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SESSF species stock structure review: Blue Warehou, Jackass Morwong and Pink Ling

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Executive summary

This study reviews and summarises the available evidence on the separation of stocks to the east and west of Tasmania (longitude 147° East) of Blue Warehou (*Seriolella brama*), Jackass Morwong (*Nemadactylus macropterus*) and Pink Ling (*Genypterus blacodes*). Available literature is reviewed and differences by region in catch, discards, length and age frequencies and CPUE are investigated.

Blue Warehou has the strongest evidence of separate stocks, with genetic differences (even though non-significant), differences in otolith microchemistry and differences in size and age distributions between the east and the west. These differences present clear evidence which supports splitting both the assessment and management arrangements between these two regions.

Jackass Morwong are not genetically different between the two regions and there is no current evidence supporting differences in otolith microchemistry. Mixing of Jackass Morwong is unknown although differences in recruitment between regions suggests some separation of populations along with differences in length and age distributions. While there has been limited research at the appropriate spatial scale to determine splits in stock structure, the differences in recruitment patterns between the two regions were considered adequate to justify conducting separate assessments to the east and west.

No genetic differences in Pink Ling have been observed and there have been no studies investigating otolith microchemistry. Other biological investigations have been limited, although there is some evidence of sedentary adult populations, differences in length and age distributions by region, along with different trends in growth between the regions. This evidence has previously been considered adequate to justify conducting separate assessments for each of the two regions.

An overview of results for each of the characteristics investigated by this study are included in Table 1.

Table 1. Summary of differences in stock structure characteristics investigated for Blue Warehou, Jackass Morwong and Pink Ling.

Characteristics	Common name		
	Blue Warehou	**Jackass Morwong**	**Pink Ling**
Genetics	Differences between east and west, although non-significant	No genetic differences between east and west	No genetic differences between east and west
Otolith microchemistry	Differences in both microchemistry and shape	Some differences, but spatial scale insufficient to determine definitive stock differences	Unknown, no investigations
Evidence of mixing	Limited information on mixing, but a highly mobile schooling species with pelagic larvae	Limited movement of adults, offshore pelagic larval phase in the east possibly impacted by changes in the EAC	Unknown larval dispersal, largely sedentary as adults
Biological parameters – (growth and morphology)	Differences in growth curves and morphology	Limited information	Differences in growth curves
Length frequency	No difference between east and west	Larger in west than east	Larger in west than east
Age frequency	Older in west than east	Older in west than east	Older in west than east
Discards	Similar trends between east and west	Sporadic and variable	Higher in east than west since 2003
Current CPUE	Similar overall trends between east and west	Similar overall trends between east and west	Similar overall trends between east and west
Reasoning for historical stock assessment split	Separate areas and timing for spawning. Differences in size, age and growth.	Expert judgement, a productivity shift is evident in the east but not the west.	Differences in size and age compositions along with differences in growth and the trends observed in standardised catch rates.

1 Introduction

1.1 Background on stock structure

Appropriate management of fish stocks is important to ensure their ongoing sustainability. Central to successful management is the determination of stock structure and identification of independent populations (Ricker 1981, Tyler 1988). A stock is classically defined as a population that is self-reproducing with members having similar life-history traits (Hilborn and Walters 1992).

Debate regarding the definition of a stock for fisheries management is ongoing. Many suggest that a stock includes a population that is assumed homogenous for a specific management purpose (Bailey and Smith, 1981, Tyler 1988, Begg and Waldman 1999). Others suggest that grouping based on divergent migration patterns and habitat use is more appropriate (Secor 1999). The definition of a fish stock depends on the methodology used to distinguish stocks, although many studies utilise a weight of evidence approach, considering the results from numerous methodologies (Begg and Waldman 1999, Begg et al. 1999, Patterson et al. 2019).

Various methodologies are used to determine the stock structure of populations. These range in suitability, sensitivity to detect changes and resourcing (including timeframes and cost) required for deployment. These methodologies range from genetic and phenotypic markers, otolith microchemistry and ageing, to parasite load determinations between populations.

The most definitive stock structure determination uses genetic techniques to determine whether there is mixing between populations and therefore, whether populations are genetically homogeneous. Genetic or genomic markers are the only techniques that can determine the level of diversity and gene flow across the generations; however it is this characteristic that poses the greatest challenges for fisheries stock assessments, as separation of populations over extended time periods and a significant lack of gene flow is required for genetic differences to be detected (Bailey and Smith 1981). These time periods are observed over multiple generations with gene flow estimates a reflection of both adult reproduction and larval mixing. Genetic differences between populations are central to the concept of a fish stock and form one of the most traditional stock definitions (Tyler 1988, Begg and Waldman 1999, Begg et al. 1999).

Phenotypic variation between populations is also used as a determinant of stock structure. Unlike genetic methods, phenotypic variation is not direct evidence of genetic isolation, however, differences in phenotypic characters (e.g. colour morphs) can indicate prolonged separation of populations subjected to different environmental conditions (Begg et al. 1999). Such phenotypic variation may include differences in body shape and features, along with differences in age and length frequency distributions, age at sexual maturity and growth rates.

Differences in otolith microchemistry are also used to determine differences between populations (Thresher 1999). Otolith microchemistry changes are observed when environmental factors influence the calcium-protein matrices of otoliths, suggesting different environmental conditions to which each population is exposed. This technique is more likely to detect differences between populations, as changes can occur on shorter timeframes than is required for genetic differences to be observed.

Parasites are used to detect differences in populations by determining whether mixing has occurred. If mixing is taking place, the same species of parasites would be observed in fish from both populations. Again, this technique can detect divergence of populations over much shorter timeframes than is required for genetic differences to be observed.

In the Southern and Eastern Scalefish and Shark Fishery (SESSF), a number of species have characteristics that have led to questions of whether there are separate stocks east and west of Tasmania, with the division between east and west generally accepted to occur at a longitude of 147° East, hereafter referred to as 'east' and 'west'. The east comprises SESSF zones 10, 20 and 30 and the west comprises SESSF zones 40 and 50 (Figure 1). In this report we consider three scalefish species: Blue Warehou (*Seriolella brama*), Jackass Morwong (*Nemadactylus macropterus*) and Pink Ling (*Genypterus blacodes*).

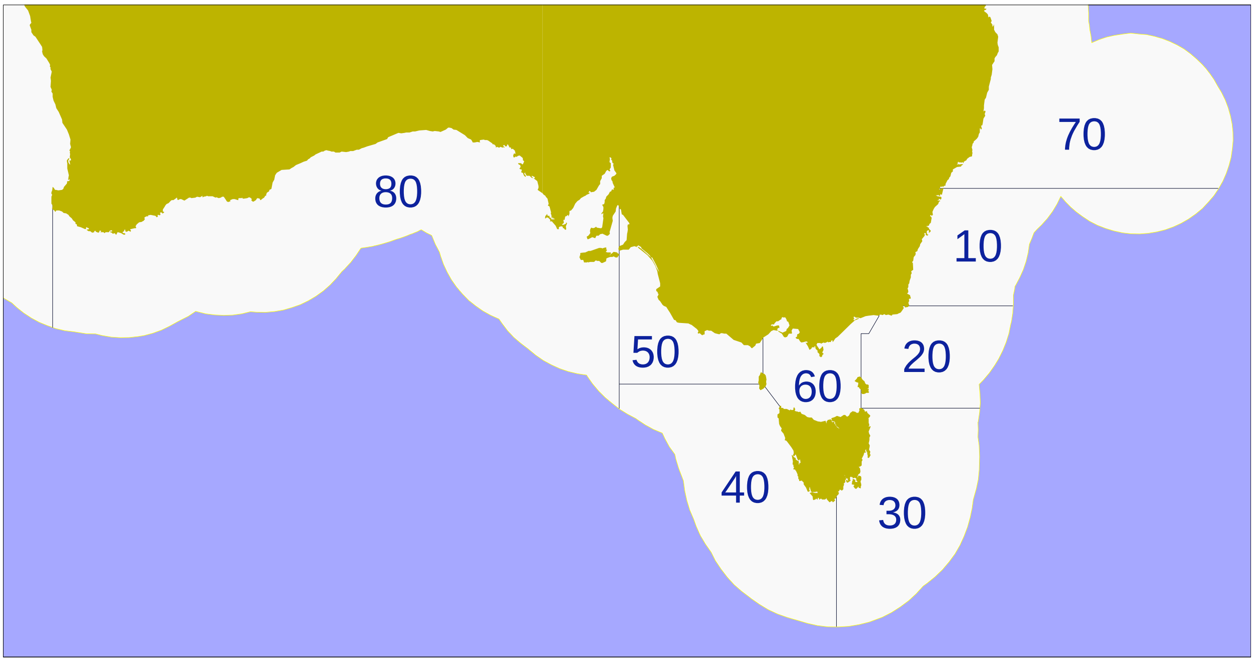

Figure 1. Map of the SESSF showing statistical zones.

All three species are currently managed under a single TAC, however, there are separate eastern and western assessments for Pink Ling (Cordue 2018) and Jackass Morwong (Day and Castillo-Jordán, 2018a, 2018b). Blue Warehou was last assessed as a Tier 4 species in 2013, with separate eastern and western assessments and is classified as a rebuilding species. Catches and discards are reported separately for the east and the west for all three species (Burch et al. 2019). In addition, separate annual standardised catch-per-unit effort (CPUE) estimates are also reported for each species split by fleet (Sporcic 2020), i.e., Pink Ling and Blue Warehou: east (SESSF zones 10, 20 and 30) and west (SESSF zones 40 and 50); Jackass Morwong: SESSF zone (i) east (SESSF zones 10 and 20); (ii) eastern Tasmania (SESSF zone 30) and (iii) west (SESSF zones 40 and 50). In this report, we examine evidence for differences in the biological and fishery characteristics between eastern and western stocks of these three species. The evidence considered here includes reviewing relevant literature, stock assessments and current biological and fisheries data, relating to the stock structure of Blue Warehou, Jackass Morwong and Pink Ling.

Knuckey et al. (2010) state that the southeast region represents an important 'gateway' between the Pacific and Indian Oceans. It is strongly influenced by the East Australian Current (EAC) from the northeast (Figure 2). This is a major western boundary current and it carries large volumes of warm, nutrient poor water southwards into the region. The EAC is highly variable and its flow is associated with large (300 km) eddies which also move southwards. Some of these features reach as far as Tasmania and drift into the Indian Ocean south of Australia. The waters around Tasmania are highly seasonal and surface currents bring warm water during winter on the west coast and in summer off the east coast.

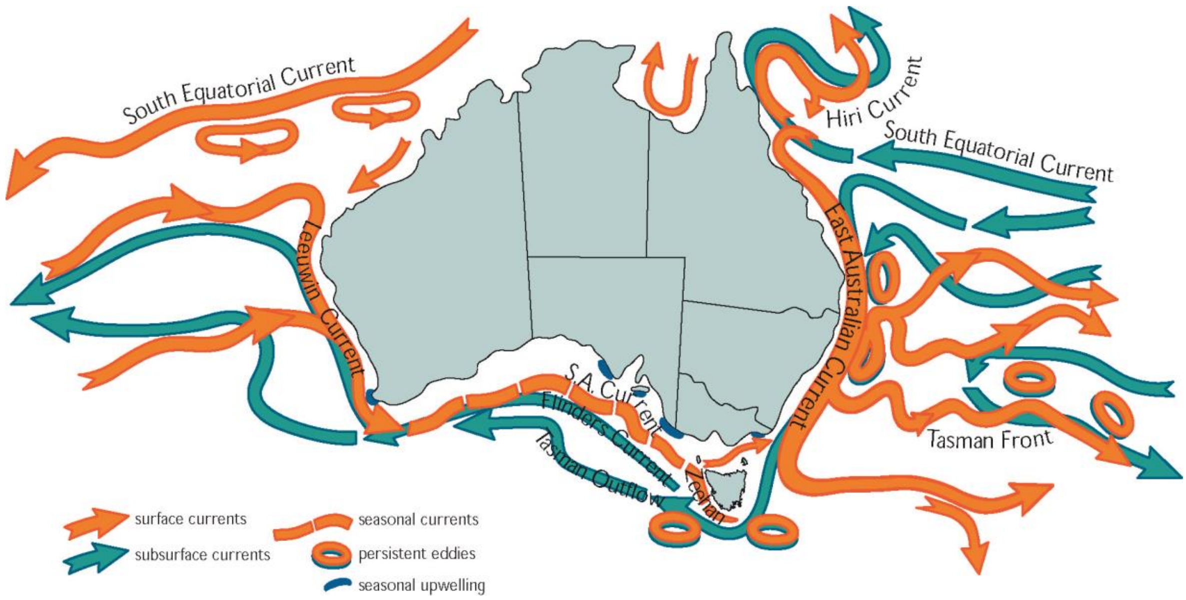

Figure 2. Schematic description of the surface and subsurface currents around Australia (from Knuckey et al. 2010).

Summer and winter patterns of the surface circulation are influenced by the EAC and the Zeehan Current respectively. On the east coast in summer (Jan-Mar) there is a polewards flow of warm, saline water forced by an episodic coastal boundary flow (Figure 3).

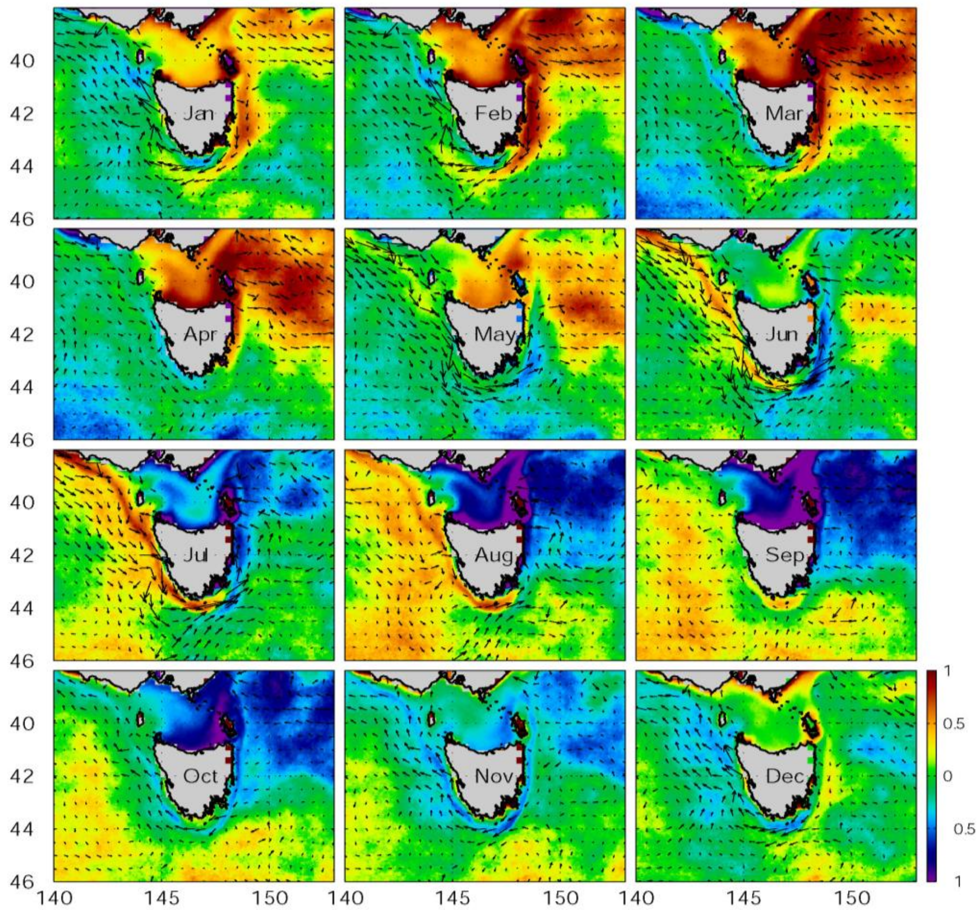

Figure 3. The monthly anomaly of SST from a composite SST product (1993-2003). We constructed the anomaly field by removing the annual mean SST from each grid-point and then removing a domain-wide seasonal anomaly (from Knuckey et al. 2010).

2 Species overview

2.1 Blue Warehou

Blue Warehou is a demersal species found in waters of southern Australia and New Zealand (Smith 1994), generally located in continental shelf and upper slope waters between 50 and 600 m (Smith 1994, Sporcic 2020), although most commercial catches occur from 50 to 300 m depth, with western catches generally a little deeper (150-300 m, Figure 34) than eastern catches (50-200 m, Figure 32). Blue Warehou live for approximately 15 years in Australian waters, although older fish (up to 25 years of age) are observed in New Zealand (Horn 2001, Knuckey and Sivakumarna 2001). The oldest specimen aged from the SESSF is 16 years (K. Krusic-Golub, pers. comm.). In Australia, spawning occurs in winter and spring in numerous locations, with larvae widely distributed (Knuckey and Sivakumarna 2001, Bruce et al. 2001a). Small juveniles are pelagic and sub-adults often occur in large bays, while adults are highly mobile (Smith 1994a). Growth occurs quickly in their first year reaching lengths of 20 cm, with maturity occurring at around three to four years of age, and 50% maturity attained at a length of 33.4 cm (Horn 2001, Knuckey and Sivakumarna 2001, Punt 2008).

Investigations into stock structure of Blue Warehou have been undertaken in New Zealand, where two stocks were identified, with northern and southern regions separated at a latitude of 44°S (Bagely et al. 1998). In Australia, Smith and Wayte (2002) acknowledge that no studies into stock structure had been conducted by 2002, but they summarised the information available, at that time, to support the single or two stock hypothesis, with high mobility of adults, the pelagic larvae and the lack of differences in growth supporting a single stock, whereas the two main spawning areas, the oceanography/biogeography of the region, larval distributions and differences in size and age distributions supporting the two stock hypothesis. An initial genetic study investigating stock structure and spatial dynamics found differences in mitochondrial DNA (mtDNA) haplotypes in Blue Warehou individuals in the east and west, suggesting the stocks were genetically different in the south east region (Talman et al. 2004). However, a subsequent study detected some sub-structuring in samples from east and west Victoria and east Tasmania although the differences were not significant; the authors suggested that further investigations were required and even though the differences observed were non-significant, separate management was warranted for the two areas (Robinson et al. 2008).

In addition to genetic differences, Talman et al. (2004) found significant differences in morphology, otolith shape and otolith microchemistry in the east and the west. Differences in spawning location and timing have also been observed between the east and west, with spawning from June to November in the east and August to November in the west (Bruce et al. 2001a, Knuckey and Sivakumarna 2001).

While there are limited studies on movement of Blue Warehou in Australia, they are understood to aggregate or school and to undertake major migrations, though these are not necessarily seasonal (Smith 1994a). Growth curves also differ in the east and west (Talman et al. 2004), with smaller fish in the west than in the east (Talman et al. 2004).

Blue Warehou is caught in both Commonwealth and state fisheries, throughout south-eastern Australia (New South Wales, Victoria, Tasmania and South Australia). Commercial fishing of this species is considered to have begun in 1986 in both the east and the west, which is relatively late compared to many other species caught in the SESSF (Punt 2009). Up until 2000, total catches were higher in the east than the west (Punt 2008), where total catches include state catches and discards, allowing for occasional very high discard rates, which are over 50% in some years. This pattern is also generally reflected in catches recorded in logbooks (Table 4). Since 2001, catches in the west have generally been higher than catches from the east, both in the total catches (Punt 2008) and in logbook catches (Table 4). Since 2011, catches in each of the east and the west have been less than 100 t per year and since 2014 they have been less than 30 t per year in each region (Table 4). State catch totals for Blue Warehou have generally been considerably smaller than Commonwealth catch totals, and, in recent years, the combined catch total (state plus Commonwealth) has been very low (<20 t since 2010).

The evidence suggesting separate stocks of Blue Warehou led to separate stock assessments being conducted for eastern and western stocks in the SESSF in 2000, and in the subsequent assessment (Punt 2008). This was based on separate main spawning areas and differences in size, age and growth between stocks in the east and the west. Assessments prior to 2000 assumed a single stock, given an absence of evidence to support a more complicated stock structure (Punt 2008).

These stock assessments have led to both the eastern and the western stocks being classified as overfished since 1999 (AFMA 2014, Punt 2008). The most recent Tier 4 assessment assumed separate eastern and western stocks with a Recommended Biological Catch of zero in each region (Haddon 2013). The Status of Australian Fish Stocks (SAFS) also separate Blue Warehou into eastern and western stocks, based on genetic differences between the two populations and separation of stock assessments (Hartmann 2018). The SAFS system classifies both stocks of Blue Warehou as depleted (Hartmann 2018). The ABARES fishery status reports in 2018 also classified Blue Warehou as overfished, with overfishing uncertain (Helidoniotis et al. 2018).

2.2 Jackass Morwong

Jackass Morwong is a relatively long-lived demersal fish species found in waters of southern Australia, New Zealand South America and South Africa, generally in waters of up to 450 m depth (Smith 1994). In Australia, they are caught from northern NSW in the east, south to Tasmania and west to the western edge of the Great Australian Bight. In southern Australia, spawning occurs between March and May, peaking in mid to late April (Bruce et al. 2001b). Smith (1994b) suggests that individuals may spawn more than once during the spawning season, with spawning at night in the midwater, and occurring throughout the full geographical range of the species. Larvae spend an extended period of between nine and 12 months offshore before metamorphosis to the adult form and settling in coastal shelf areas at approximately 70–90 mm length (Neira et al. 1998). In Australia, no large-scale migration of adult Jackass Morwong has been reported and tagging experiments found little movement of adults (Smith 1994b).

In New Zealand, early tagging experiments showed Jackass Morwong to move large distances around the coasts (Smith 1994b), which initially supported the hypothesis of a single stock around New Zealand, although, at this time, the stock around the Chatham Islands was considered to be a separate stock (Annala 1991). The oldest specimen aged from the SESSF is 46 years (K. Krusic-Golub, pers. comm.), but very few individuals live to this age. The oldest and largest fish tend to be caught either offshore or in deeper waters (Figure 17, Figure 20, Figure 21), with larger fish generally caught in the west (Figure 37, Figure 39, Figure 41). Jackass Morwong are thought to live longer in New Zealand than in Australia (Smith, 1994b). Growth for adults appears to be different between the sexes, with females growing faster and living to older ages than males (Smith 1994a). According to the estimated growth curve from the eastern stock, based on a single gender model, growth occurs steadily in the first five years reaching lengths over 25 cm by age five, with maturity occurring at around three to four years of age and around 24.5 cm and growing to a maximum length of around 50cm, but with most individuals achieving a maximum length less than 40cm (Day and Castillo-Jordán 2018a). The plus group for length used in the latest stock assessment is 47 cm, with the plus group for age at 25 years (Day and Castillo-Jordán 2018a). There is insufficient data to allow growth rates to be estimated from the western stock (Day and Castillo-Jordán, 2018b). Thresher et al. (2007) show that juvenile growth rates have increased by 28.5% from 1954 to 1992, potentially due to warming water in this same period.

Several genetic studies (based on allozymes, mtDNA and microsatellites) have been undertaken on Jackass Morwong throughout southern Australia. Most studies found no significant differences in populations ranging from Western Australia to New South Wales and across the Tasman Sea to New Zealand (Richardson 1982, Elliott and Ward 1994, Grewe et al. 1994, Burridge and Smolenski 2003). One study detected allozyme and mtDNA differences between samples in Australia and New Zealand, thereby indicating at least two genetically distinct stocks in the region, although no genetic differences were detected in samples collected within Australian waters (Thresher et al. 1993).

Investigation into otolith microchemistry of Jackass Morwong at 10 locations around southern Australia from Perth to Eden suggested that there may be up to four stocks; NSW and Victoria, southern Tasmania, the Great Australian Bight and Western Australia (Thresher et al. 1993). The study suggested that there is evidence of mixing between these populations, making stock discrimination difficult (Thresher et al. 1993). Further differences were observed between Jackass Morwong from southern Tasmania and those off NSW and Victoria, but it is unclear if such differences indicate separate stocks (Proctor et al. 1992).

In New Zealand, Jackass Morwong is commonly called Tarakihi and is an important component of inshore fisheries (Annala 1988). Larger fish caught in the North of New Zealand are anecdotally referred to as King Tarakihi, with stock investigations revealing they are genetically different to the smaller Tarakihi to the south, with this study concluding that they are different species (Smith et al. 1996).

In Australia, Jackass Morwong have been caught in the east since the early twentieth century and the inception of the steam trawl fishery (Klaer 2001, Day and Castillo-Jordán, 2018a, 2018b). The catch is predominantly taken by the Commonwealth sector, with very small catches taken by state registered vessels in New South Wales, South Australia and Tasmania. Catches in the west are typically much smaller than in the east, and the fishery in the west started much later in 1986. Catches generally declined in the east since 1980 and in the west since 2000. Jackass Morwong are mostly caught between 80 and 300 m by demersal trawlers.

The TAC for Jackass Morwong was first set in 1992 and has always been set for the combined eastern and western stocks. The western catches of Jackass Morwong were not included in stock assessments conducted before 2007. Since 2007, when the first (preliminary) assessment of the western stock was conducted, the western stock has been assessed separately from the eastern stock (Wayte and Fay, 2007). The recommended biological catch (RBC), used to determine the TAC (for the combined stock), has been calculated as the sum of the RBC for the eastern stock and the RBC for the western stock since 2007.

Wayte (2011) states that differences in Jackass Morwong in the east and the west were suggested by Smith and Knuckey (D.C. Smith, MAFRI, pers. comm. 2004; I. Knuckey, Fishwell, pers. comm. 2004), and it was assumed for the purposes of the 2011 assessment that there are separate stocks of this species in the eastern and western zones. This is largely the rationale for conducting separate eastern and western stock assessments of Jackass Morwong since 2007.

Wayte (2013) introduced a productivity shift in 1988 to the assessment to account for the declining autocorrelated recruitment since this time and found better model fits. It is hypothesised that strengthening of the East Australian Current (EAC) has reduced recruitment to the fishery and has had a large impact on this species due to the long offshore larval stage and changing oceanographic conditions, especially off the east coast of Tasmania.

The eastern and western stocks have always been managed under a single TAC, so an RBC of zero, which was set for the eastern stock for 2008, was combined with a non-zero RBC from the western stock. This still allowed a non-zero TAC to be set for the combined stock, allowing some of that TAC to be caught in the eastern part of the stock. Stock assessments have been completed separately for eastern and western stocks in every stock assessment conducted since 2007.

The eastern stock assessment uses fishery data starting in 1915. In contrast, catches in the west were not recorded until 1986. Both the fishing effort and the level of catch is considerably less in the west than in the east. Further there are some issues with the quantity and representativeness of the biological data collected in the west. The most recent Tier 1 assessment of Jackass Morwong was conducted in 2018, with separate assessments conducted on eastern (Day and Castillo-Jordán, 2018a) and western stocks (Day and Castillo-Jordán, 2018b). Recruitment appears to have declined steadily in the eastern stock since around 1970 (Day and Castillo-Jordán, 2018a). There appears to be no evidence of a productivity shift in the western stock (Day and Castillo-Jordán, 2018b).

Growth curves in the eastern assessment were estimated for Jackass Morwong, although this was not possible for the western assessment, with parameters in the west borrowed from the east (Day and Castillo-Jordán, 2018a, 2018b).

Stock assessments of Jackass Morwong have led to the classification of both eastern and western stocks as sustainable through the SAFS classification system (Mazloumi et al. 2018), although this is dependent on the acceptance of the productivity shift in the eastern stock. Two stocks were demarcated (east and west) based on the separation of stock assessments between these regions (Mazloumi et al. 2018, Day and Castillo-Jordán 2018a, 2018b). The ABARES fishery status reports in 2018 classified Jackass Morwong stocks in both the east and west as not overfished and not subject to overfishing (Helidoniotis et al. 2018).

2.3 Pink Ling

Pink Ling (*Genypterus blacodes*) is a demersal fish species found in Australia, New Zealand and Chile (Cohen and Nielsen 1978). In Australia it is found from central NSW to the south-west coast of WA (Cohen and Nielsen 1978, Withell and Wankowski 1989). Pink Ling are relatively long lived, reaching up to 30 years of age, growing to around one metre in length and weighing up to 20 kg (Withell and Wankowski 1989). The oldest specimen aged from the SESSF is 28 years (K. Krusic-Golub, pers. comm.). Pink Ling inhabit the coastal shelf and slope in waters ranging between 20 and 1000 m depth, from New South Wales in the east, Tasmania in the south, and west through the Great Australian Bight to Albany (Kailola et al. 1993). Juveniles are generally found in shallower locations than adults (Last et al. 1983, Tilzey 1994). Pink Ling spawn in late winter to spring with eggs and sperm widely distributed, however the degree of larval dispersal is unknown (Kailola et al. 1993, Tilzey 1994). Anecdotal evidence from New Zealand suggests that adult Pink Ling may be relatively sedentary and hence potentially vulnerable to localised depletion (Smith and Tilzey 2000). Early growth rates are relatively slow, reaching approximately 20 cm in length by two years of age (Withell and Wankowski 1989). Pink Ling mature relatively late, at around 5 years or 72 cm (Whitten and Punt 2013), although assessments of Pink Ling in New Zealand use an age of maturity between eight and 12 years of age, or between 70 and 100 cm length. Females are thought to grow faster and larger than males (Tilzey 1994). Catches in Australia have been recorded since the 1970s, initially starting as a bycatch of blue grenadier and gemfish targeted fisheries (Tilzey 1994).

There are at least three species of ling that have been identified globally, however, there is still ongoing investigation into their similarity and taxonomy. In Australia, New Zealand and Chile there is Pink or Mottled Ling (*Genypterus blacodes*), which differs from Rock Ling in Australia (*G. tigerinus*) and Kingklip (*G. capensis*) in South Africa (Smith and Paulin 2003).

Investigations into the pink and red morphs of Pink Ling were not able to detect any genetic differences in the two morphs and it was concluded that the colour differences were due to varying age and development (Daley et al. 2000, Ward et al. 2001).

Several genetic studies (based on allozymes, mtDNA and microsatellites) have been undertaken in Pink Ling populations throughout southern Australia, New Zealand and Chile. In Australia, no significant differences in genetic structure were identified in five locations including NSW, eastern Victoria, western Victoria, eastern Tasmania and western Tasmania (Ward et al. 2001, Ward and Elliott 2001). The null hypothesis of a single Pink Ling stock in the south east fishery could not be rejected (Ward et al. 2001).

In Chile, no significant population level differentiation, based on microsatellites, was found among 15 locations, grouped into three regions ranging from north to south (Canales-Aguirre et al. 2010). These results supported an earlier study that found no differences in otolith morphology within Chilean waters (Chong 1993).

In New Zealand, mtDNA haplotype differences were observed between populations in the north and south (Smith and Paulin 2003). However, later investigations identified four biological stocks based on synthesis of morphometrics, growth rates, population size structure, commercial catch per unit effort, parasites and biochemical analyses (Horn 2005). This study found the waters south of the South Island to split two neighbouring biological stocks with the Campbell Plateau and Stewart-Snares shelf to the west and the Bounty Plateau to the east, split down the longitude of 176° east (Horn 2005).

In South Africa, stock structure investigations of Kingklip identified three stocks (Payne 1977, 1985). These stocks were identified through differences in otolith morphology and growth rates, rather than genetic differences between the populations (Payne 1977, 1985).

Although no genetic differences have been observed in Pink Ling in southern Australia, differences in biological parameters have been observed in data used in stock assessments. Investigations into size and age structures found that Pink Ling caught in the east are on average smaller and younger than those caught in the west (Thomson et al. 2001; Figure 24, Figure 27, Figure 28). Additionally, differences have also been observed in catchability (Kailola et al. 1993).

In southern Australia Pink Ling have been caught commercially since the 1970s by both Commonwealth and state fisheries (Whitten and Punt 2012, Whitten and Punt 2013). Most of the catch is taken in Commonwealth waters, split between trawl and longline fisheries (Whitten and Punt 2013), with moderate catches (less than 10% of the total) from New South Wales state waters (catches up to 70 t per year since 1998) and very small catches taken by state fisheries from Victoria and Tasmania (with a combined total less than 1 t since 1999). The majority of catches are taken at depths between 400 and 600 m, with catches also recorded from waters as shallow as 100m and up to 900m.

A stock assessment for Pink Ling in southern Australia was first completed in 2001 and assumed one stock, however a sensitivity was tested with two stocks (Thomson et al. 2001). Assessments in 2007, 2010, 2011 and 2013 included the two areas as separate stocks (Taylor 2007, 2010, 2011a, 2011b, Whiten and Punt 2012). Splitting assessments for the east and west stocks was based on differences in size and age compositions along with differences in the trends observed in standardised catch rates (Whitten and Punt 2013). It was concluded that there is likely some genetic exchange between the two stocks in the east and west, however, differences in biological parameters were sufficient to warrant separate assessment and management (Whitten and Punt 2013).

In the most recent stock assessment, growth curves were estimated in both east and west assessments (Cordue 2018). In these analyses, Pink Ling were estimated to grow larger in the east than in the west (Cordue 2018). Additionally, in the west fish reach larger sizes at a younger age than in the east (Cordue 2018).

Classification of sustainability through the SAFS system for Pink Ling splits the stock into eastern and western stocks based on biological differences between the two populations (Georgeson and Chick 2018). This assessment process has classified both Pink Ling stocks as sustainable (Georgeson and Chick 2018). ABARES fishery status reports in 2018 classified Pink Ling stocks in both the east and west as not overfished and not subject to overfishing (Helidoniotis et al. 2018).

3 Logbook catches and discards

3.1 Blue Warehou

Recorded logbook catches of Blue Warehou were of similar magnitude in the east and the west between 1986 and 2000 (Figure 4). From 2000-2013, recorded catches in the logbooks were considerably higher in the west than in the east, with less than 8 t recorded in either the east or the west from 2015, with the exception of 2018 when 25 t was caught in the west (Figure 4, Table 2, Table 4).

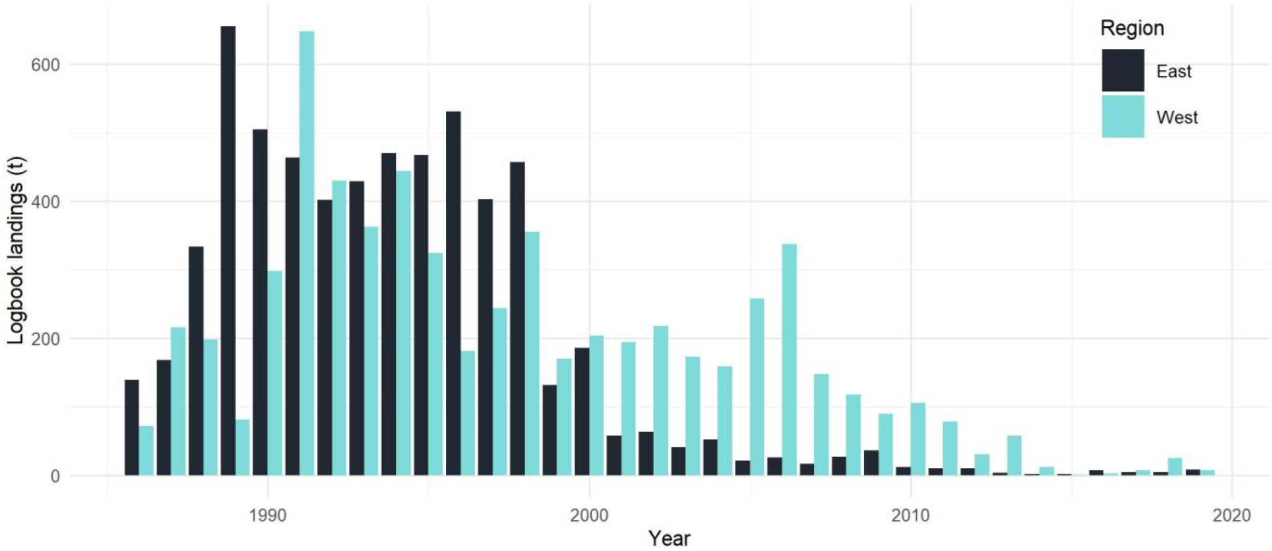

Figure 4. Recorded logbook catch (t) of Blue Warehou by zone.

Trawl discards of Blue Warehou display similar trends in the east and the west through time (Figure 5). Sample sizes have been filtered following protocols used to prepare stock assessment data and all records with less than 10 observations have been removed. Sample sizes for non-trawl observations ranged between 10–28 in the east, and 10–41 in the west. For trawl observations, sample sizes ranged between 10–143 in the east and 10–103 in the west (Figure 5).

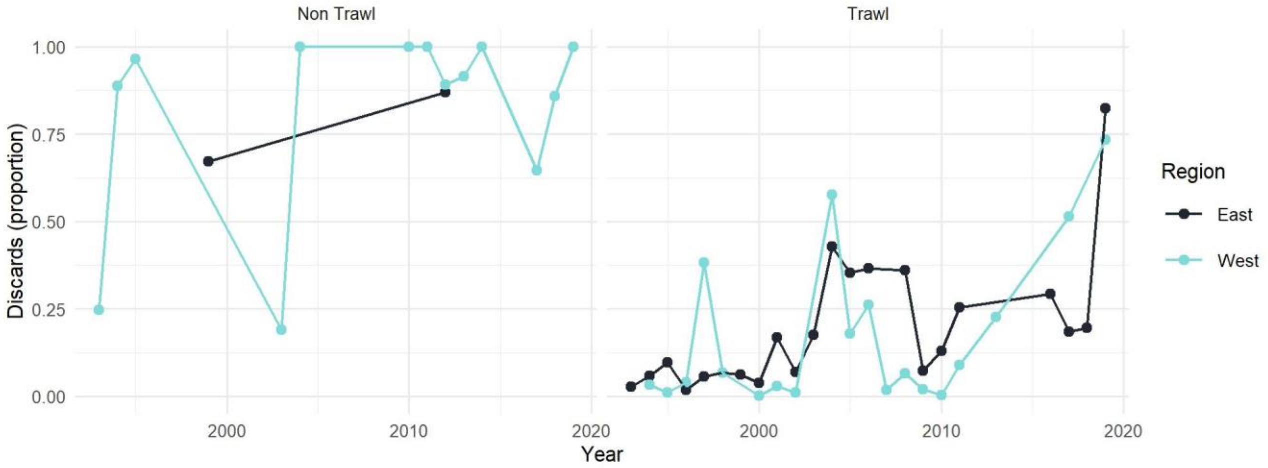

Figure 5. Proportion of Blue Warehou discarded by zone.

3.2 Jackass Morwong

Recorded logbook catches of Jackass Morwong are much larger in the east than the west and have generally been declining in both areas since around 2000 (Figure 6, Table 3,

Annual standardised CPUE has been below the long-term average since about 2000 with apparent periodicity (Figure 36). The number of vessels reporting Jackass Morwong in 2019 was 14, the lowest over the 1986-2019 period (Table 8). Most fishing occurs in waters to about 250 m (Figure 34). In the east, most logbook catch occurred in zone 20, followed by zone 30 and zone 10 (Table 8). Most logbook catch was from the east (~86%) compared with the west (~14%).

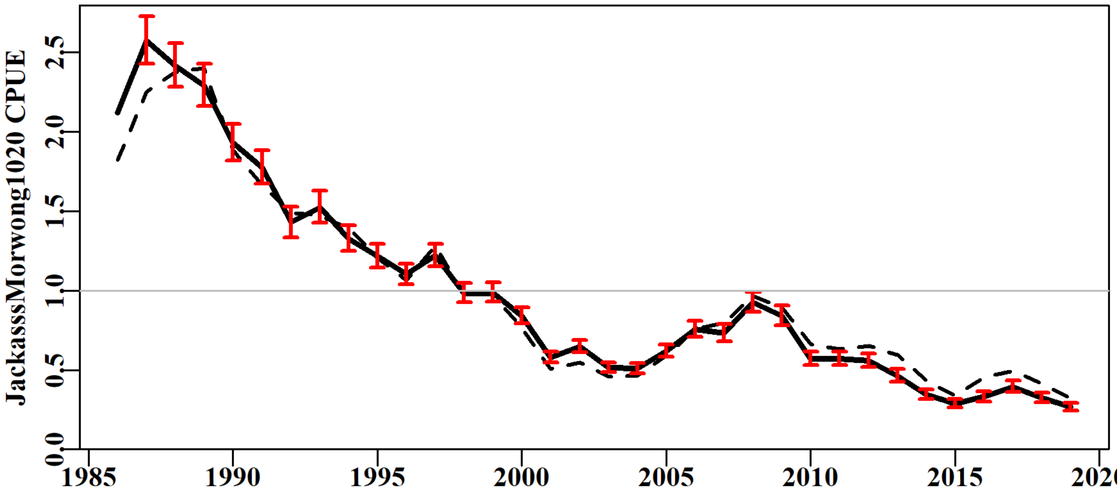

Figure 36. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Jackass Morwong east (zones 10 and 20 only). The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 5).

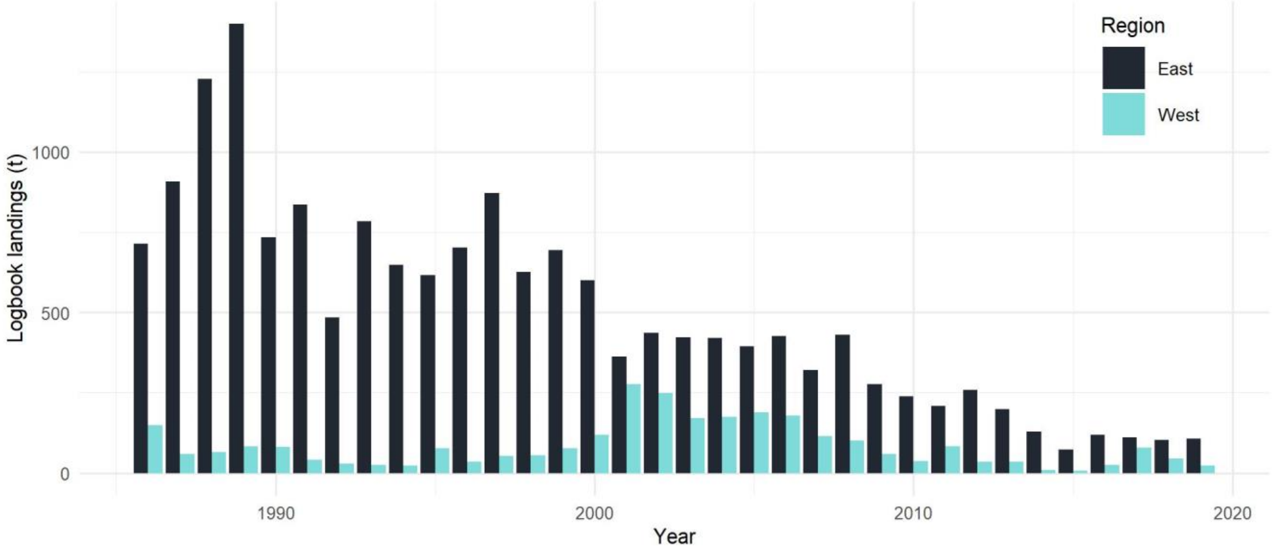

Figure 6. Recorded logbook catch (t) of Jackass Morwong by zone.

Discards are much higher for the Danish seine fleet than in either of the trawl fleets for Jackass Morwong (Figure 7), however the Danish seine fleet is a small proportion of the total catch. For the trawl fleet in both the east and the west, discards are variable, with sporadic peaks observed in the east, and one large peak in the west in 2014 (Figure 7). Sample sizes were filtered following protocols used to prepare stock assessment data in the SESSF and all records with less than 10 observations were removed. Samples sizes for Danish seine observations range between 10–41, those for Tasmanian trawl range between 10–60, and for the trawl fleet they range between 33–275 in the east and 10–111 in the west (Figure 7).

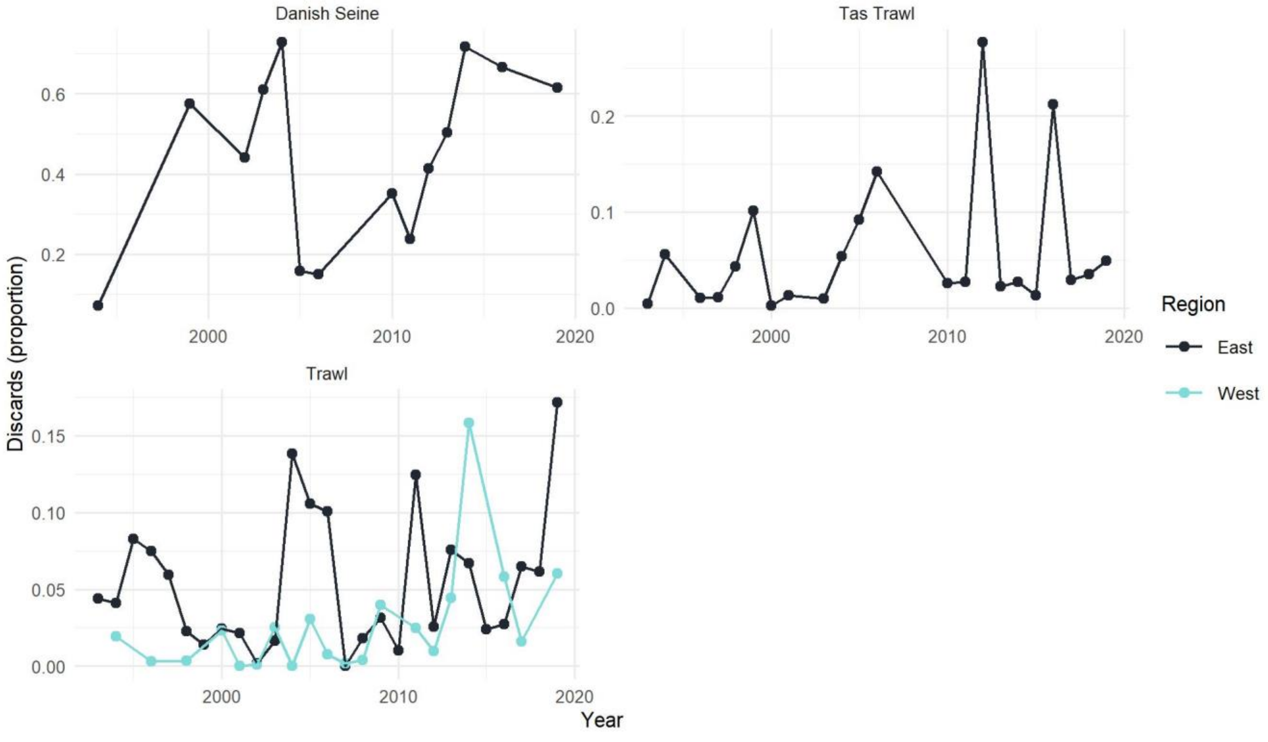

Figure 7. Proportion of Jackass Morwong discarded by zone.

3.3 Pink Ling

Logbook catches of Pink Ling differed between regions from 1986 to 2000, with considerably lower catch totals in the west compared to the east (Figure 8). From 2000 onwards, logbook catches were similar between regions (Figure 8).

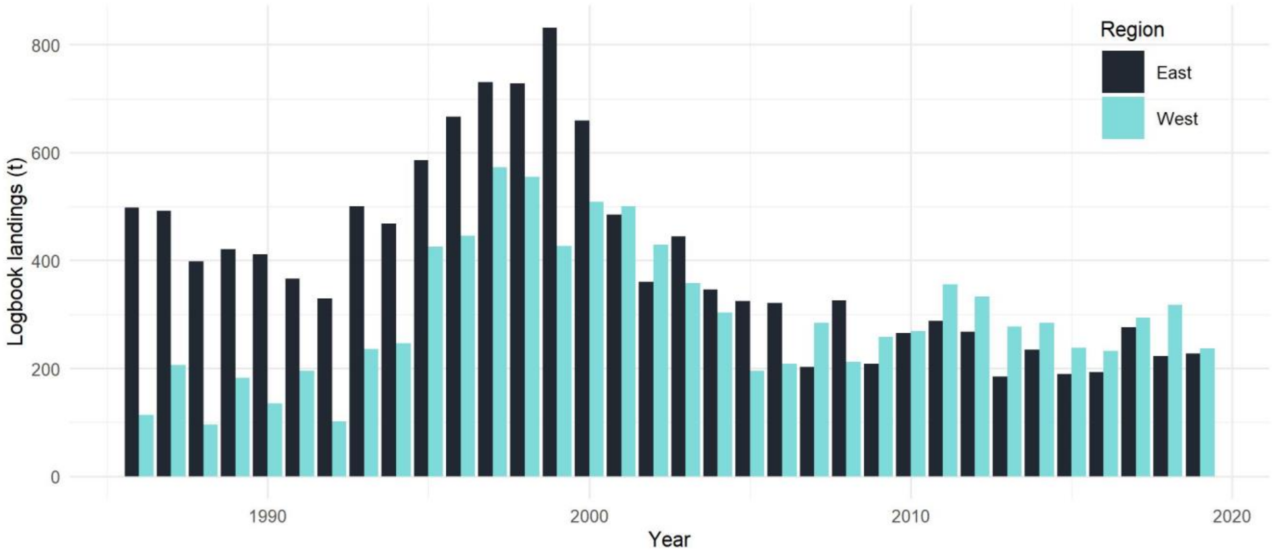

Figure 8. Recorded logbook catch (t) of Pink Ling by zone.

Discard rates are similar for the trawl fleet in the east and the west until 2010, where sporadic peaks are present in the east (Figure 9). For the non-trawl fleet, discards were generally low in the east with two large peaks and there is limited data in the west (Figure 9). Sample sizes were filtered following protocols used to prepare stock assessment data in the SESSF and all records with less than 10 observations were removed. Samples sizes for non-trawl observations ranged between 13–123 in the east, and 28–82 in the west, for trawl observations, sample sizes ranged between 21–453 in the east and 38–173 in the west (Figure 9).

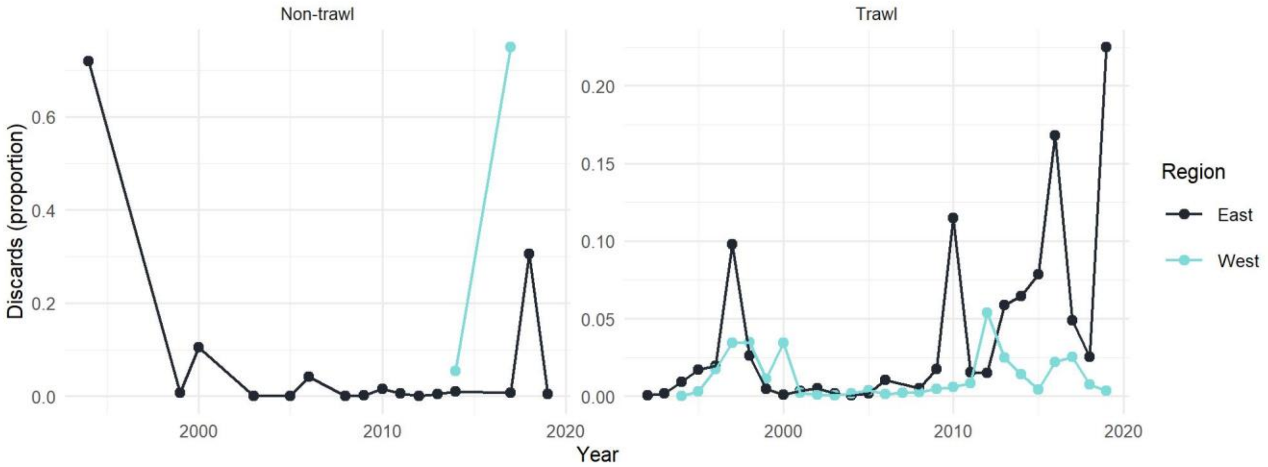

Figure 9. Proportion of Pink Ling discarded by zone.

4 Length and age frequency distributions

Length and age frequency distributions presented below have been collated using the same methods that are used to prepare data for Tier 1 stock assessments in the SESSF. Length frequencies are filtered to only include years with more than 100 samples and are catch-weighted by shot to ensure they are not biased by unbalanced sampling and to produce length frequencies that represent the true length distribution as closely as possible. Age frequency distributions have been scaled by the length frequencies to ensure they are representative of the population, as typically length samples are collected with the intention of gathering a representative length sample, whereas age samples are often collected selectively to sample the full range of ages, producing an age sample that may not be representative of the population. This follows the same approach used in preparing and presenting length and age data for Tier 1 stock assessments in the SESSF.

4.1 Blue Warehou

Length frequencies of Blue Warehou by depth and by retained or discarded status from onboard sampling show different trends in the east and the west (Figure 10). There are insufficient samples of discarded fish in the east in deep water (> 200 m), although for retained fish those in the east are larger than in the west (Figure 10). Also, discarded fish are generally larger in the west compared to the east from shallow depths (<= 200 m), although in the east the distribution is much larger, with a broader range of fish sizes sampled (Figure 10). A bimodal distribution is evident for retained fish from shallow waters in the east, with two peaks, (25 cm and 47 cm), while those in the west have a single mode around 35 cm, which corresponds to the length for which fish appear most often (Figure 10).

The relationships between length and depth by region and discard status for Blue Warehou are is displayed in Figure 11, with the lines representing the average trend through the data with 95% confidence intervals illustrated in the shaded area. Trends between depth and length for discarded Blue Warehou show larger fish are found at greater depths, with this relationship stronger for fish caught in the east compared to those caught in the west (Figure 11). Generally, there are more discards from deeper waters in the west compared to the east (Figure 11). An increasing trend in length by depth is also evident for retained fish, with similar rates of increase observed between the two regions (Figure 11). In general, Blue Warehou are caught deeper in the west compared to the east (Figure 10 and Figure 11) and this difference may be due to limited availability of suitable fishing grounds in western shallow water locations.

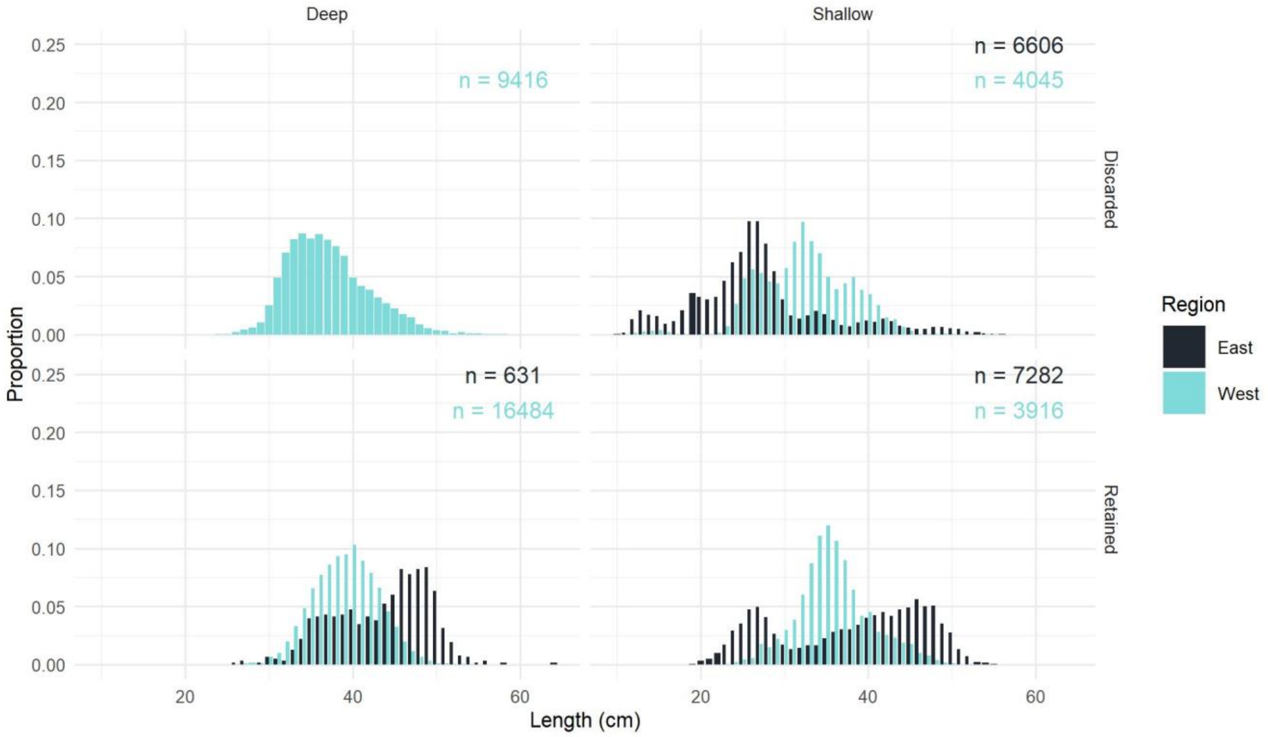

Figure 10. Length frequencies of Blue Warehou by region, sorted into (i) deep and shallow (columns), and (ii) discarded and retained (rows) between 1987 and 2019. The division between shallow and deep shots is 200 m. The number of samples (n) used to generate the length frequencies is indicated on each sub-plot.

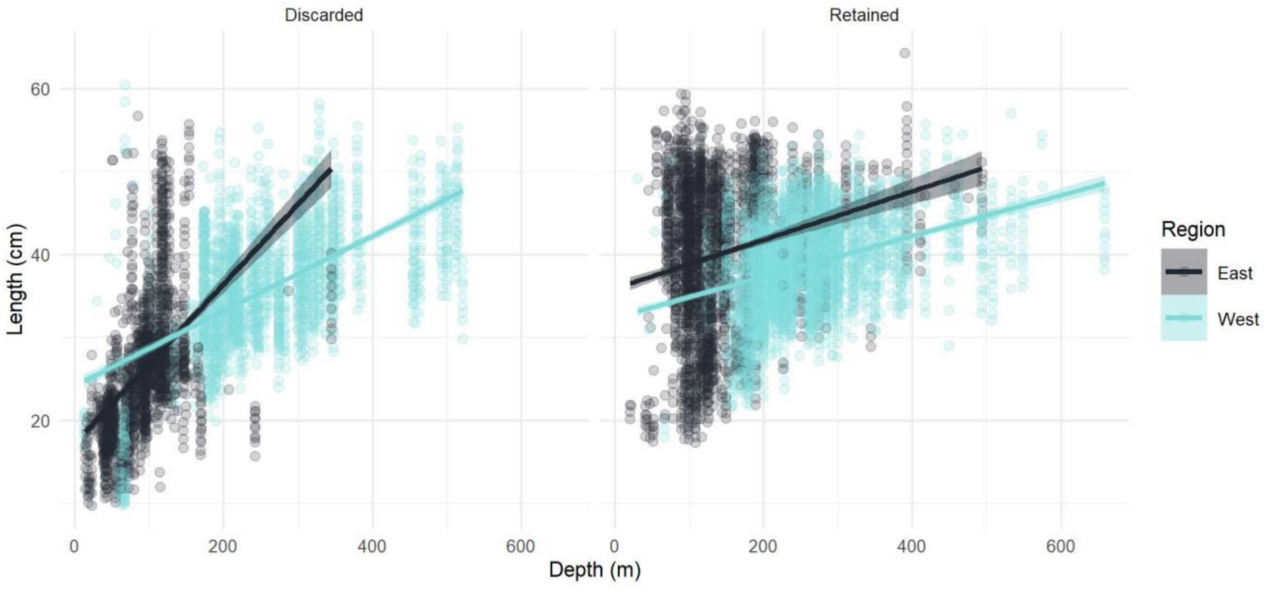

Figure 11. Relationship between length and depth for Blue Warehou caught by region and fate from onboard sampling. Data includes measurements between 1987 and 2019.

The relationship between lengths and latitude by region and by retained or discarded status are displayed in Figure 12, with the lines representing the average trend through the data with 95% confidence intervals illustrated in the shaded area. Blue Warehou discards generally are smaller with increasing latitude, or as you move further north, in both the east and the west, with smaller fish generally observed in the east compared to in the west (Figure 12). Retained Blue Warehou do not show a strong relationship between length and latitude for either of the regions, with similar sized retained fish also observed in the east and west, regardless of latitude (Figure 12). Blue Warehou are caught and retained at lower latitudes (further north) in the east compared to the west, where the Australian mainland prevents catches any further north (Figure 12).

Onboard length frequencies by fleet, retained or discarded status and region of Blue Warehou were variable between the east and west (Figure 13). Small sample sizes for non-trawl fleets only allow plots to be created for discards in the west and retained length frequencies in the east, with the western discards much smaller than the eastern retained samples (Figure 13). Trawl fleets show a more consistent length structure for both discarded and retained distributions in the east and west (Figure 13). Trawl discards show a wide distribution of lengths in both the east and west. Retained trawl length frequencies again show a bimodal distribution in the east, with a single mode at around 40 cm in the west (Figure 13).

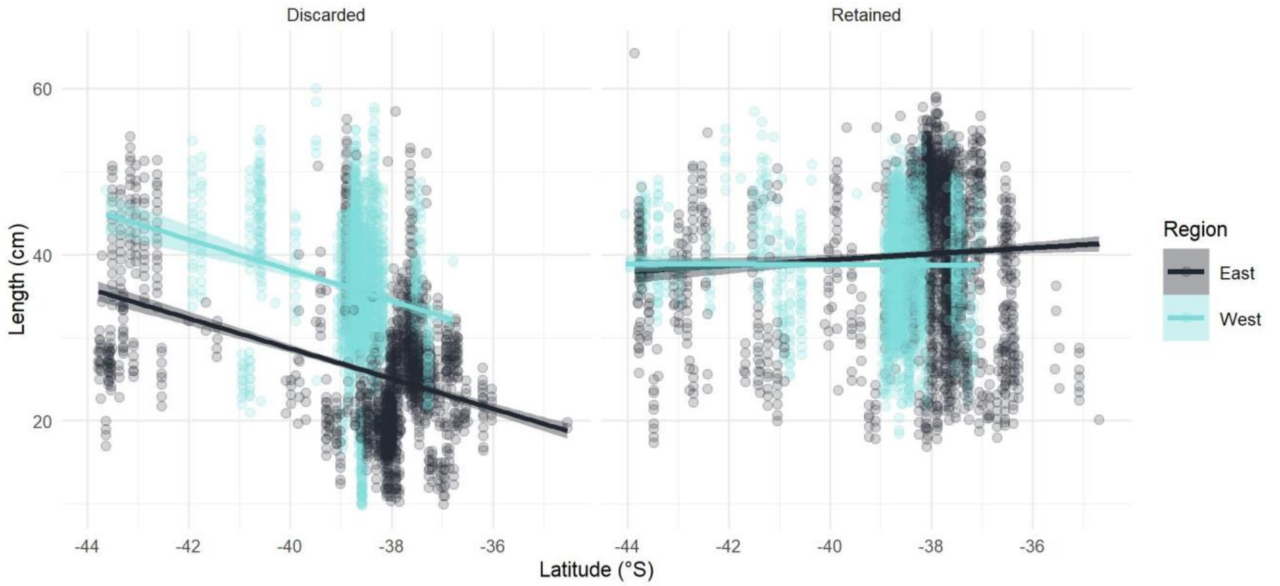

Figure 12. Relationship between length and latitude for Blue Warehou caught by region (colour) and discard status (columns) from onboard sampling. Data includes measurements between 1987 and 2019.

Port sampling of retained Blue Warehou shows similar trends to those observed onboard (lower right sub-plot in Figure 13 and right sub-plot in Figure 14). In the western non-trawl fleet, most fish are between 18 and 30 cm, with a bimodal distribution in the east, with modes at 25 and 50 cm (Figure 14). Blue Warehou caught by eastern trawl range in size from 20 to 55 cm, with a bimodal distribution, whereas in the west, there is a single mode in the length structure at around 35 cm (Figure 14).

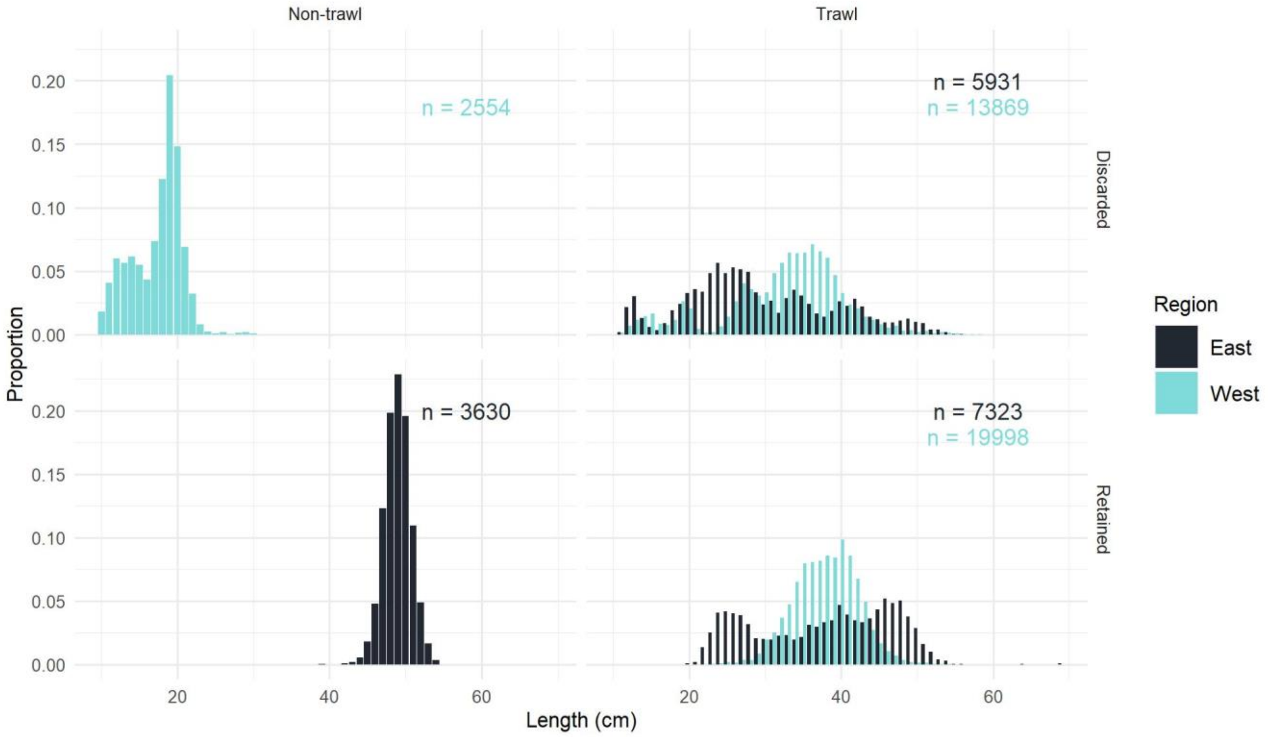

Figure 13. Onboard length frequencies of Blue Warehou by region (colour), fleet (columns) and discard status (rows), aggregated between 1987 and 2019.

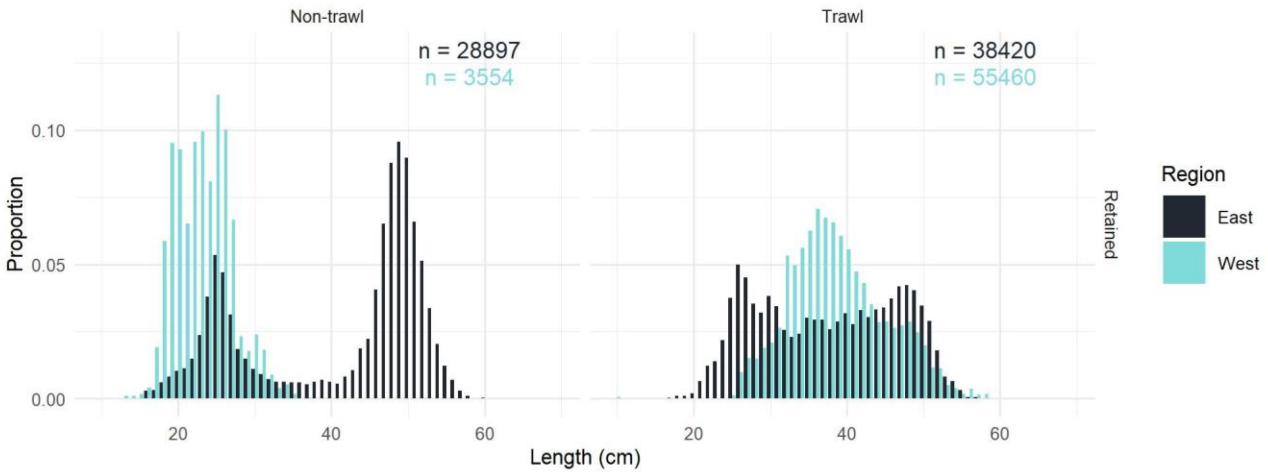

Figure 14. Length frequencies of Blue Warehou by region (colour) and fleet (columns) from port sampling. Data is aggregated between 1987 and 2019.

Age structures of Blue Warehou from onboard varied by fleet, discard status and region (Figure 15). Insufficient samples were available to compare regions in the non-trawl fleet, with young fish discarded in the west, with a range of older fish retained in the east (Figure 15). Discards in the trawl fleet were generally older in the west than the east, with no difference in age between regions for those that were retained (Figure 15).

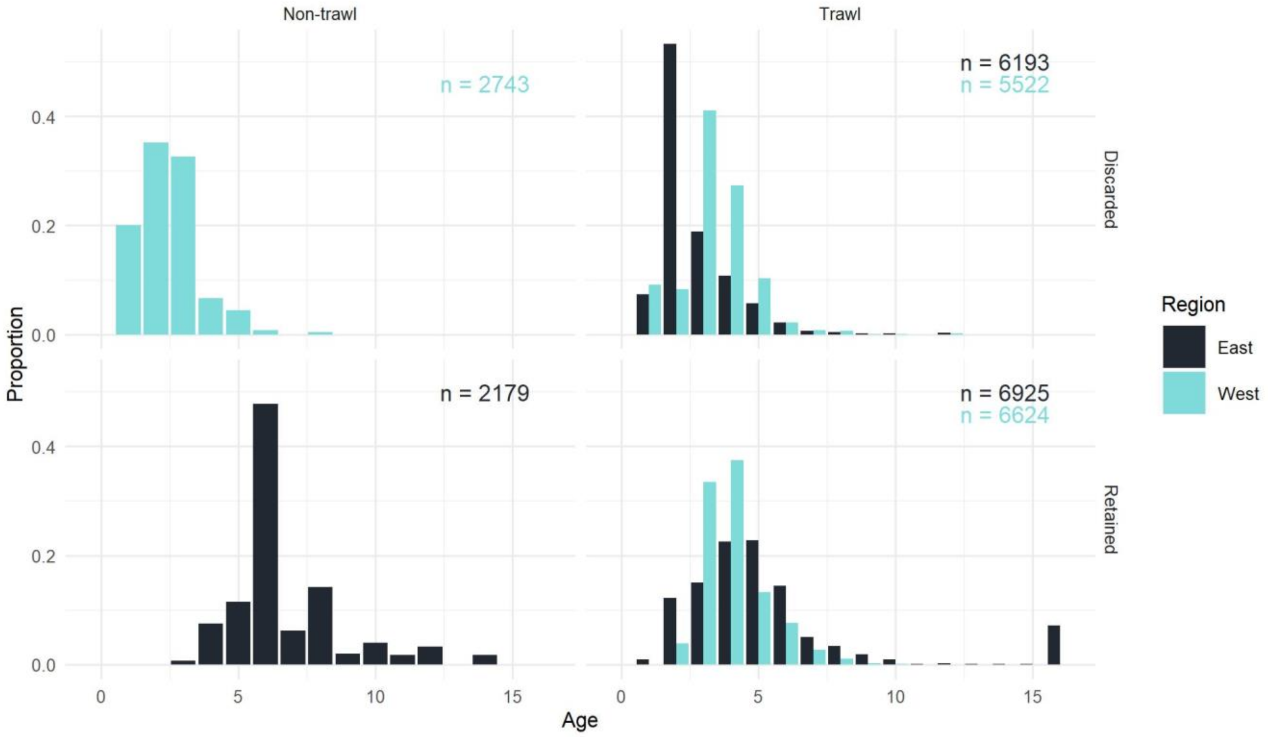

Figure 15. Age frequencies of Blue Warehou by region (colour), fleet (columns) and discard status (rows) from onboard sampling. Data is aggregated between 1993 and 2010.

Ages from port sampling again varied with younger fish in non-trawl catches in the east than west, which corresponds with smaller lengths also observed (Figure 14, Figure 16). Trawl fleets had similar aged fish in the east and west (Figure 16).

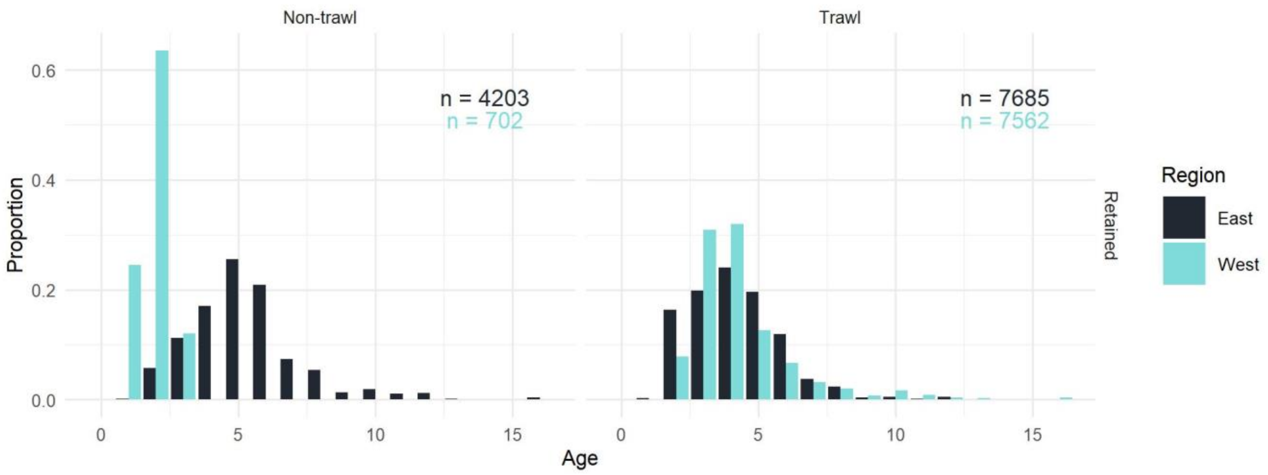

Figure 16. Age frequencies of Blue Warehou by region (colour) and fleet (columns) from port sampling. Data is aggregated between 1993 and 2010.

4.2 Jackass Morwong

Length frequencies of Jackass Morwong by depth and discard status show differences between regions (Figure 17). Discard length frequencies from deeper waters are similar between regions, although there is a greater proportion of mid-sized fish in the middle of the distribution in the west (Figure 17). Western discards from shallower waters are generally larger than those discarded in the east (Figure 17). Length frequencies for retained fish caught in deeper waters are similar across regions, but retained length frequencies from shallower waters are generally larger in the west than in the east, as indicated by the mode of the distribution (Figure 17).

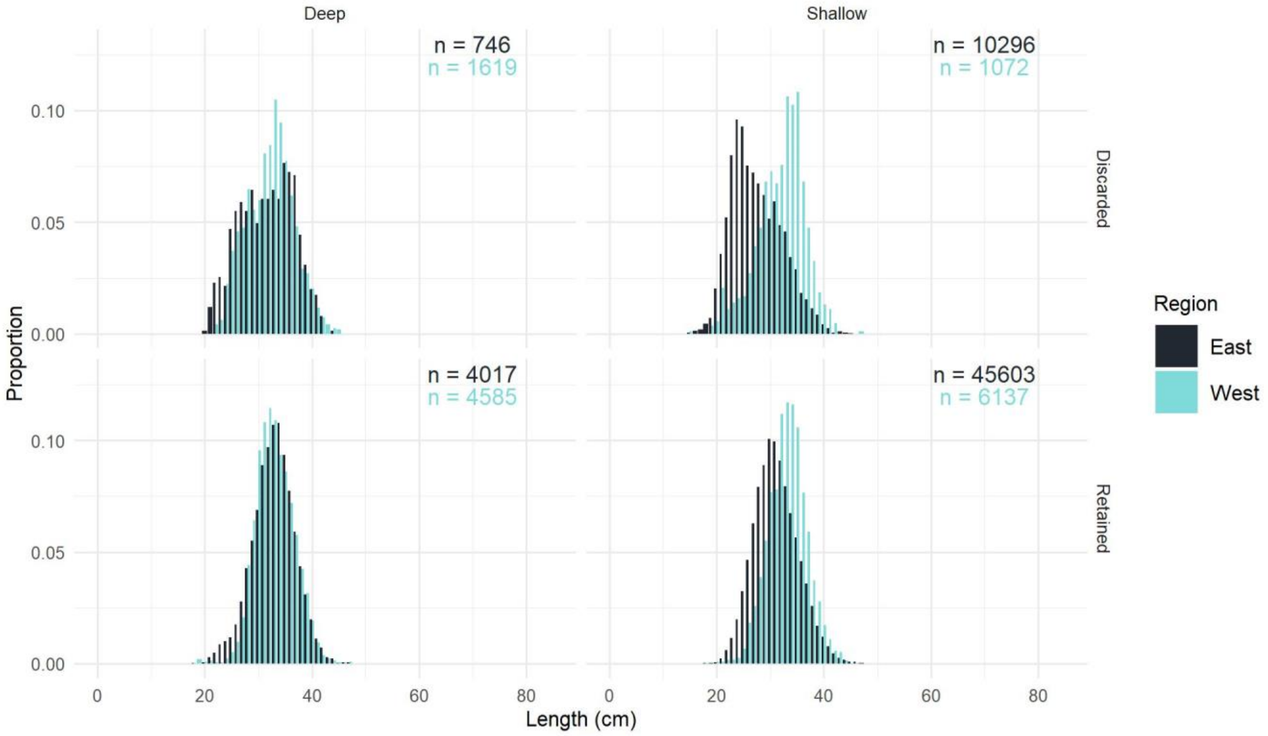

Figure 17. Aggregated length frequencies of Jackass Morwong by region, sorted into deep and shallow (columns), discarded and retained (rows). The division between shallow and deep shots is 200 m. Length data are aggregated between 1987 and 2019. The number of samples (n) used to generate the length frequencies is indicated on each sub-plot.

The relationship between lengths and depth by region and discard status for Jackass Morwong are displayed in Figure 18, with the lines representing the average trend through the data with 95% confidence intervals illustrated in the shaded area. Discards show a positive relationship between depth and length, with larger fish caught in deeper waters in both the east and the west, with a stronger effect observed in the east (Figure 18). Retained length frequencies do not show such a strong relationship between depth and length, with only a small increase in length with increasing depth (Figure 18). Overall, larger fish were observed in deeper waters in the east than the west, regardless of whether they were discarded or retained (Figure 18).

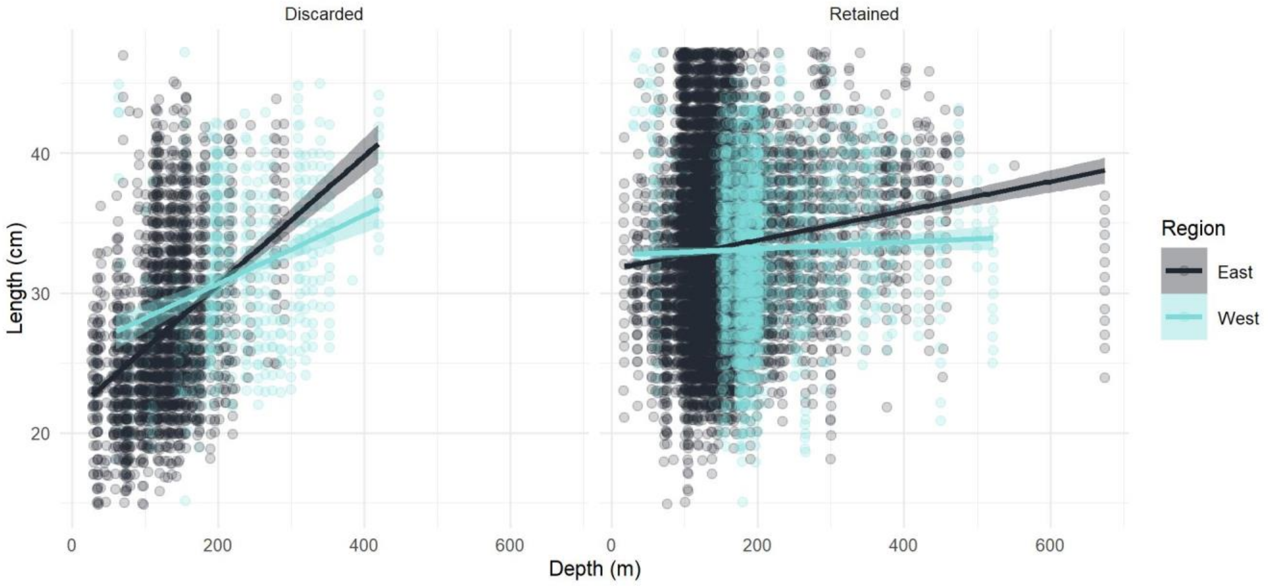

Figure 18. Relationship between length and depth for Jackass Morwong from onboard sampling by region (colour) and discard status (columns). Data includes measurements between 1987 and 2019.

The relationship between lengths and latitude by region and discard status for Jackass Morwong are displayed in Figure 19, with the lines representing the average trend through the data with 95% confidence intervals represented by the shaded area. A variable relationship between length and latitude is apparent for Jackass Morwong discards by region (Figure 19). In the east, there is a decline in length with increasing latitude (to the north) (Figure 19). In the west the opposite trend is apparent, with an increase in length further north, although there are relatively few observations to inform this trend (Figure 19). Retained length frequencies show no relationship between length and latitude in either region, with similar lengths caught across the full latitude range (Figure 19). Jackass Morwong are caught and retained at lower latitudes (further north) in the east compared to the west, where the Australian mainland prevents catches any further north (Figure 19).

Length frequencies from onboard samples vary by fleet and discard status for Jackass Morwong (Figure 20). For Danish seine length frequencies in the east, most discards were below 25 cm, while retained length frequencies have a mode of just above 30 cm (Figure 20). Tasmanian trawl length frequencies show a similar, but less extreme, pattern as Danish seine with smaller discards compared to the retained length frequencies (Figure 20). Again for trawl fleets, smaller fish were discarded than were retained, and this was most prominent in the east, with a wider/broader range of lengths observed for discards in the west (Figure 20). Retained length frequencies were again generally larger in the west compared to the east, as indicated by the mode of the distribution (Figure 20).

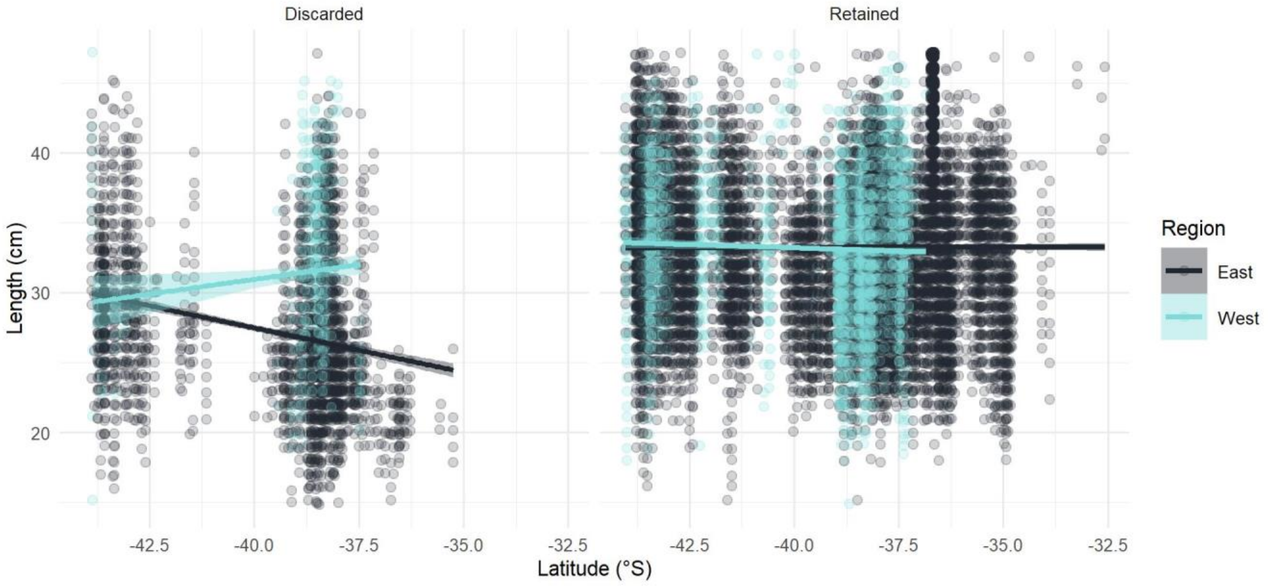

Figure 19. Relationship between length and latitude for Jackass Morwong from onboard sampling by region (colour) and discard status (columns). Data includes measurements between 1987 and 2019.

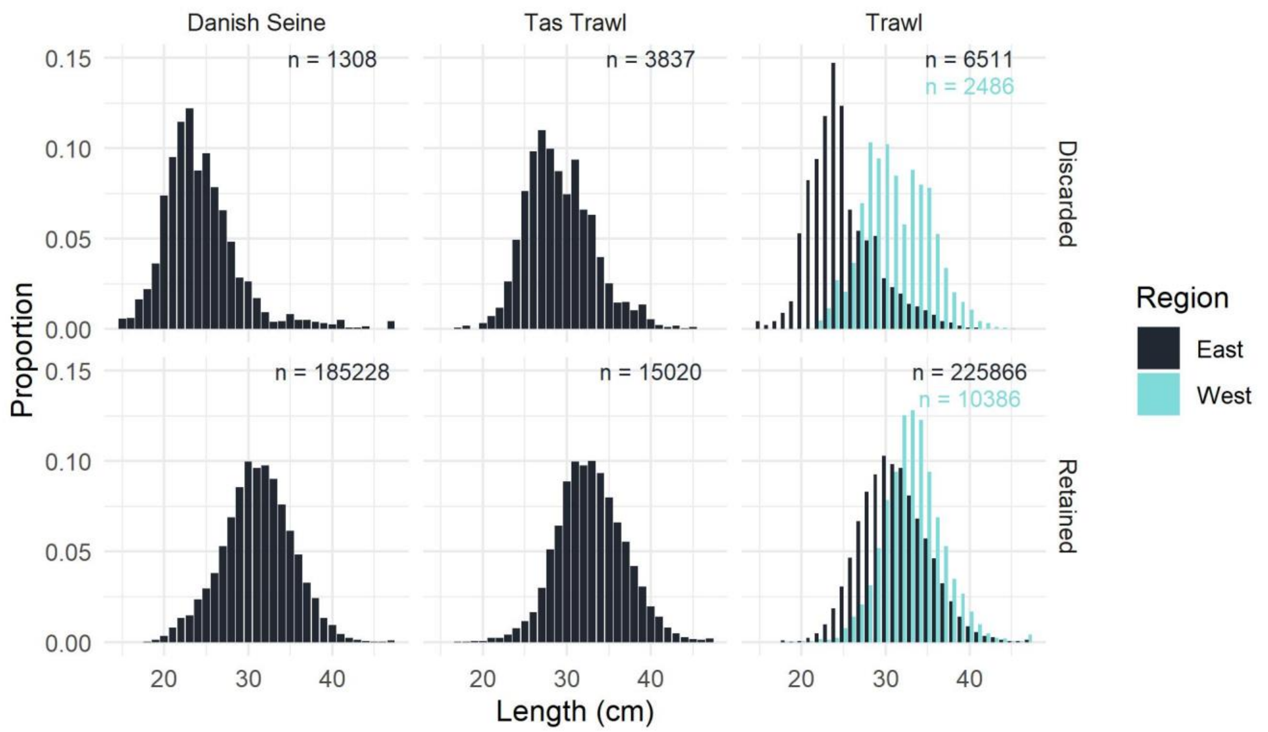

Figure 20. Length frequencies of Jackass Morwong from onboard sampling by region (colour), fleet (column) and discard status (row). Data is aggregated between 1986 and 2019.

Port sampling of retained Jackass Morwong show differences in length frequencies for the three fleets (Figure 21). Danish seine length frequencies in the east ranged between 20 and 40 cm, with 30 cm the most common length (Figure 21). Fish caught by Tasmanian trawl were again most commonly around 30 cm, although more larger fish were caught than smaller fish (Figure 21). Fish caught by trawl were generally larger in the west than in the east, with modes of 35 cm and 30 cm respectively (Figure 21).

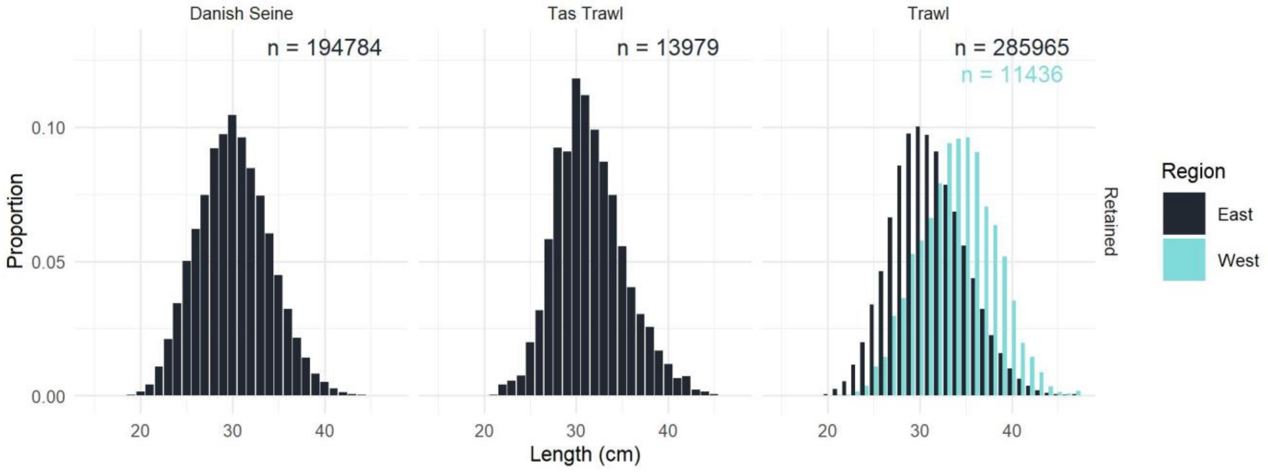

Figure 21. Length frequencies of Jackass Morwong from port sampling by region (colour) and fleet (column). Data is aggregated between 1986 and 2019.

Onboard sampling of Jackass Morwong age structures show similar patterns between fleets, with ages ranging between 1 and 25 years (Figure 22). In the trawl fleet, where samples are available in both regions, older fish were observed in the west than the east (Figure 22). Discards in the west from the trawl fleet also had a larger proportion of fish above 20 years of age (Figure 22).

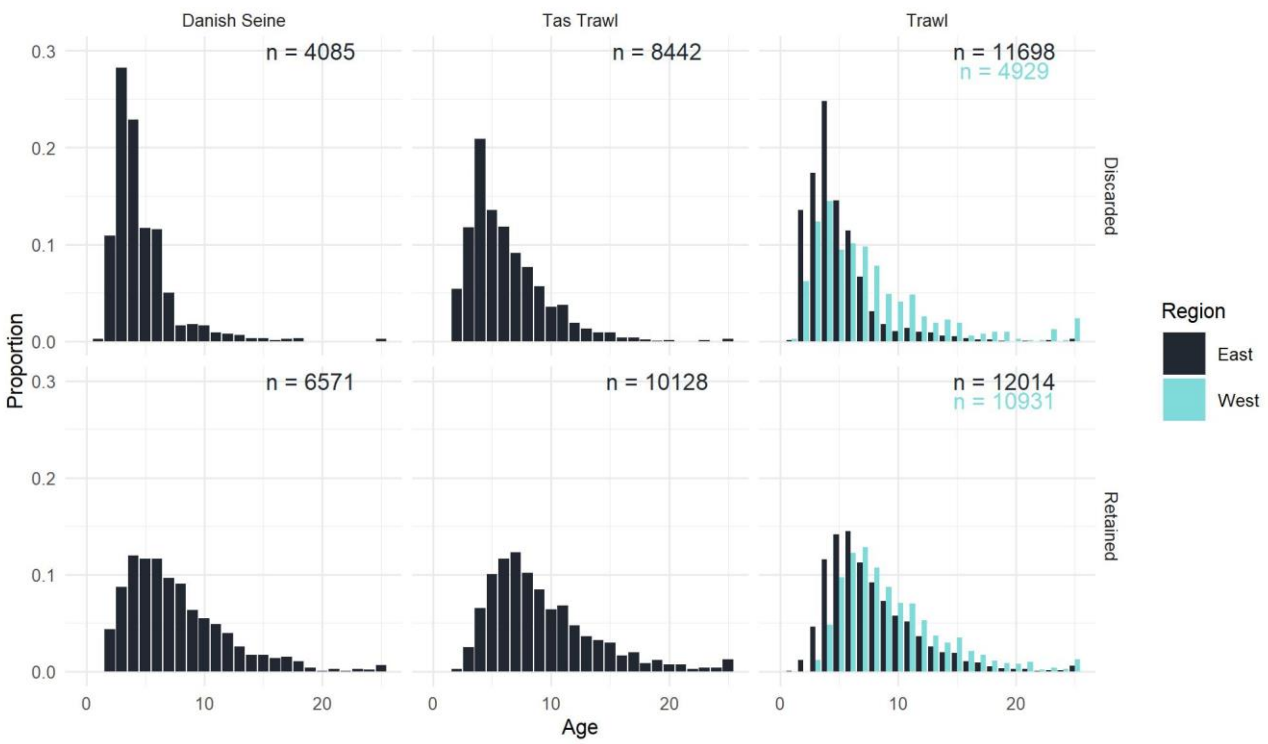

Figure 22. Age frequencies of Jackass Morwong from onboard sampling by region (colour), fleet (column) and discard status (row). Data is aggregated between 1991 and 2017.

Port samples age structures of Jackass Morwong showed similar trends to those observed from onboard sampling (Figure 22, Figure 23). Similar trends were observed between fleets, with the mode of ages around 7 years old (Figure 23). For the trawl fleet, there were older fish in the west than the east (Figure 23).

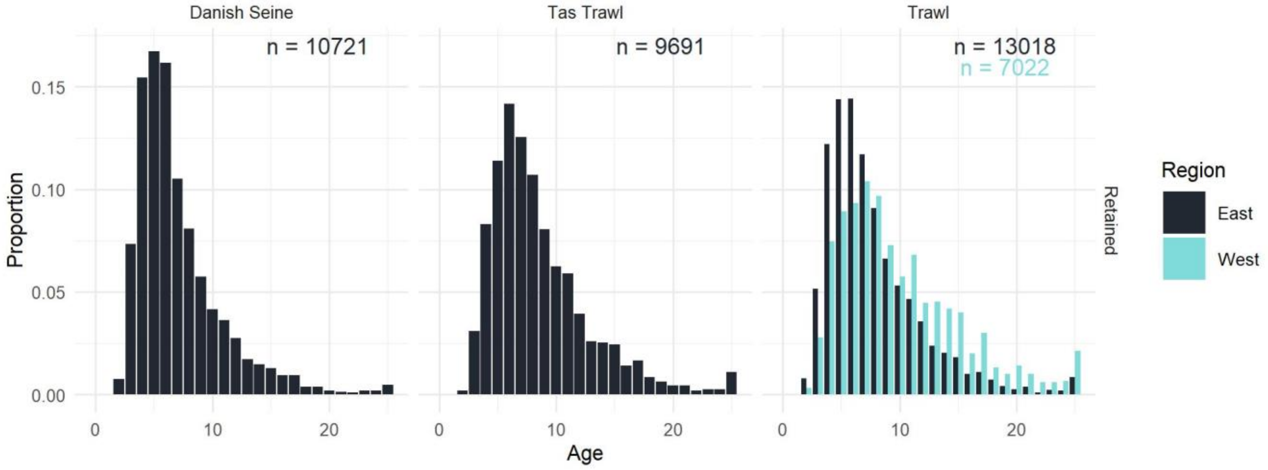

Figure 23. Age frequencies of Jackass Morwong from port sampling by region (colour) and fleet (column). Data is aggregated between 1991 and 2017.

4.3 Pink Ling

Length frequencies of Pink Ling by depth and discard status of the fish (retained or discarded) show varying trends (Figure 24). The majority of fish are caught in deep water (> 200 m) with larger fish observed in the west than the east (both discarded and retained) (Figure 24). Sampling was limited in shallow waters, particularly in the west, with only 15 discarded and 80 retained fish sampled (Figure 24). These limited samples were not sufficient to produce sensible/representative length frequencies (Figure 24). For deeper catches, which made up the majority of the samples, larger fish were caught in the west than the east (Figure 24).

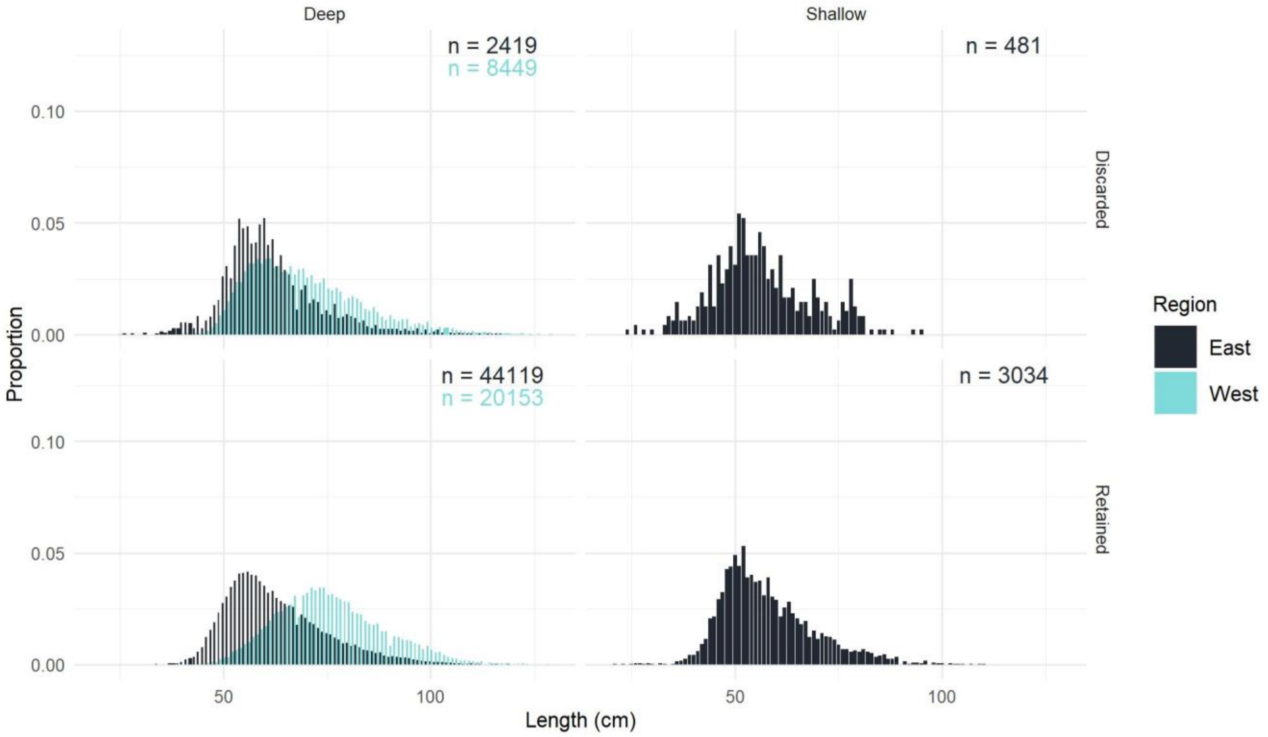

Figure 24. Aggregated length frequencies of Pink Ling by region, sorted into deep and shallow (columns), discarded and retained (rows). The division between shallow and deep shots is 200 m. Length data are aggregated between 1987 and 2019. The number of samples (n) used to generate the length frequencies is indicated on each sub-plot.

The relationship between length and depth by region and discard status of the fish (discarded or retained) for Pink Ling are displayed in Figure 25, with the lines representing the average trend through the data with 95% confidence intervals illustrated in the shaded area. A positive relationship between depth and length is apparent for both discards and retained Pink Ling in both the east and the west (Figure 25). For discards, length increases with depth in the east, with many fish shorter than 50 cm caught in depths less than 300 m (Figure 25). The relationship in the west is not as strong with only a small increase in length with increasing depth (Figure 25). However, there are considerably more large fish in the west than in the east (Figure 25). For retained Pink Ling, there is again a strong increase in length with depth in the east and this relationship is not as strong in the west (Figure 25).

The relationship between length and latitude by region and discard status of the fish (discarded or retained) for Pink Ling is shown in Figure 26, with the lines representing the average trend through the data with 95% confidence intervals represented by the shaded area. The relationship between length and latitude for Pink Ling is negative across both discards and retained length frequencies in both the east and the west (Figure 26). Discards in the west decrease in length as latitude increases (moving south) and this negative relationship is stronger than in the east (Figure 26). Discards in the east are observed across a larger range of latitudes than in the west, with discarding generally occurring further south in the west (Figure 26). Trends are similar for retained fish, with a negative relationship between length and latitude in both the east and the west, with a similar trend between the two regions (Figure 26). Again, fish are caught at lower latitudes (further north) in the east compared to the west as mainland Australia places a limit on how far north catches can be taken in the western region (Figure 26).

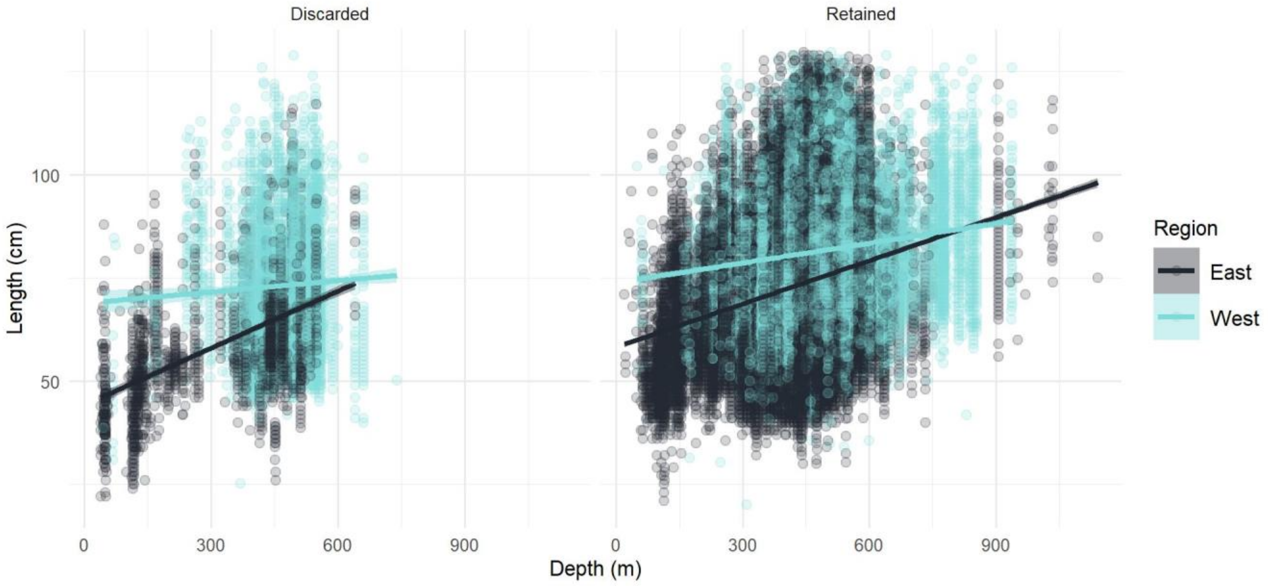

Figure 25. Relationship between length and depth for Pink Ling by region (colour) and discard status (column) from onboard sampling. Data includes measurements between 1987 and 2019.

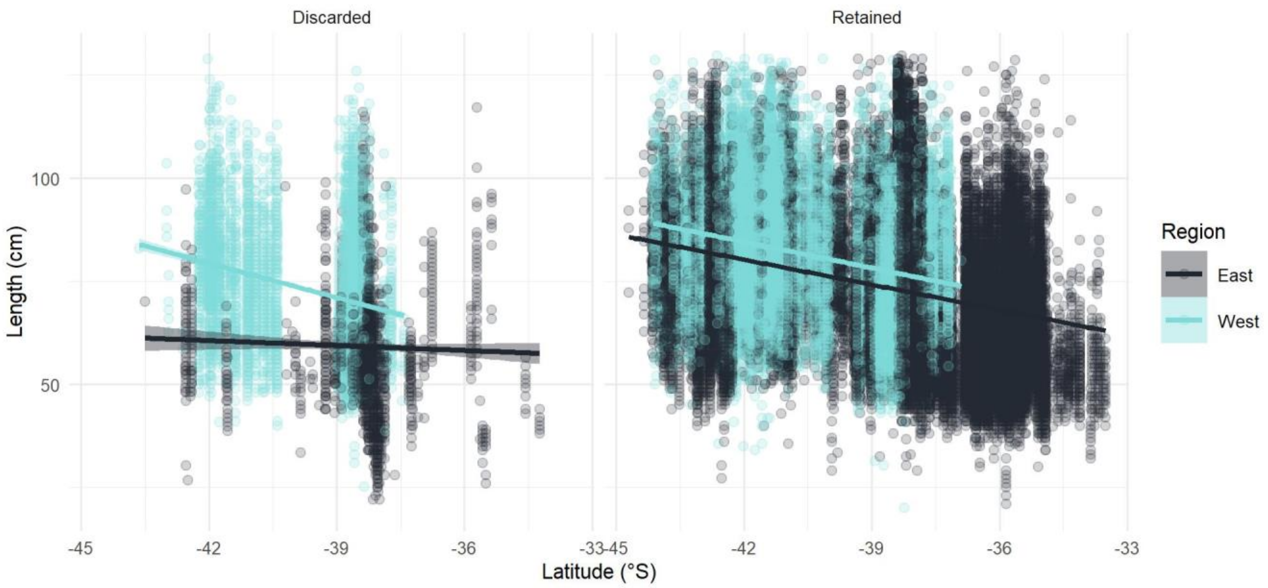

Figure 26. Relationship between length and latitude for Pink Ling by region (colour) and discard status (column) from onboard sampling. Data includes measurements between 1987 and 2019.

Onboard length frequencies by fleet, discard status and region vary (Figure 27). For discards in the non-trawl fleet there are no observations recorded in the west and discards in the east are predominantly small fish of less than 50 cm (Figure 27). Non-trawl retained Pink Ling are slightly larger in the west than in the east (Figure 27). Larger retained and discarded trawl samples are observed in the west compared to the east, as indicated by the mode of the distribution (Figure 27).

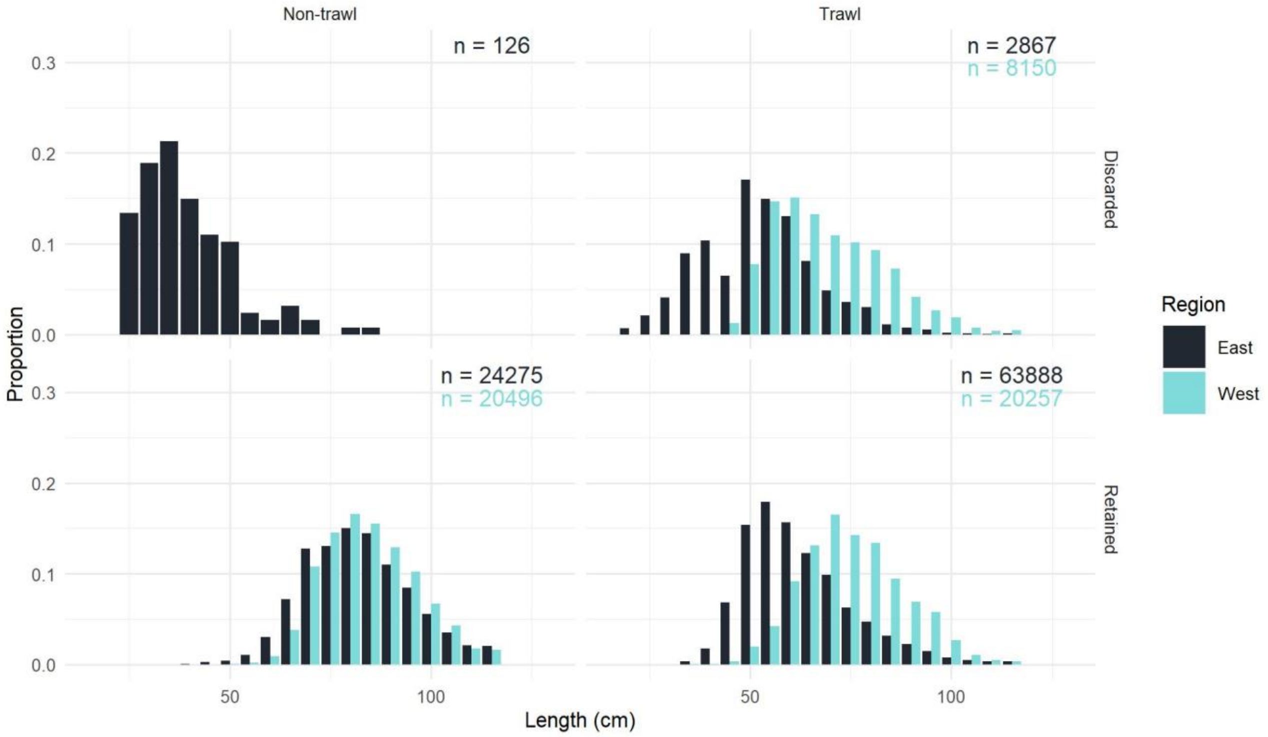

Figure 27. Length frequencies of Pink Ling from onboard sampling by region (colour), fleet (column) and discard status (row). Data is aggregated between 1991 and 2017.

Port length frequencies shows similar trends to onboard sampling (Figure 27, Figure 28). Non-trawl port length frequencies are only recorded in the east, whereas trawl port length frequencies indicate larger fish in the west compared to the east, as indicated by the mode of the distribution (Figure 28).

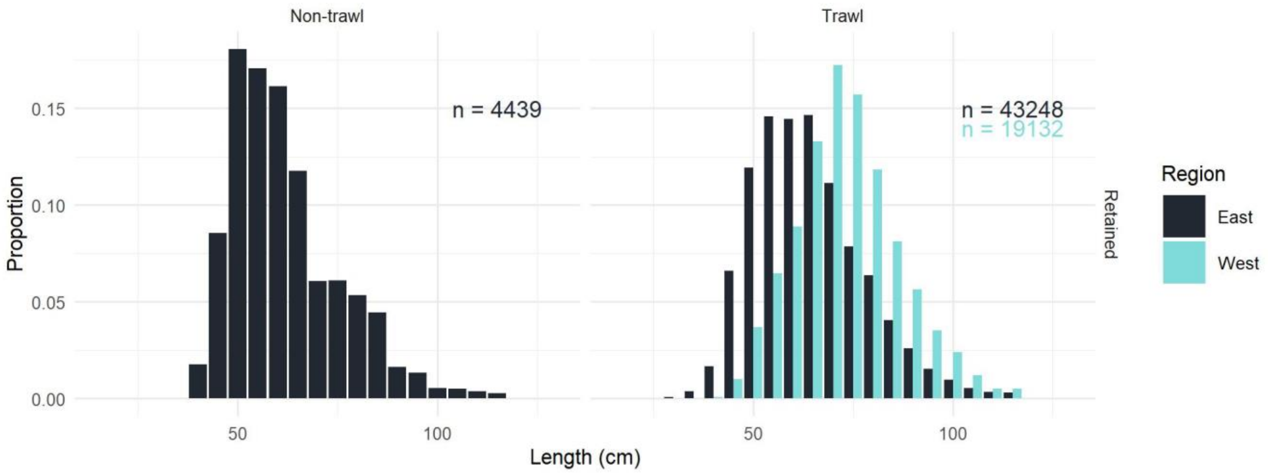

Figure 28. Port sampled length frequencies of Pink Ling by region (colour) and fleet (column). Data is aggregated between 1991 and 2017.

Non-trawl onboard age frequencies from discards are variable in both the east and the west, due to small sample sizes, although fewer younger fish are observed in the west (Figure 29). The retained non-trawl age frequency distributions had a more consistent shape between east and west, albeit with slightly older fish in the west (Figure 29). The trawl fleet generally catches younger fish than the non-trawl fleet, with older fish caught in the west compared to those caught in the east (Figure 29).

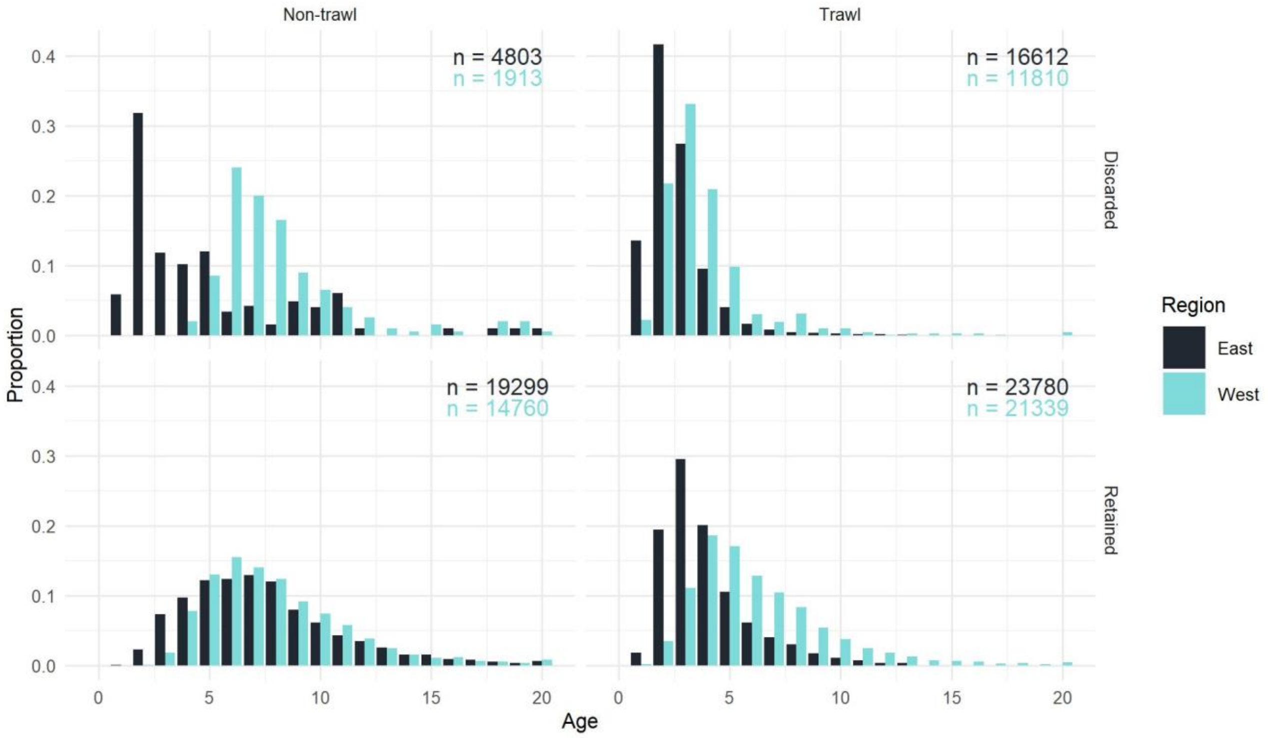

Figure 29. Age frequencies of Pink Ling from onboard sampling by region (colour), fleet (column) and discard status (row). Data is aggregated between 1993 and 2017.

Port and onboard age frequencies of Pink Ling show the same trend, again with older fish caught in the west compared to those caught in the east for the trawl fleet (Figure 29, Figure 30). There were insufficient samples in the west from the non-trawl fleet to construct an age frequency distribution (Figure 30).

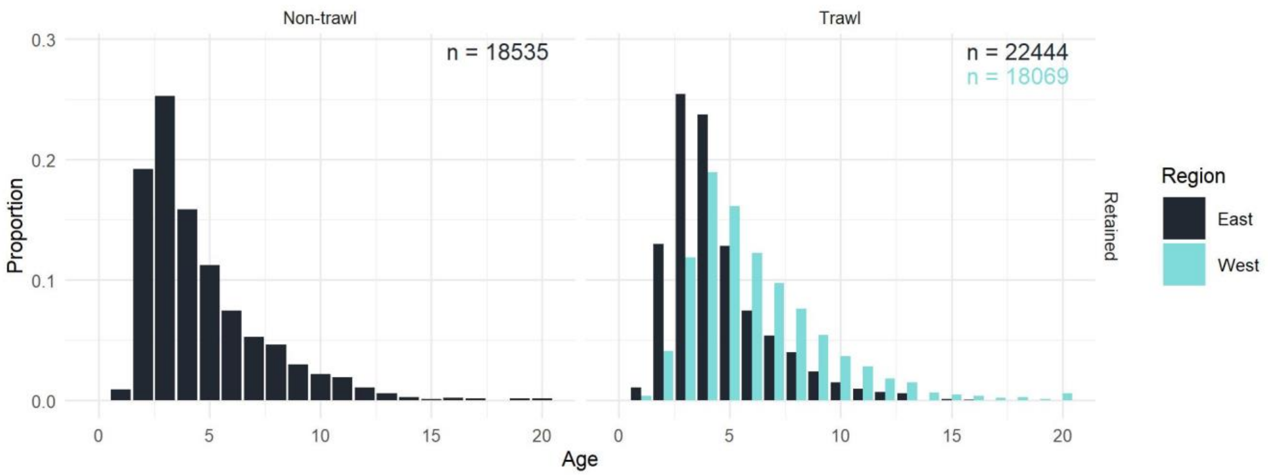

Figure 30. Age frequencies of Pink Ling from port sampling by region (colour) and fleet (column). Data is aggregated between 1993 and 2017.

5 CPUE standardisations

5.1 Blue Warehou: East

Time-series of standardised catch per unit effort (CPUE) indices are used in Tier 1 and Tier 4 assessments in the SESSF as an index of relative abundance, based on a general linear modelling technique (Sporcic 2020). All tables and figures presented in this section, except for annual logbook catches by zone, are excerpts from Sporcic (2020).

Total annual logbook catches for Blue Warehou east used in the standardisation analysis have been below 10 t since 2011, from between nine and 17 vessels (Table 2). Most of the catch in the east is from zone 20, followed by zone 30 and zone 10 (Table 4). Standardised CPUE has been below the long-term average since 1999 (Figure 31). Blue Warehou were caught in waters up to 400 m, but mostly less than 200 m (Figure 32).

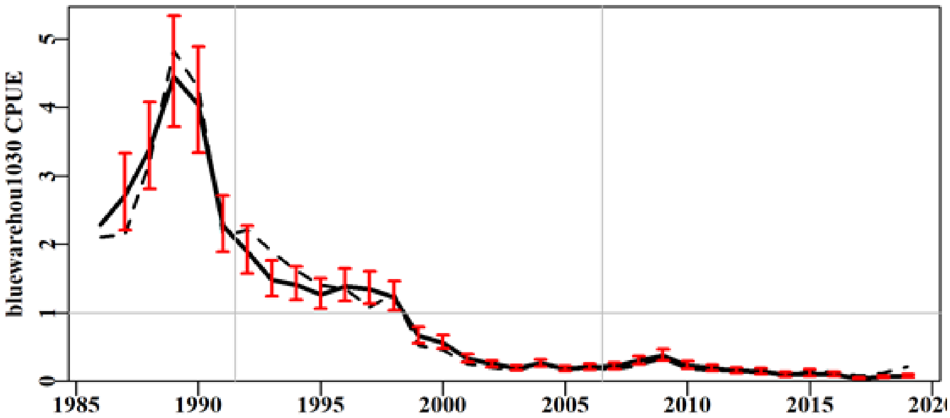

Figure 31. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Blue Warehou east. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 2. Total catch (Total; t) is the total reported Blue Warehou catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Blue Warehou east in the area (east) and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	211.9	700	138.7	40	2.2909	0.000
1987	405.9	457	168.2	40	2.7137	0.105
1988	544.0	772	333.6	33	3.3858	0.095
1989	776.0	1172	654.9	41	4.4534	0.092
1990	881.4	816	504.6	41	4.0426	0.097
1991	1284.2	1557	462.9	54	2.2696	0.092
1992	934.4	1331	401.4	40	1.8947	0.093
1993	829.6	2174	428.5	45	1.4839	0.089
1994	944.8	2428	469.7	43	1.4109	0.088
1995	815.4	2631	467.1	44	1.2669	0.088
1996	724.4	3543	530.7	48	1.3911	0.087
1997	935.2	2467	403.0	42	1.3500	0.090
1998	903.2	2552	457.2	39	1.2330	0.089
1999	591.1	1640	131.6	39	0.6640	0.092
2000	470.5	2221	185.7	41	0.5672	0.090
2001	285.5	1469	57.3	33	0.3345	0.094
2002	290.5	1854	62.9	36	0.2545	0.092
2003	234.0	1311	40.8	38	0.1947	0.095
2004	232.4	1243	51.8	38	0.2648	0.097
2005	289.1	820	21.2	33	0.1842	0.101
2006	379.5	772	25.6	28	0.2107	0.102
2007	177.8	577	16.5	14	0.2192	0.107
2008	163.3	730	26.5	18	0.3028	0.103
2009	135.2	443	35.7	15	0.3772	0.112
2010	129.3	361	11.7	15	0.2324	0.117
2011	103.3	427	9.6	13	0.1930	0.114
2012	52.3	346	9.8	14	0.1567	0.119
2013	68.0	163	3.7	17	0.1471	0.147
2014	15.3	88	1.8	12	0.0986	0.183
2015	5.4	55	1.6	9	0.1152	0.223
2016	18.8	189	6.8	14	0.1019	0.142
2017	16.4	280	3.9	12	0.0471	0.127
2018	39.0	230	3.9	9	0.0663	0.134
2019	17.8	169	7.7	12	0.0815	0.156

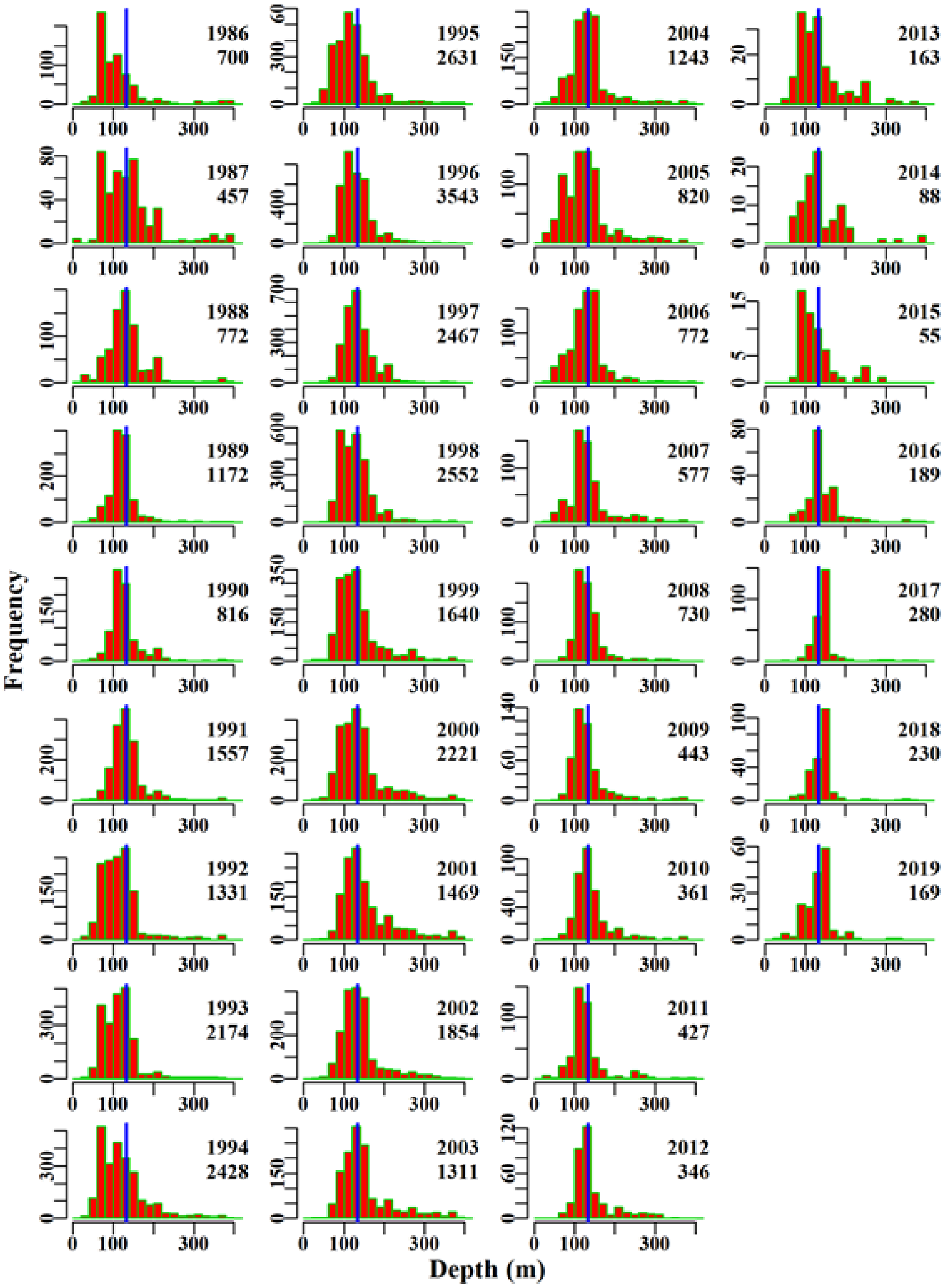

Figure 32. The average depth of fishing for each year of data available for Blue Warehou east to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.2 Blue Warehou: West

The average annual catch for Blue Warehou west has been 12.3 t since 2015, from only five or eight vessels (Table 2). Standardised CPUE has been below the long-term average since 1999, except in 2005 (Figure 33). Blue Warehou are caught in waters up to 600 m, while the average fishing depth is 280 m over the 1986-2019 period (Figure 34). This contrasts with fishing depth in the east, which occurs in shallower waters, i.e., less than 200 m. Most of the logbook catch in the west is from zone 50 followed by zone 40 (Table 4).

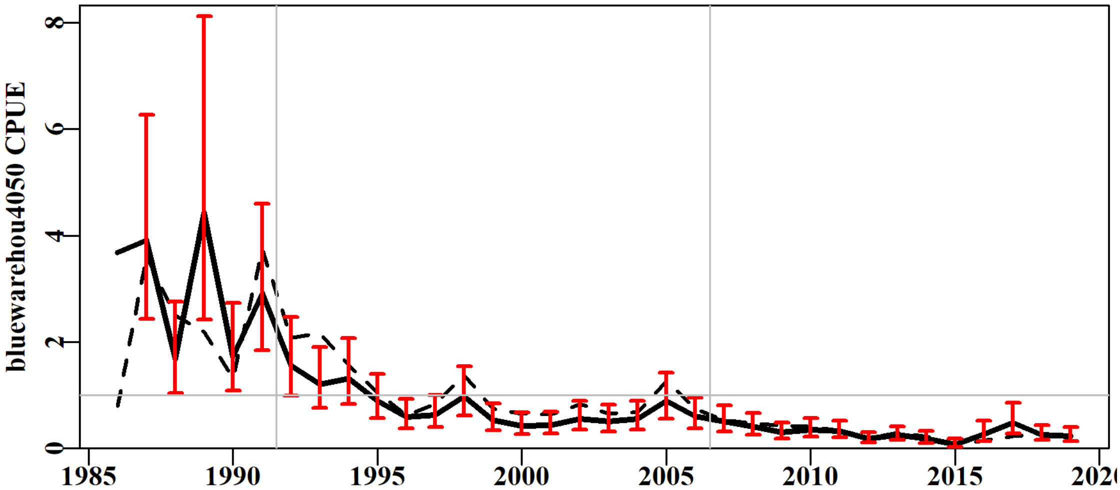

Figure 33. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Blue Warehou west. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 3. Total catch (Total; t) is the total reported Blue Warehou catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Blue Warehou west in the area (west) and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	211.9	159	71.4	14	3.6869	0.000
1987	405.9	183	215.6	10	3.9134	0.241
1988	544.0	179	198.0	12	1.6902	0.249
1989	776.0	56	81.3	13	4.4337	0.309
1990	881.4	439	298.1	13	1.7251	0.234
1991	1284.2	595	647.1	18	2.9179	0.232
1992	934.4	536	429.7	17	1.5611	0.234
1993	829.6	494	362.7	21	1.2046	0.235
1994	944.8	820	444.1	21	1.3199	0.231
1995	815.4	820	323.6	22	0.8973	0.228
1996	724.4	696	180.9	24	0.5975	0.230
1997	935.2	430	243.5	23	0.6331	0.235
1998	903.2	582	354.5	19	0.9765	0.234
1999	591.1	687	169.4	19	0.5395	0.233
2000	470.5	651	203.6	24	0.4295	0.233
2001	285.5	685	194.0	23	0.4424	0.232
2002	290.5	528	217.9	23	0.5634	0.235
2003	234.0	361	172.4	19	0.5152	0.241
2004	232.4	430	158.8	21	0.5646	0.237
2005	289.1	457	257.4	18	0.8938	0.238
2006	379.5	693	337.5	16	0.6043	0.234
2007	177.8	462	147.7	16	0.5060	0.238
2008	163.3	349	117.0	12	0.4157	0.240
2009	135.2	308	89.0	11	0.3056	0.243
2010	129.3	407	105.3	12	0.3599	0.238
2011	103.3	517	77.8	14	0.3330	0.236
2012	52.3	254	30.7	14	0.1881	0.247
2013	68.0	304	57.9	13	0.2605	0.243
2014	15.3	60	11.6	9	0.1825	0.304
2015	5.4	17	0.6	5	0.0790	0.438
2016	18.8	42	2.6	8	0.2740	0.332
2017	16.4	85	7.3	8	0.4917	0.286
2018	39.0	164	25.2	8	0.2632	0.257
2019	17.8	86	7.3	8	0.2308	0.283

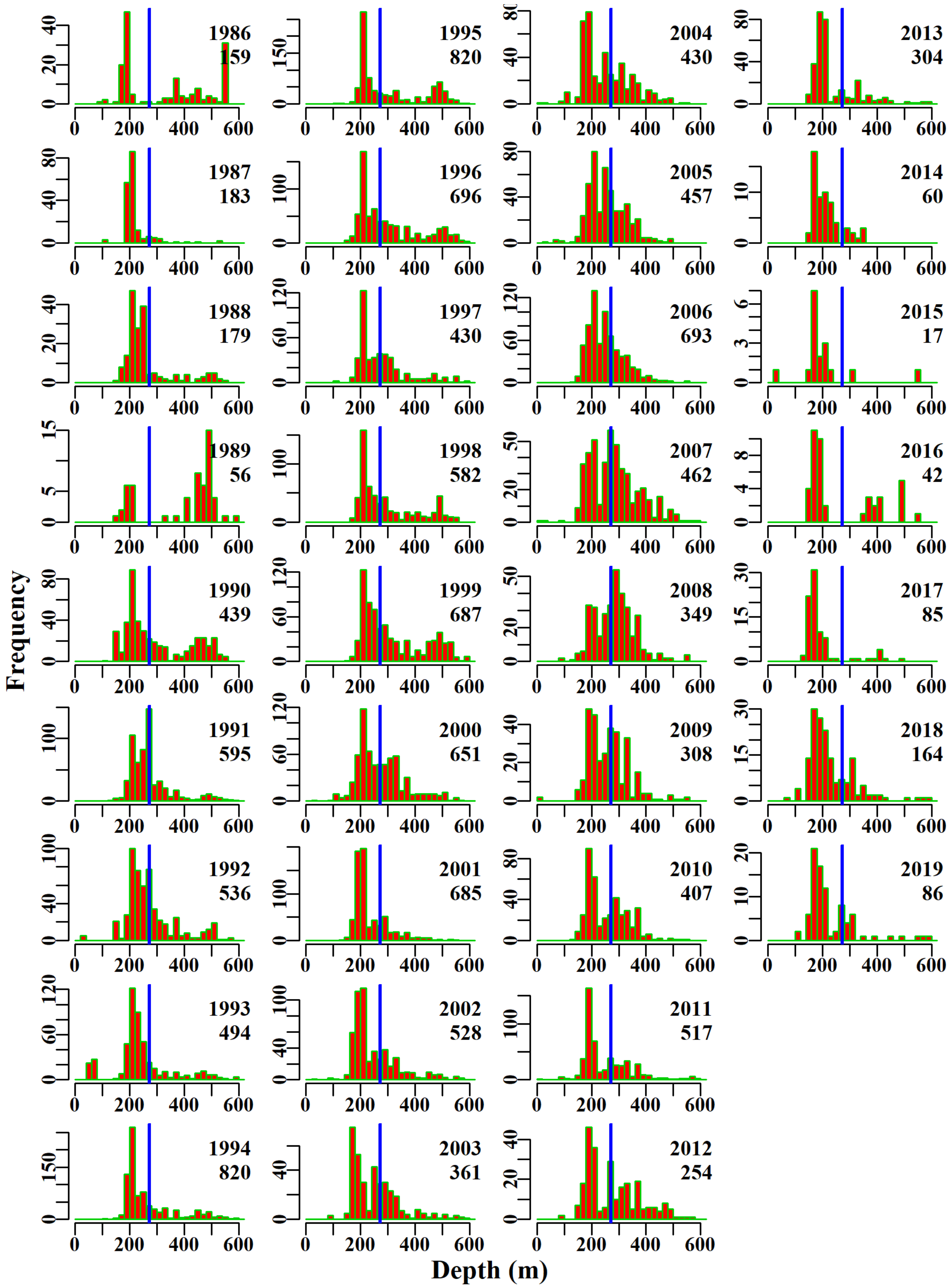

Figure 34. The average depth of fishing for each year of data available for Blue Warehou west to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.3 Blue Warehou: Comparisons

The standardised CPUE series shows a similar overall trend in the east and the west, with a gradual decline from 1990 to 2000 and below the long-term average since 1999 except for 2006 in the west (Figure 35). Most of the logbook recorded catch is from the east rather than the west (Table 4), although when state catches and discards are included, this is not necessarily the case.

Table 4. Total logbook catch (t) for Blue Warehou by SESSF zones 10, 20, 30, 40 and 50, combined east (zones 10, 20, 30) and west (zones 40, 50).

Year	10	20	30	40	50	East	West
1986	68.2	70.7		8.9	62.5	138.9	71.4
1987	86	86	7.9	7.3	210.6	179.9	217.9
1988	34.4	301.2	0.8	27.3	170.6	336.4	198
1989	44.6	345	280.2	78.9	17.1	669.8	95.9
1990	29.9	430.8	82.4	14.2	292	543.1	306.2
1991	94.5	332.5	120.9	17.5	710.5	547.9	728
1992	25.8	262.8	154.9	37.8	447.3	443.4	485.2
1993	67.4	170.9	212.9	48.6	318.3	451.2	366.9
1994	123.1	286.7	73.8	59.8	390.4	483.5	450.2
1995	169.5	229.5	71.3	70.3	261.6	470.4	331.9
1996	184.4	259.1	91.6	37.9	146.4	535.2	184.3
1997	25.1	559.2	73.2	5.7	241	657.6	246.7
1998	44.4	453	32.7	25.3	331.5	530.1	356.8
1999	22.1	346	16.7	31.1	144.7	384.8	175.8
2000	40.3	203	15.1	62.8	142.7	258.4	205.4
2001	3.1	60.8	18.9	12.9	185.7	82.7	198.6
2002	2.9	45.9	19.6	82.6	137.6	68.3	220.2
2003	3.9	34.8	5.5	41.6	142	44.1	183.6
2004	1.7	21.5	29.7	8	165.4	52.8	173.4
2005	2.4	15.6	4.2	7	252.1	22.3	259.1
2006	1.3	6.7	18.8	7.8	335.5	26.8	343.3
2007	0.2	13	4.8	8.8	141.5	18.1	150.2
2008	1.9	28.7	1.5	1.5	123.5	32.2	124.9
2009	2.8	36.3	0.5	2.7	88.7	39.7	91.4
2010	1	14.7	0.9	5.3	103.3	16.6	108.6
2011	0.8	19	2.4	8.4	70.3	22.2	78.7
2012	5.9	7.9	4.7	6.3	26.6	18.4	32.9
2013	0.8	5.4	0.5	29.1	30.5	6.7	59.7
2014	0.4	2	0.3	1.9	10.2	2.7	12
2015	0.1	4.2	0.1	0.1	0.5	4.4	0.6
2016	0.7	9.7	3.3	0.3	2.3	13.6	2.6
2017	0.3	0.5	3.2	0.3	7.5	4	7.8
2018	0.3	1.7	2.3	0.9	24.4	4.2	25.3
2019	0.9	0.8	6.7	0.1	7.3	8.4	7.4
Total:	1091.1	4665.6	1362.3	759	5742.1	7118.8	6500.9

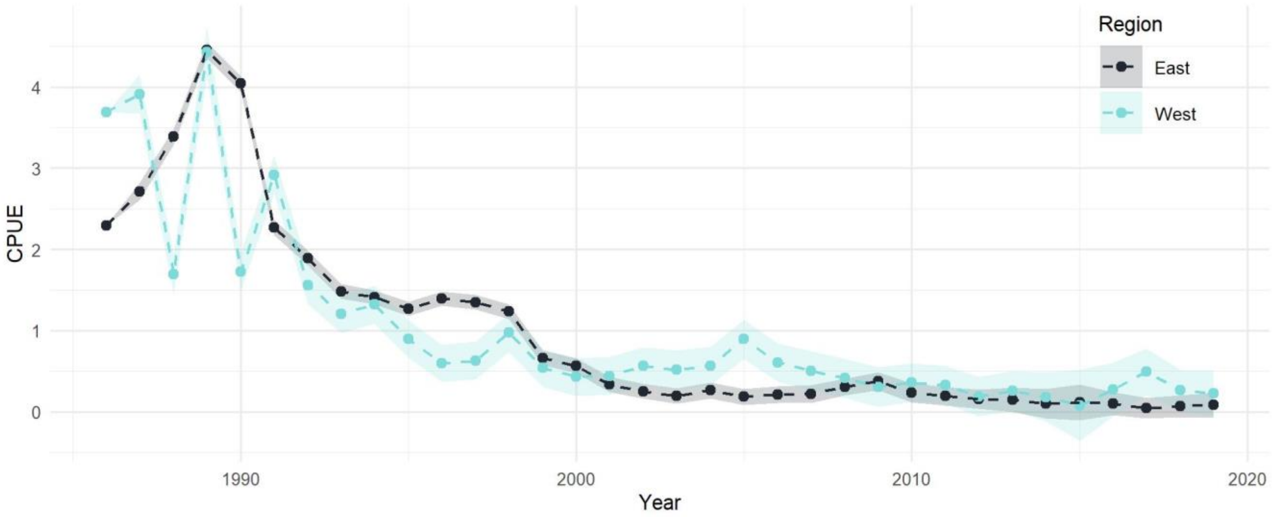

Figure 35. Standardised CPUE of Blue Warehou by region (east; west). Shading represents the standard error associated with model estimates.

5.4 Jackass Morwong: East (Zone 10, 20)

Annual standardised CPUE has been below the long-term average since about 2000 with apparent periodicity (Figure 36). The number of vessels reporting Jackass Morwong in 2019 was 14, the lowest over the 1986-2019 period (Table 8). Most fishing occurs in waters to about 250 m (Figure 34). In the east, most logbook catch occurred in zone 20, followed by zone 30 and zone 10 (Table 8). Most logbook catch was from the east (~86%) compared with the west (~14%).

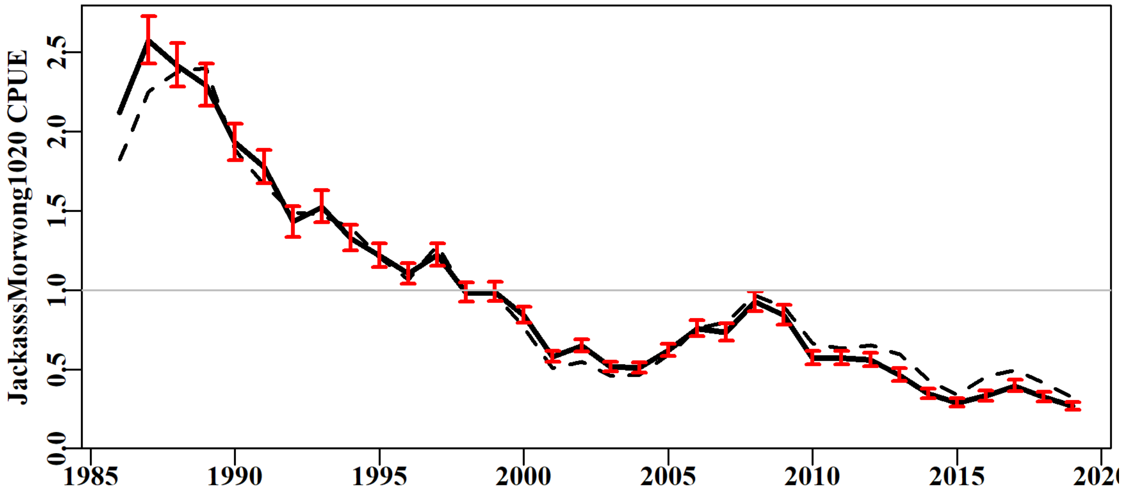

Figure 36. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Jackass Morwong east (zones 10 and 20 only). The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 5. Total catch (Total; t) is the total reported Jackass Morwong catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Jackass Morwong east in the area (zones 10 and 20) and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	982.8	5041	685.5	87	2.1212	0.000
1987	1087.7	4231	851.6	79	2.5734	0.030
1988	1483.5	5127	1020.0	79	2.4160	0.029
1989	1667.4	4305	924.2	65	2.2911	0.030
1990	1001.4	4090	593.5	59	1.9307	0.031
1991	1138.1	4398	651.3	55	1.7753	0.031
1992	758.3	2828	377.4	47	1.4296	0.034
1993	1015.0	3321	462.0	49	1.5249	0.033
1994	818.4	4418	469.0	49	1.3282	0.031
1995	789.5	4575	433.7	47	1.2165	0.031
1996	827.2	6181	541.8	50	1.1025	0.029
1997	1063.4	5994	669.8	52	1.2222	0.030
1998	876.4	4772	435.1	46	0.9850	0.031
1999	961.5	4408	446.6	50	0.9889	0.032
2000	945.2	5615	477.9	55	0.8432	0.030
2001	790.2	4793	251.5	46	0.5796	0.031
2002	811.2	5700	328.2	44	0.6486	0.031
2003	774.6	4555	236.4	47	0.5158	0.032
2004	765.5	4178	219.7	52	0.5103	0.032
2005	784.2	4320	258.8	39	0.6195	0.032
2006	811.3	3388	273.8	36	0.7560	0.034
2007	607.9	2412	211.2	20	0.7325	0.037
2008	700.4	3105	313.1	25	0.9270	0.035
2009	454.4	2400	223.7	19	0.8408	0.037
2010	380.0	2478	184.9	19	0.5727	0.037
2011	428.0	2291	161.6	18	0.5707	0.038
2012	395.6	2111	169.7	19	0.5589	0.039
2013	323.9	1393	96.5	15	0.4639	0.044
2014	216.6	1513	75.9	17	0.3456	0.043
2015	152.5	1094	42.3	20	0.2891	0.048
2016	183.4	1144	70.7	16	0.3314	0.048
2017	246.2	1232	72.6	16	0.3957	0.046
2018	209.7	1397	77.6	16	0.3267	0.046
2019	161.5	1215	52.3	14	0.2667	0.047

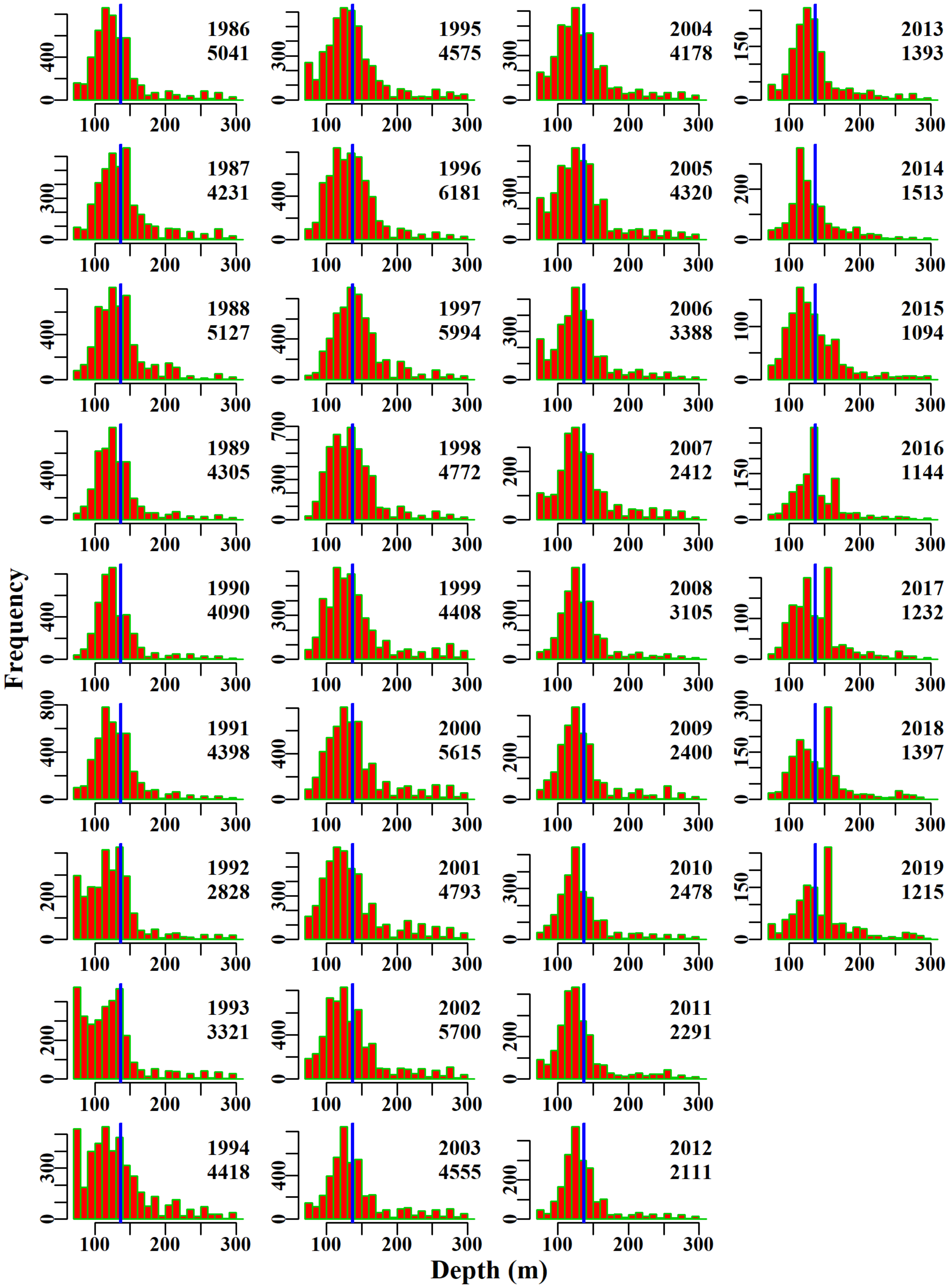

Figure 37. The average depth of fishing for each year of data available for Jackass Morwong east (zones 10 and 20 only) to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.5 Jackass Morwong: East (Zone 30)

Annual standardised CPUE has been below the long-term average since about 2001 and not statistically different from each other over the last six years, based on the 95% confidence intervals (Figure 38). Between nine and 12 vessels have fished Jackass Morwong in zone 30 since about 2007 (after the structural adjustment; **Error! Not a valid bookmark self-reference.**). Most fishing occurs in waters to about 160 m (Figure 39).

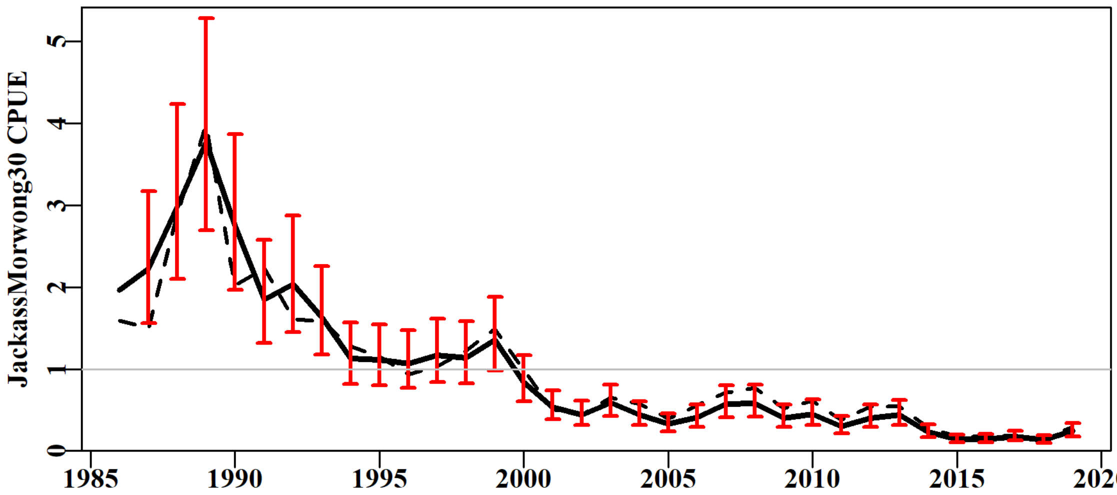

Figure 38. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Jackass Morwong east (zone 30 only). The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 6. Total catch (Total; t) is the total reported Jackass Morwong catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Jackass Morwong east in the area (zone 30) and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	982.8	68	29.8	6	1.9626	0.000
1987	1087.7	205	57.0	13	2.2239	0.181
1988	1483.5	282	207.7	13	2.9819	0.179
1989	1667.4	687	475.0	19	3.7688	0.172
1990	1001.4	379	140.2	26	2.7545	0.173
1991	1138.1	408	184.4	29	1.8454	0.171
1992	758.3	333	106.7	18	2.0384	0.175
1993	1015.0	1031	322.3	27	1.6305	0.166
1994	818.4	759	179.1	22	1.1291	0.167
1995	789.5	821	183.7	19	1.1143	0.167
1996	827.2	888	161.3	19	1.0643	0.167
1997	1063.4	938	202.3	15	1.1677	0.166
1998	876.4	768	190.7	15	1.1410	0.167
1999	961.5	854	246.9	17	1.3561	0.167
2000	945.2	548	123.4	23	0.8409	0.169
2001	790.2	807	110.3	19	0.5343	0.166
2002	811.2	1039	108.3	15	0.4421	0.165
2003	774.6	1121	186.2	19	0.5870	0.164
2004	765.5	1494	200.8	15	0.4389	0.164
2005	784.2	1136	135.6	17	0.3297	0.165
2006	811.3	1112	152.8	14	0.4071	0.165
2007	607.9	705	110.6	8	0.5747	0.168
2008	700.4	752	117.2	9	0.5817	0.168
2009	454.4	456	53.4	10	0.4052	0.171
2010	380.0	340	54.9	9	0.4483	0.174
2011	428.0	444	47.4	8	0.3047	0.172
2012	395.6	518	88.8	8	0.4038	0.170
2013	323.9	595	102.9	10	0.4452	0.169
2014	216.6	359	53.3	9	0.2313	0.174
2015	152.5	455	30.4	11	0.1445	0.171
2016	183.4	770	48.3	10	0.1481	0.167
2017	246.2	611	37.9	9	0.1743	0.169
2018	209.7	468	26.4	9	0.1344	0.172
2019	161.5	624	54.0	12	0.2451	0.170

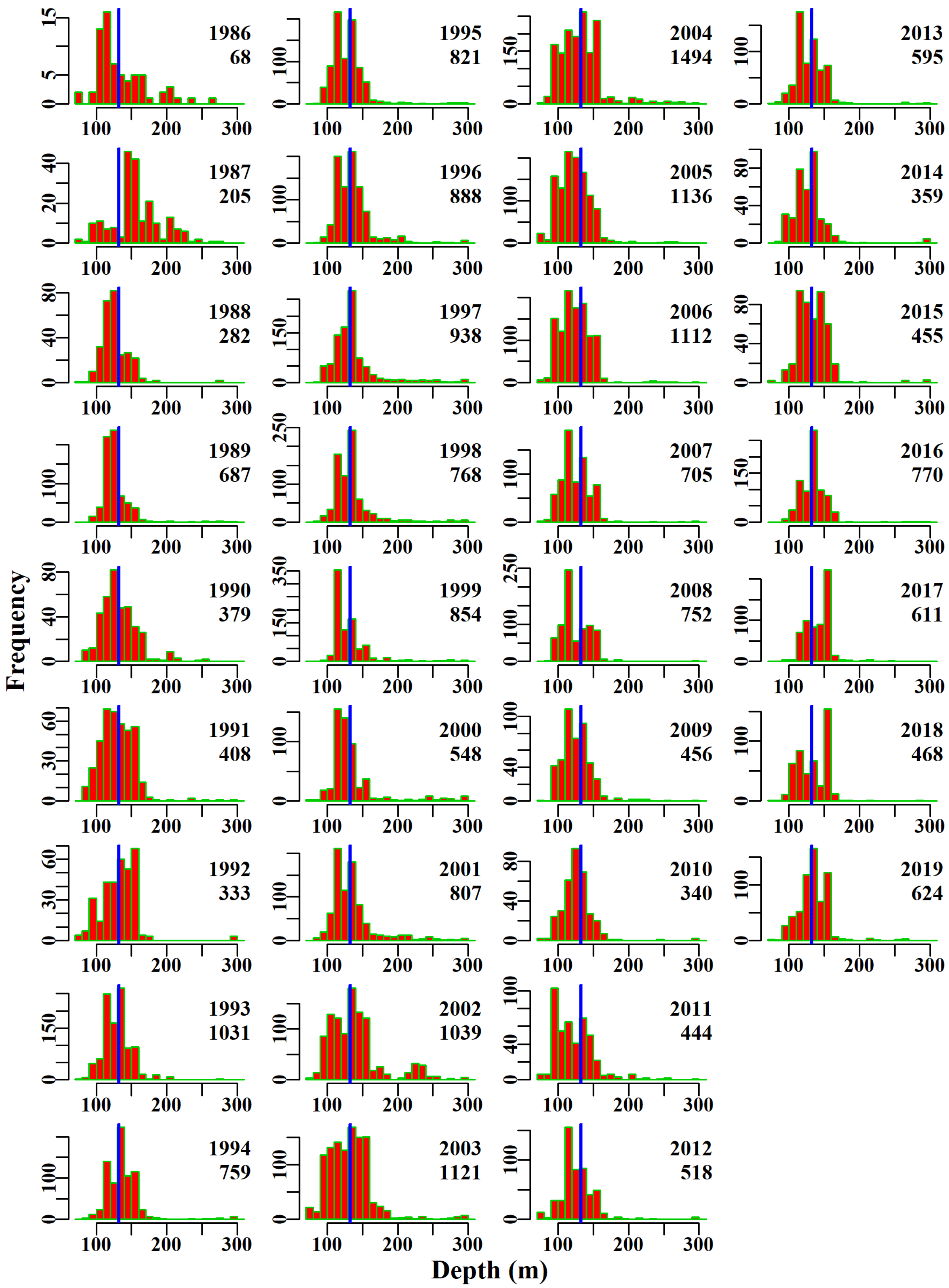

Figure 39. The average depth of fishing for each year of data available for Jackass Morwong east (zone 30 only) to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.6 Jackass Morwong: West (Zone 40, 50)

Most catch from zone 40 occurs at a shallower depth compared to zone 50. Since 2007, standardised CPUE has been below the long-term average, with a decline to 2014, followed by an increase to 2017 and then a decrease in 2018 and 2019 (Figure 40). Ten vessels caught Jackass Morwong in 2019, the second lowest over the 1986-2019 period (Table 8). Most fishing occurs in waters to about 360 m (Figure 41). In the west, most catch occurs in zone 40, followed by zone 50 (Table 8).

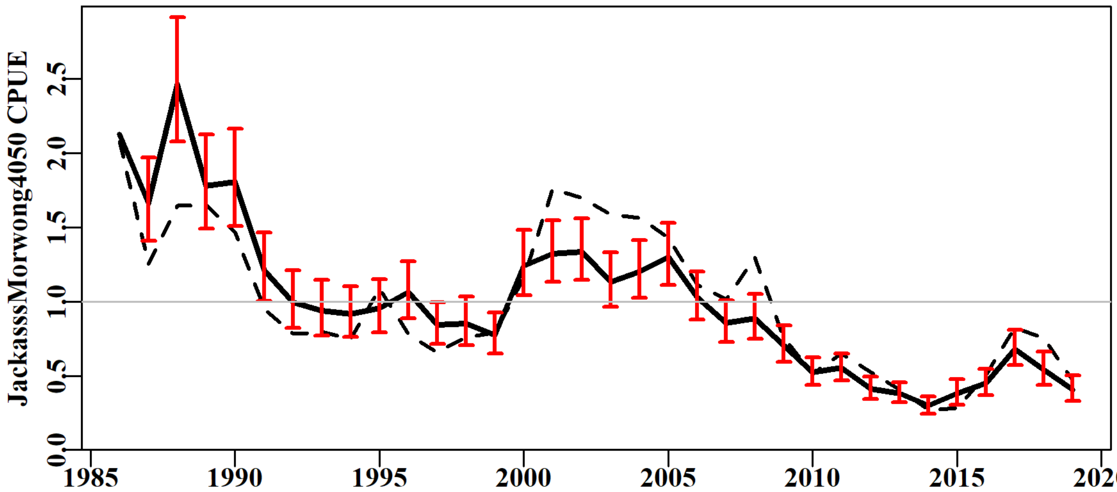

Figure 40. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Jackass Morwong west. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 7. Total catch (Total; t) is the total reported Jackass Morwong catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Jackass Morwong west in the area (zones 40 and 50) and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	982.8	550	149.1	19	2.1216	0.000
1987	1087.7	349	58.4	21	1.6632	0.086
1988	1483.5	401	65.4	19	2.4583	0.086
1989	1667.4	345	83.2	21	1.7776	0.091
1990	1001.4	410	80.3	22	1.8036	0.092
1991	1138.1	279	40.3	26	1.2112	0.097
1992	758.3	249	28.6	14	0.9954	0.099
1993	1015.0	248	25.0	17	0.9392	0.101
1994	818.4	309	22.5	16	0.9171	0.094
1995	789.5	291	76.9	17	0.9545	0.095
1996	827.2	345	36.1	17	1.0606	0.092
1997	1063.4	489	53.9	20	0.8414	0.086
1998	876.4	266	54.6	19	0.8530	0.098
1999	961.5	382	76.9	17	0.7736	0.091
2000	945.2	429	118.9	29	1.2412	0.090
2001	790.2	920	276.8	25	1.3223	0.079
2002	811.2	850	249.4	21	1.3354	0.079
2003	774.6	649	170.7	24	1.1308	0.083
2004	765.5	674	174.5	25	1.2023	0.082
2005	784.2	717	188.5	21	1.3017	0.082
2006	811.3	799	178.3	19	1.0267	0.080
2007	607.9	585	114.2	15	0.8546	0.083
2008	700.4	466	101.5	16	0.8840	0.087
2009	454.4	409	58.3	13	0.7053	0.089
2010	380.0	408	38.2	13	0.5216	0.089
2011	428.0	621	82.8	14	0.5519	0.083
2012	395.6	341	34.5	14	0.4131	0.093
2013	323.9	463	35.7	13	0.3827	0.088
2014	216.6	252	10.1	13	0.2977	0.100
2015	152.5	154	7.0	9	0.3811	0.114
2016	183.4	255	25.0	11	0.4492	0.099
2017	246.2	495	79.8	12	0.6810	0.088
2018	209.7	224	44.4	10	0.5390	0.104
2019	161.5	209	22.3	10	0.4080	0.107

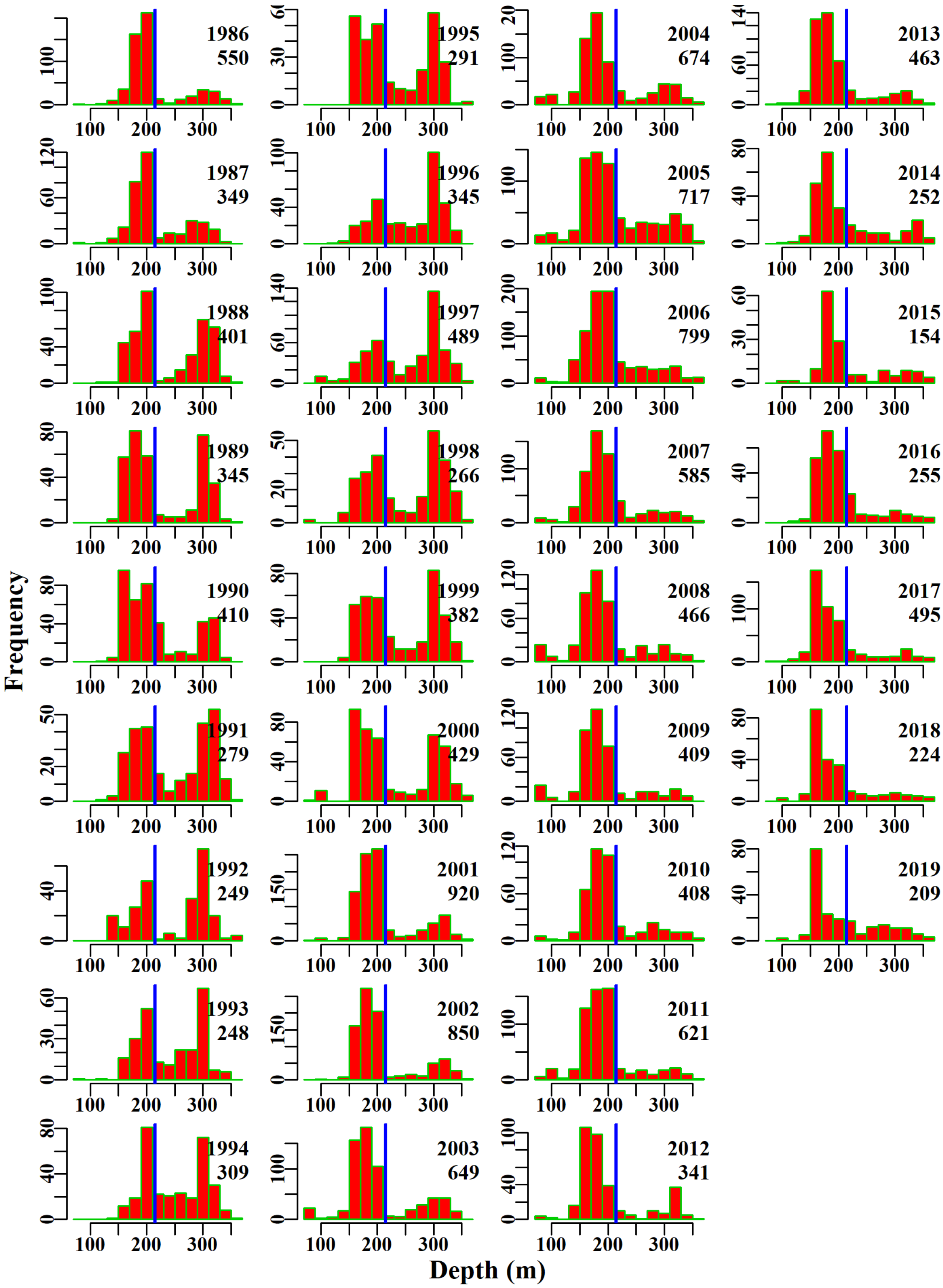

Figure 41. The average depth of fishing for each year of data available for Jackass Morwong west to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.7 Jackass Morwong: Comparisons

Standardised CPUE for Jackass Morwong shows similar trends between all three regions assessed, with an overall decline in CPUE through time (Figure 42). A peak in CPUE is apparent in 1989 in zone 30 compared to the other two regions (Figure 42). However, there are fewer records used in the analysis in zone 30 in the early years compared with records in the west (

Annual standardised CPUE has been below the long-term average since about 2001 and not statistically different from each other over the last six years, based on the 95% confidence intervals (Figure 38). Between nine and 12 vessels have fished Jackass Morwong in zone 30 since about 2007 (after the structural adjustment; **Error! Not a valid bookmark self-reference.**). Most fishing occurs in waters to about 160 m (Figure 39).

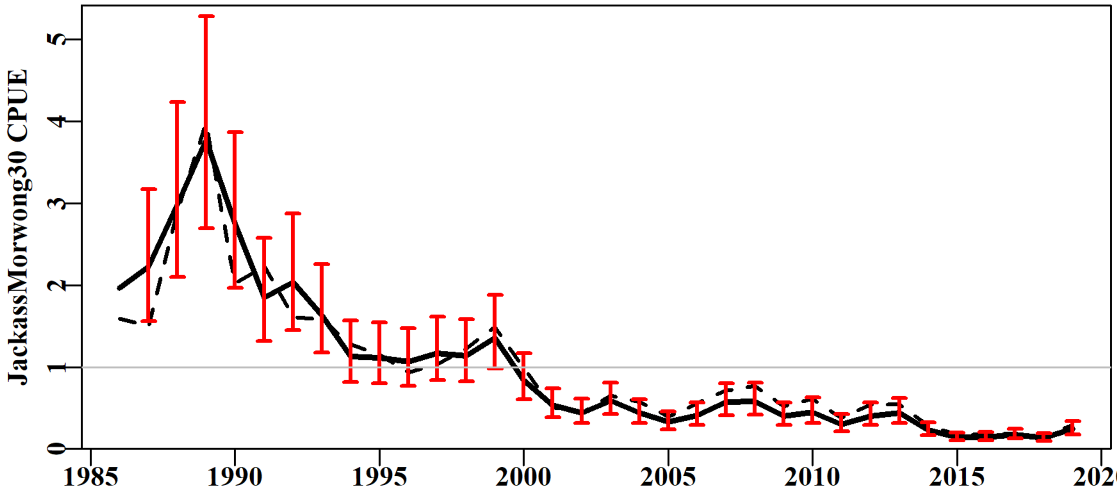

Figure 38. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Jackass Morwong east (zone 30 only). The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 6;

Most catch from zone 40 occurs at a shallower depth compared to zone 50. Since 2007, standardised CPUE has been below the long-term average, with a decline to 2014, followed by an increase to 2017 and then a decrease in 2018 and 2019 (Figure 40). Ten vessels caught Jackass Morwong in 2019, the second lowest over the 1986-2019 period (Table 8). Most fishing occurs in waters to about 360 m (Figure 41). In the west, most catch occurs in zone 40, followed by zone 50 (Table 8).

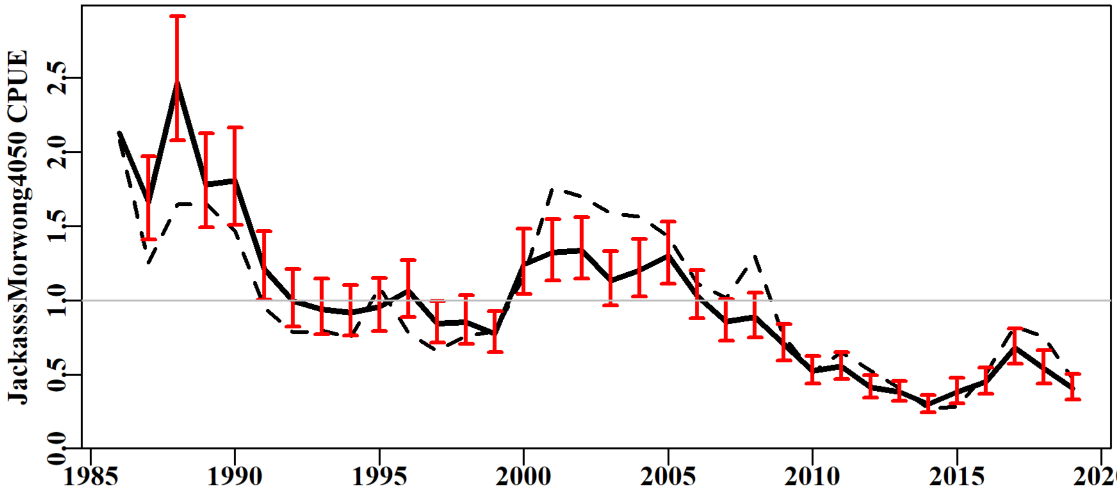

Figure 40. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Jackass Morwong west. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 7). Between 2000 and 2006 there was a period of increased CPUE in the west compared to the east (zone 10 and 20 combined, and zone 30). SESSF statistical zones are shown in Figure 1.

Table 8. Total logbook catch (t) for Jackass Morwong by SESSF zones 10, 20, 30, 40 and 50, combined east (zones 10 and 20) and west (zones 40, 50).

Year	10	20	30	40	50	Zone 10,20	West
1986	153.3	597.8	32.3	0.4	152.2	751.1	152.6
1987	143.6	769.6	80.4	13.8	46.4	913.2	60.2
1988	181.2	918.8	214	16.7	51.1	1100	67.8
1989	80.2	896.6	505.1	50.8	34.2	976.8	85
1990	82.8	606.5	158.5	14.7	68.4	689.3	83.1
1991	108.8	691.2	225.7	14.4	33.1	800	47.5
1992	56.7	443.8	132.7	27.5	34.5	500.5	62
1993	109	420.9	344.4	4.5	21.1	529.9	25.6
1994	109.7	431.8	185.2	4.6	18.7	541.5	23.3
1995	79.7	385.6	187.5	67.8	10.9	465.3	78.7
1996	100.5	472.7	162.7	10.9	27.4	573.2	38.3
1997	64.8	650	205.3	30	27.2	714.8	57.2
1998	59.7	440.6	193.3	45.3	13	500.3	58.3
1999	45.9	443.8	249	64.5	16.5	489.7	81
2000	49.7	475.4	126.2	107.8	13.7	525.1	121.5
2001	37.1	274.1	113	137.9	149.7	311.2	287.6
2002	75.3	292.5	110.8	98.9	156.5	367.8	255.4
2003	32.5	240.9	196.7	62.2	114.7	273.4	176.9
2004	30.8	224	205.9	48.4	141.8	254.8	190.2
2005	36.7	289.6	151.9	36.9	162.9	326.3	199.8
2006	30.2	290	166	24.7	167.6	320.2	192.3
2007	14.1	231.5	118.9	25.8	96.7	245.6	122.5
2008	38.4	327.9	122.7	29.9	74.7	366.3	104.6
2009	27	231.2	55.9	20.8	45.1	258.2	65.9
2010	21.8	190.9	59.8	13.7	27.3	212.7	41
2011	16.6	185.8	51.3	35.1	51.2	202.4	86.3
2012	21.7	171	94.5	20.3	16.3	192.7	36.6
2013	7.5	103.7	106	21.6	16.1	111.2	37.7
2014	10.6	75	54.2	2	9.3	85.6	11.3
2015	7.8	40.2	31.1	0.4	7.7	48	8.1
2016	5.3	71.6	49	3.5	22.8	76.9	26.3
2017	5.3	72.9	39.6	19.2	62.2	78.2	81.4
2018	6.4	76.1	27.3	27.6	17.5	82.5	45.1
2019	4	56.6	57.7	14.1	9.5	60.6	23.6
Total:	1854.7	12090.6	4814.6	1116.7	1918	13945.3	3034.7

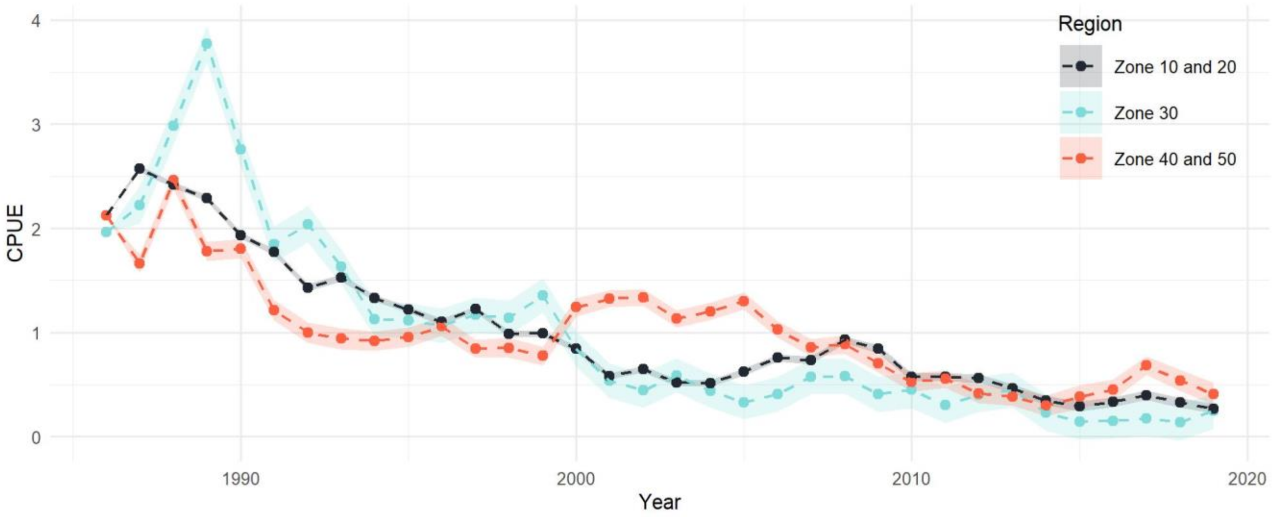

Figure 42. Standardised CPUE of Jackass Morwong by region, with zone 10 and 20 and zone 30 comprising parts of the eastern stock and zones 40 and 50 comprising the western stock. Shaded areas represent the standard error associated with model estimates.

5.8 Pink Ling: East

Annual standardised trawl CPUE for eastern Pink Ling has been below average corresponding to a relatively flat trend over the 2001-2019 period, with the most recent estimate reaching the long-term average, based on 95% confidence intervals (Figure 43). Nineteen vessels caught Pink Ling in the east in 2019, the lowest over the 1986-2019 period (**Error! Not a valid bookmark self-reference.**). Most fishing occurred between 250 and 600 m (Figure 44). Pink Ling were mostly caught in zone 20, followed by zone 10 and 30 across the analysis period (Table 11), although since 2011, catches in the west have been higher than catches in the east.

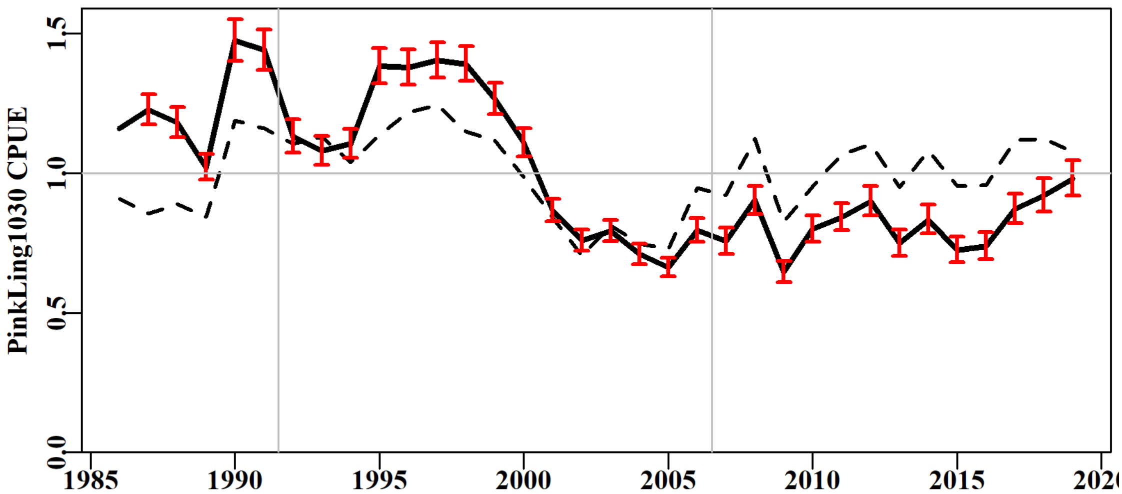

Figure 43. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Pink Ling east. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 9. Total catch (Total; t) is the total reported Pink Ling catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Pink Ling east in the area and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	679.0	4510	498.2	80	1.1607	0.000
1987	765.1	4251	491.4	77	1.2272	0.022
1988	583.1	3603	398.3	77	1.1809	0.024
1989	678.9	3869	421.2	76	1.0215	0.023
1990	674.5	2768	411.6	67	1.4743	0.026
1991	736.8	2903	366.0	71	1.4402	0.026
1992	568.3	2417	329.4	58	1.1311	0.027
1993	892.8	3471	500.7	58	1.0806	0.025
1994	895.4	4036	468.4	62	1.1052	0.024
1995	1208.9	4346	585.6	57	1.3833	0.023
1996	1233.3	4254	666.7	63	1.3786	0.023
1997	1696.8	4772	730.9	61	1.4027	0.023
1998	1592.4	4883	728.3	56	1.3906	0.023
1999	1651.6	5934	831.1	59	1.2661	0.022
2000	1507.5	5100	658.8	63	1.1089	0.023
2001	1393.0	4555	484.9	52	0.8666	0.024
2002	1330.3	3882	360.3	52	0.7590	0.025
2003	1353.1	4277	444.3	57	0.7923	0.024
2004	1522.9	3328	345.6	54	0.7098	0.026
2005	1203.3	3370	324.5	51	0.6620	0.026
2006	1069.2	2566	321.1	38	0.7956	0.028
2007	875.9	1627	202.8	23	0.7569	0.032
2008	980.3	2342	325.4	24	0.9022	0.029
2009	775.0	1886	208.3	27	0.6467	0.030
2010	906.2	1923	265.5	23	0.7997	0.030
2011	1081.9	2122	287.3	22	0.8415	0.029
2012	1030.9	1919	268.1	24	0.8990	0.030
2013	752.9	1560	184.3	22	0.7484	0.032
2014	861.2	1638	234.2	24	0.8329	0.032
2015	721.8	1650	188.9	24	0.7250	0.032
2016	735.8	1517	192.7	25	0.7386	0.033
2017	896.7	1862	276.1	22	0.8721	0.031
2018	874.0	1587	223.1	20	0.9202	0.033
2019	799.2	1706	227.3	19	0.9800	0.033

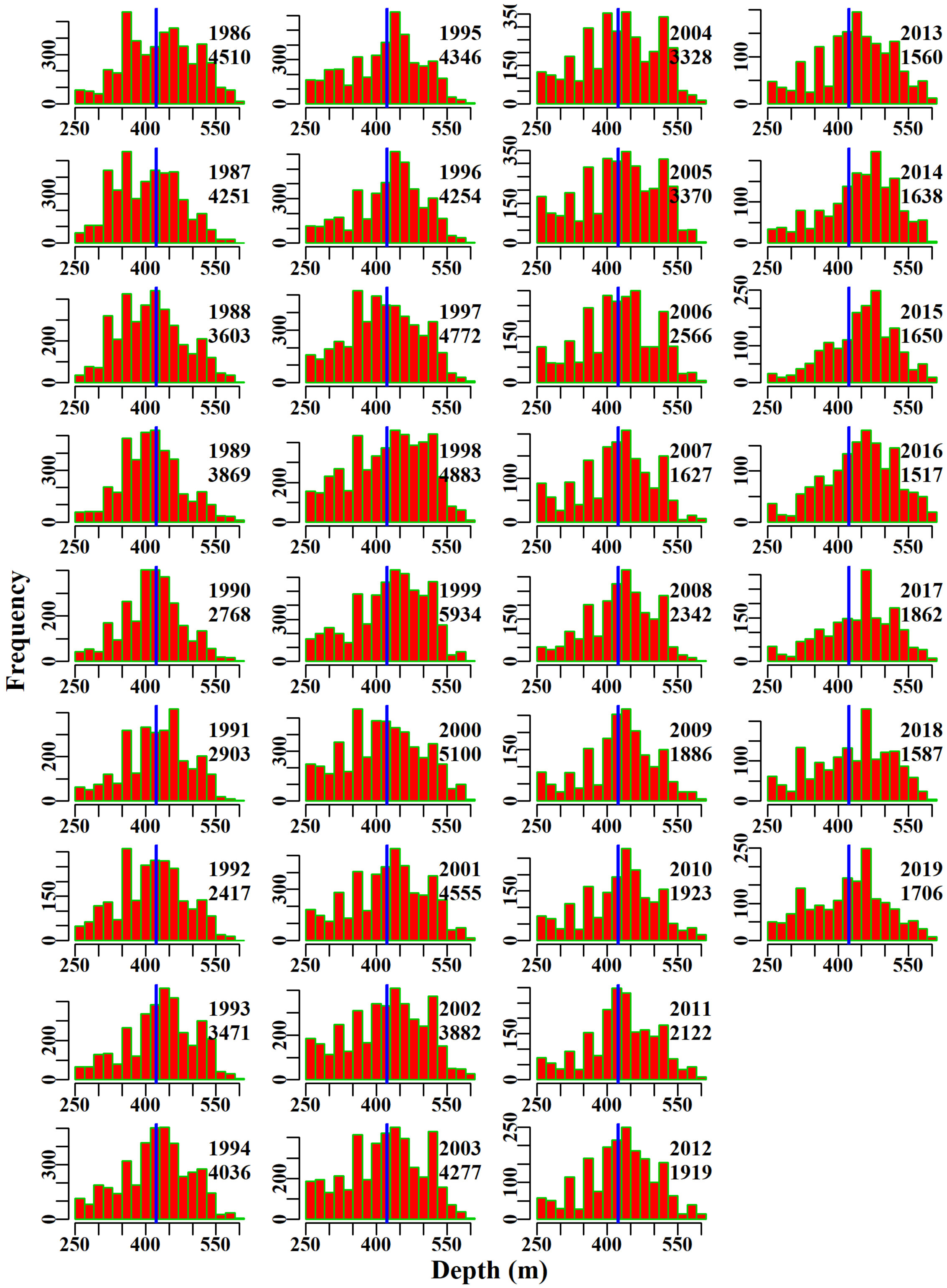

Figure 44. The average depth of fishing for each year of data available for Pink Ling east to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.9 Pink Ling: West

Annual standardised trawl CPUE for western Pink Ling reached a minimum in 2005 and has increased since then to the long-term average from 2013 to 2016, followed by an increase to above average in 2017 to 2018 and then decreased to the long-term average in 2019, based on the 95% confidence intervals (Figure 45). In the west, most of the logbook catch of this slope species occurs in zone 40 followed by zone 50 (Table 11). Most fishing occurs between 200 and 800 m (Figure 46).

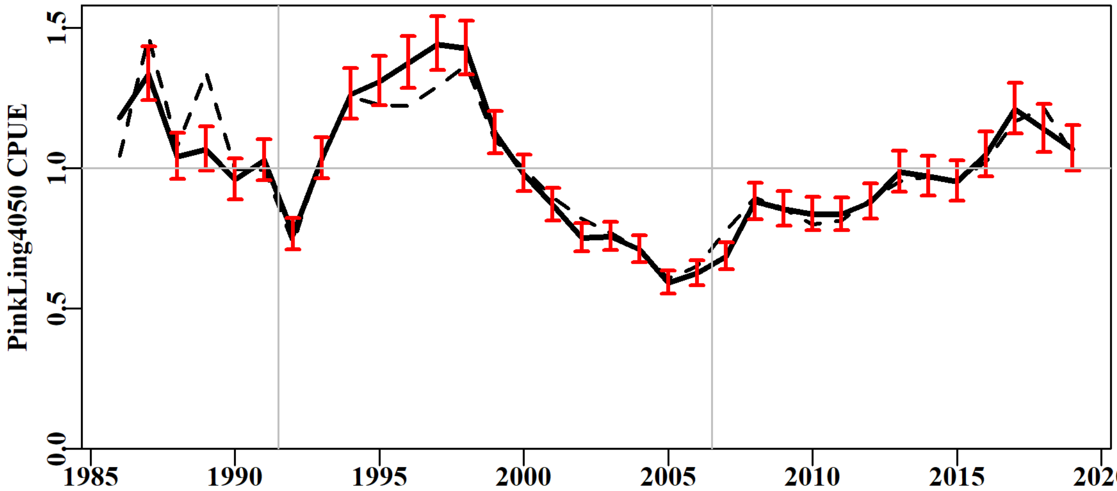

Figure 45. The dashed black line represents the geometric mean CPUE, solid black line the standardised CPUE for Pink Ling west. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series relative to the mean of each time-series.

Table 10. Total catch (Total; t) is the total reported Pink Ling catch (across all fishing methods) in the logbook database, number of records used in the analysis (N), reported trawl catch (Catch; t) for Pink Ling west in the area and depth used in the analysis and number of vessels used in the analysis (Vess). Standard deviation (StDev) relates to the optimum model. Opt refers to the standardised series.

Year	Total	N	Catch	Vess	Opt	StDev
1986	679.0	1265	112.9	23	1.1807	0.000
1987	765.1	1306	205.7	28	1.3346	0.037
1988	583.1	1025	95.5	32	1.0413	0.040
1989	678.9	1466	182.8	34	1.0680	0.038
1990	674.5	1483	135.2	32	0.9596	0.038
1991	736.8	1874	194.8	37	1.0277	0.037
1992	568.3	1629	101.9	24	0.7650	0.038
1993	892.8	2249	235.2	24	1.0343	0.036
1994	895.4	2096	246.1	24	1.2634	0.036
1995	1208.9	3503	425.5	25	1.3094	0.034
1996	1233.3	3385	446.1	26	1.3754	0.034
1997	1696.8	3716	572.2	24	1.4422	0.034
1998	1592.4	3704	555.3	21	1.4270	0.034
1999	1651.6	3784	426.2	24	1.1262	0.034
2000	1507.5	4642	508.4	31	0.9811	0.034
2001	1393.0	5084	500.3	28	0.8700	0.034
2002	1330.3	4619	428.9	27	0.7527	0.034
2003	1353.1	3806	358.4	27	0.7567	0.034
2004	1522.9	3880	302.7	25	0.7108	0.034
2005	1203.3	2650	194.9	23	0.5925	0.036
2006	1069.2	2298	207.9	21	0.6256	0.036
2007	875.9	2505	284.5	16	0.6859	0.036
2008	980.3	1777	211.8	17	0.8816	0.037
2009	775.0	1956	258.3	13	0.8555	0.037
2010	906.2	2316	268.9	14	0.8358	0.036
2011	1081.9	2772	355.3	16	0.8359	0.035
2012	1030.9	2264	333.0	14	0.8808	0.036
2013	752.9	1756	277.7	17	0.9872	0.038
2014	861.2	1943	284.6	15	0.9711	0.037
2015	721.8	1631	237.6	13	0.9529	0.038
2016	735.8	1574	231.8	13	1.0481	0.038
2017	896.7	1768	294.1	12	1.2103	0.038
2018	874.0	1684	317.7	11	1.1405	0.038
2019	799.2	1525	236.7	12	1.0701	0.039

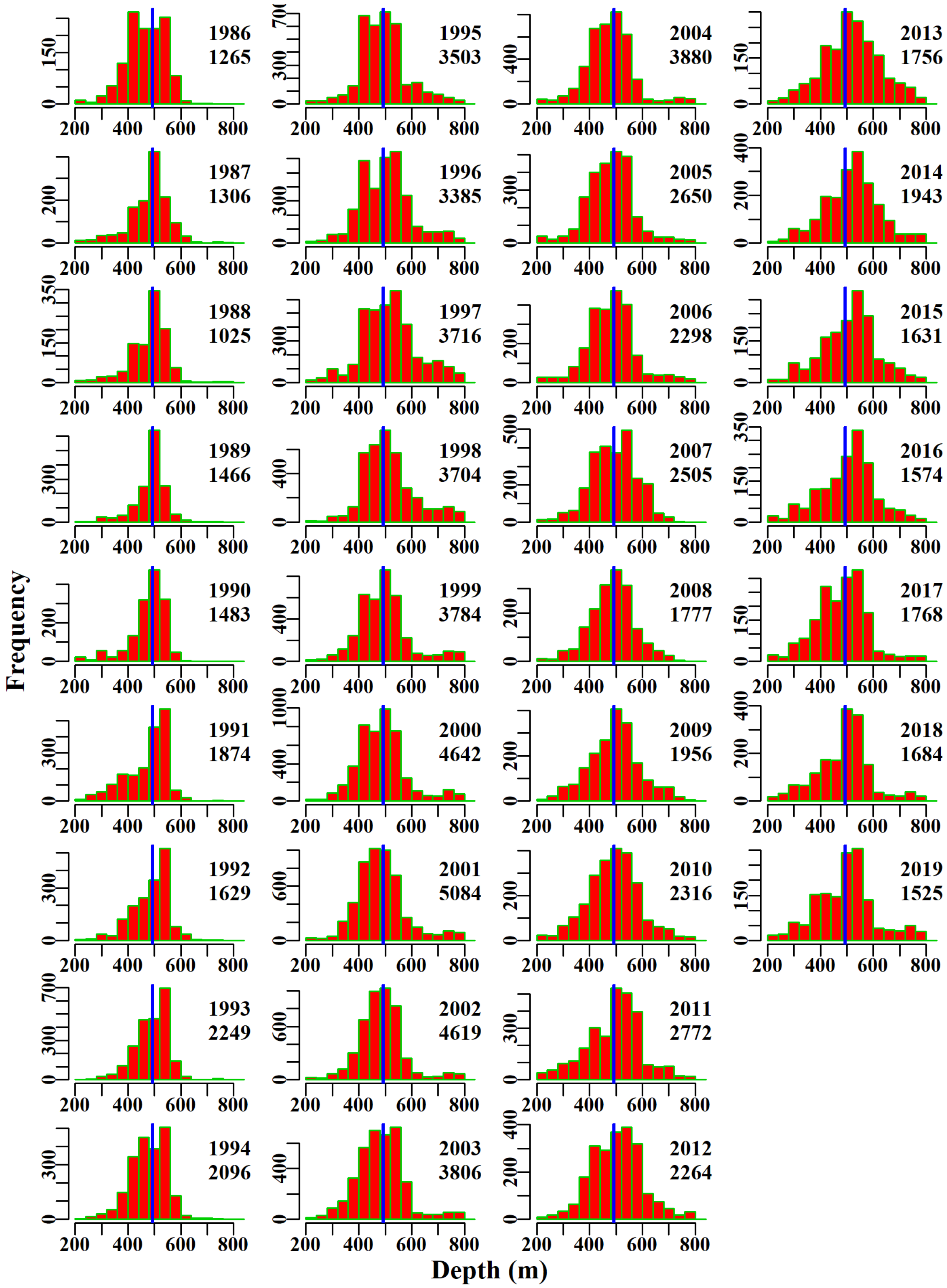

Figure 46. The average depth of fishing for each year of data available for Pink Ling west to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records.

5.10 Pink Ling: Comparisons

Standardised trawl CPUE show similar trends between the east and the west for Pink Ling, with this particularly apparent in the decline observed between 1998 and 2005 (Figure 47). Since 2013 standardised CPUE has been higher in the west compared to the east. Also, standardised CPUE has decreased since 2017 in the west, but has increased since 2015 and reached the long-term average in 2019 in the east (Figure 47).

Table 11. Total logbook catch (t) for Pink Ling by SESSF zones 10, 20, 30, 40 and 50, combined east (zones 10, 20, 30) and west (zones 40, 50).

Year	10	20	30	40	50	East	West
1986	351.2	204.6	2.6	51.6	63	558.4	114.6
1987	287.9	250.5	2.9	159.7	56	541.3	215.7
1988	235.6	223.4	4.9	54.1	43.3	463.9	97.4
1989	200.3	272.1	8.8	139	45.9	481.2	184.9
1990	194.4	308	11.6	101.5	49.3	514	150.8
1991	172	271.3	33.1	134.1	106.8	476.4	240.9
1992	205.4	226.5	7.1	48.3	70.8	439	119.1
1993	268.8	307.7	21.4	130.1	117.4	597.9	247.5
1994	314.5	278.6	30.8	134.5	115.8	623.9	250.3
1995	350.8	377.3	37.4	215.1	216.3	765.5	431.4
1996	314.2	406.6	42.6	242.5	214.2	763.4	456.7
1997	365.1	521.4	61	434.1	240.8	947.5	674.9
1998	393.7	436	36.5	434.4	211.7	866.2	646.1
1999	408.2	551.9	61.8	348	191.4	1021.9	539.4
2000	271.3	520.4	70.1	395.3	175.3	861.8	570.6
2001	134.3	373.1	184.5	508.2	142.6	691.9	650.8
2002	117.3	302.4	179	566.6	146.6	598.7	713.2
2003	123.2	470.4	138.6	476.5	122.6	732.2	599.1
2004	75.6	531.7	134.5	434.1	251.6	741.8	685.7
2005	88.4	459.7	91.2	261.4	191.9	639.3	453.3
2006	72.2	438.5	62	221.7	119.7	572.7	341.4
2007	37.5	314	72.5	289.5	69.4	424	358.9
2008	55.1	439.4	114.9	197.3	67.1	609.4	264.4
2009	44.1	279.9	78.8	255.4	68.5	402.8	323.9
2010	77.2	305.8	55.3	266	108.4	438.3	374.4
2011	60.5	327.6	101.4	397.6	116.5	489.5	514.1
2012	63.7	286.5	117.4	432.7	76.8	467.6	509.5
2013	49	198.1	55.9	321.6	75.9	303	397.5
2014	45.7	215.8	52	400.2	75.9	313.5	476.1
2015	32.3	205.4	49.1	340.8	77.9	286.8	418.7
2016	42.6	193.9	57.9	339.1	88.5	294.4	427.6
2017	53	247.3	99.2	322.8	140.9	399.5	463.7
2018	38.8	235.9	78.1	397	96.1	352.8	493.1
2019	40.6	250.8	81.7	273.4	111.6	373.1	385
Total:	5584.5	11232.5	2236.6	9724.2	4066.5	19053.6	13790.7

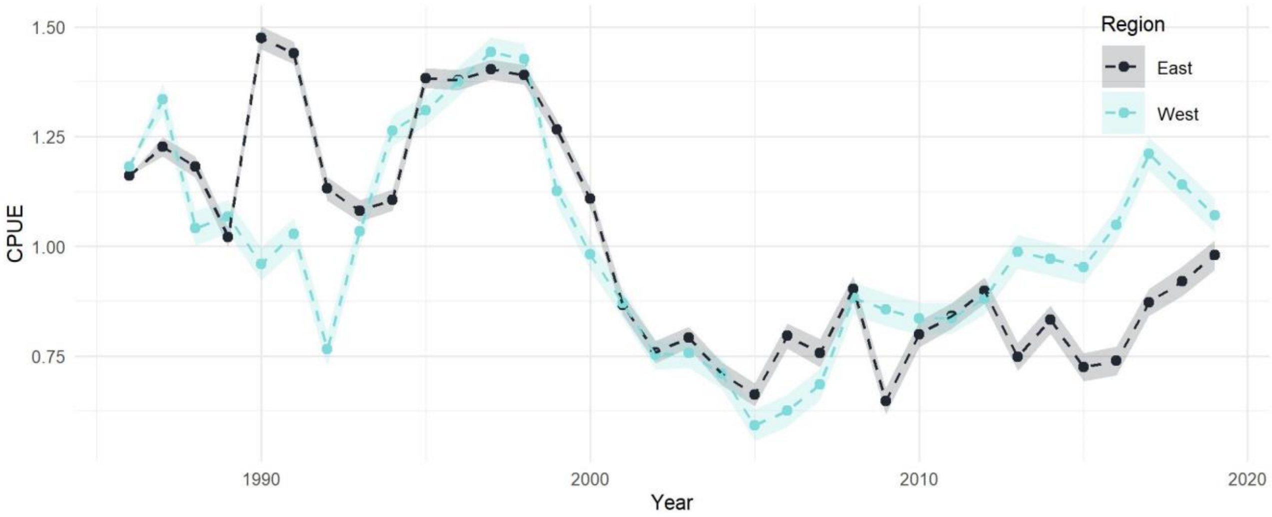

Figure 47. Standardised trawl CPUE of Pink Ling in the east and west. Shaded areas represent standard error associated with model estimates.

6 Discussion and conclusions

Decisions on stock structure would ideally be made by considering a broad combination of information sources including genetics, parasites, otolith microchemistry, morphology, physical mixing and differences in a range of biological characteristics. In practice, decisions on stock structure are made using the data and research available, using expert opinion and often adopting a weight of evidence approach (Begg and Waldman 1999, Begg et al. 1999, Patterson et al. 2019). While some decisions have been made, for stock assessment purposes, on the stock structure for Blue Warehou, Jackass Morwong and Pink Ling, it is useful to review the studies and the data supporting these decisions. Alternatively, this process can identify further work that may be required if the stock structure for these species requires further clarification.

To date, there have been limited genetic studies of Blue Warehou, Jackass Morwong and Pink Ling. Depending on the species, those genetic studies were undertaken 18 to 26 years ago and no new samples of these species have been screened for contemporary genomic markers. Currently, more powerful genomic tools, such as Single Nucleotide Polymorphisms (SNPs), can be developed and screened within individuals (Schlötterer 2004, Hauser and Seeb 2008). SNPs provide the ability to screen for thousands of markers across the genome and these markers are bi-parentally inherited, in comparison to mtDNA which is inherited maternally (reviewed by Allendorf et al. 2010, Narum et al. 2013). Such genome wide assessments have increased differentiation power, in contrast to a single mtDNA marker or less than 20 microsatellite markers. Updated diversity, gene flow and connectivity studies using these contemporary genomic techniques could shed additional light on the stock structure of these species. Although, for significant genetic differences to be observed in populations, separation needs to have occurred over extended time periods and only a very small transfer of genes is required to prevent observation of differences (Bailey and Smith 1981).

Investigations into differences in otolith microchemistry have only been conducted for Blue Warehou and Jackass Morwong. The differences observed for Blue Warehou suggest there are two stocks, one either side of Tasmania. No differences were detected in Jackass Morwong otolith microchemistry, although sampling to the east and west of Tasmania may not have been sufficient to determine differences as the study investigated a broader geographical area. Determining whether differences are apparent in Pink Ling could prove useful in determining stock structure in southern Australia, and particularly differences in the east and west.

Studies investigating mixing between the east and west have been limited for all three species. Such studies are important as they determine whether populations are separate and may detect differences in stocks on shorter timescales than those required for genetic differences. Oceanographic conditions in eastern Tasmania move water to the east preventing settlement in the west, which prevents mixing between the regions. Traditionally mixing has been determined through investigations into parasites to determine if exchange is occurring between populations and such investigations may provide insight into mixing for each of the three species investigated here.

Differences between the CPUE series in the east and the west appear to be relatively minor for all three species. If they were apparent, strong differences may suggest different fishing mortality by region and support stock discrimination, or at least contribute evidence towards a decision on stock discrimination. Concerns of whether CPUE is indexing abundance for all three species are apparent, with management changes resulting in a break down in the Pink Ling CPUE in recent years. Low catches and targeting of Blue Warehou have again raised concerns over CPUE indices and Jackass Morwong CPUE in the west are uncertain. This breakdown suggests that making inferences of stock structure from CPUE for these species may be misleading.

Phenotypic differences, manifesting as differences in length and age distributions are apparent for all three species. Although, these may be confounded by different fishing practice and habitat availability in the east and the west, especially with the limited availability of shallower trawlable grounds in the west, and the tendency for older and larger fish to be found in deeper habitat.

A summary of differences in parameters investigated by this study for each of the three species is available in Table 12. This report provides some evidence for separate stocks in the east and west for all three species, although further work, especially genomic and mixing studies, could be useful to draw more comprehensive conclusions.

Table 12. Summary of differences in characteristics investigated for Blue Warehou, Jackass Morwong and Pink Ling.

Characteristics	Common name		
	Blue Warehou	**Jackass Morwong**	**Pink Ling**
Genetics	Differences between east and west, although non-significant	No genetic differences between east and west	No genetic differences between east and west
Otolith microchemistry	Differences in both microchemistry and shape	Some differences, but stock discrimination difficult with spatial scale insufficient to determine definitive stock differences	Unknown, no investigations
Evidence of mixing	Limited information on mixing, but a highly mobile schooling species with pelagic larvae	Limited movement of adults, offshore pelagic larval phase in the east possibly impacted by changes in the EAC	Unknown larval dispersal, largely sedentary as adults
Biological parameters – (growth and morphology)	Differences in growth curves and morphology	Limited information	Differences in growth curves
Length frequency	No difference between east and west	Larger in west than east	Larger in west than east
Age frequency	Older in west than east	Older in west than east	Older in west than east
Discards	Similar trends between east and west	Sporadic and variable	Higher in east than west since 2003
Current CPUE	Similar overall trends between east and west	Similar overall trends between east and west	Similar overall trends between east and west
Reasoning for historical stock assessment split	Separate areas and timing for spawning. Differences in size, age and growth.	Expert judgement, a productivity shift is evident in the east but not the west.	Differences in size and age compositions along with differences in growth and the trends observed in standardised catch rates.

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