083	0.354			
Nov	0.479	-0.104	0.448		
Dec	0.771	0.833	0.760	0.677	
Jan	0.458	0.479	0.510	0.365	0.229

(d) Boat Ramp

2011: *P* = 0.860, Global R = 0.072

	Aug	Sep	Oct	Nov	Dec
Sep	-0.042				
Oct	0.104	0.010			
Nov	0.073	-0.042	0.302		
Dec	0.094	0.250	0.208	0.052	
Jan	0.010	0.188	0.115	0.042	-0.083

2012: *P* = 0.003, Global R = 0.220

	Aug	Sep	Oct	Nov	Dec
Sep	0.365				
Oct	0.531	0.073			
Nov	0.531	0.552	0.375		
Dec	0.146	0.000	-0.010	0.375	
Jan	0.375	0.354	0.250	-0.104	-0.281

2013: *P* = 0.002, Global R = 0.244

	Aug	Sep	Oct	Nov	Dec
Sep	0.042				
Oct	-0.042	0.146			
Nov	-0.042	0.042	-0.167		
Dec	0.813	0.750	0.406	0.250	
Jan	0.479	0.531	0.417	0.365	0.219

Appendix 6 (continued).

(e) Boat Ramp North

2011: P = 0.011, Global R = 0.150

	Aug	Sep	Oct	Nov	Dec
Sep	0.094				
Oct	0.198	0.104			
Nov	0.177	-0.042	0.198		
Dec	0.167	0.094	0.167	0.135	
Jan	0.063	0.219	0.375	0.240	0.031

2012: P = 0.001, Global R = 0.369

	Aug	Sep	Oct	Nov	Dec
Sep	0.448				
Oct	0.688	0.719			
Nov	0.323	0.531	0.365		
Dec	0.292	0.500	0.531	0.417	
Jan	0.219	0.333	0.125	0.510	0.219

2013: P = 0.001, Global R = 0.281

	Aug	Sep	Oct	Nov	Dec
Sep	0.667				
Oct	0.167	0.313			
Nov	0.302	0.219	0.208		
Dec	0.375	0.708	0.188	0.490	
Jan	0.396	0.188	0.031	0.271	-0.031

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