Fisheries Research Report No. 251, 2014

Biological synopsis of Australian herring *(Arripis georgianus)*

K. Smith and J. Brown

Government of **Western Australia**
Department of **Fisheries**

Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH, Western Australia 6920

Fish for the future

Correct citation:

Smith, K. and Brown, J. 2014. Biological synopsis of Australian herring (*Arripis georgianus*). Fisheries Research Report No. 251. Department of Fisheries, Western Australia. 40pp.

Enquiries:

WA Fisheries and Marine Research Laboratories, PO Box 20, North Beach, WA 6920
Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: www.fish.wa.gov.au
ABN: 55 689 794 771

A complete list of Fisheries Research Reports is available online at **www.fish.wa.gov.au**

ISSN: 1035 - 4549 ISBN: 978-1-921845-73-4

Contents

1.0 Introduction

Arripis georgianus ('Australian herring') is targeted by commercial and recreational fishers in Western Australia (WA) and South Australia (SA). Historically, *A. georgianus* has been the most commonly retained species of finfish taken by shore- and boat-based recreational fishers in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) (Smith *et al.* 2013a) (Fig. 1). The species is harvested by several commercial fisheries which use shore-based netting methods (beach seine, haul and gill nets). Historically, the vast majority of the commercial fishery catch has been taken by the herring 'trap net' fishery which operates on various beaches near Albany (SCB).

Arripis georgianus is part of a suite of indicator species currently being used by the Department of Fisheries (DoF) to monitor and assess the status of the finfish resources of WA (DoF 2011). The status of the *A. georgianus* stock was assessed in 2013, based on biological data collected during 2009–2011 (Smith *et al.* 2013a). The stock was previously assessed in 1999, based on biological data collected during 1996–1999 (Ayvazian *et al.* 1999).

The 2013 assessment was part of a wider investigation into the status of nearshore[1] finfish resources in the WCB and SCB. This investigation assessed the status of other nearshore indicator species (tailor, whiting species, southern garfish) over the same period (Smith *et al.* 2013b, Brown *et al.* 2013, Smith *et al.* in prep.).

This biological synopsis summarises published and unpublished information about *A. georgianus* available at the time of writing. It is intended to be read as a companion document to Smith *et al.* (2013a).

2.0 Taxonomy and nomenclature

Phylum:	Chordata
Subphylum:	Vertebrata
Class:	Teleostomi
Superclass:	Osteichthyes
Class:	Actinopterygii
Subclass:	Neopterygii
Infraclass:	Teleostei
Superorder:	Acanthopterygii
Order:	Perciformes
Suborder:	Percoidei
Family:	Arripidae
Genus:	*Arripis*
Species:	*georgianus*

1 The "nearshore finfish resource" is defined as the fish community which primarily inhabit coastal waters from 0 to 20 m depth

2.1 Synonyms

Centropristes georgianus Valenciennes 1831.

2.2 Common names

The accepted Australian standard common name is “Australian herring”. Other common names used include “herring” in WA and “ruff”, “tommy ruff” or “tommy rough” in SA. Recreational fishers in WA sometimes use the term “bull herring” to describe very large *A. georgianus*, which are usually female.

Although named because of their superficial resemblance to the true herring (Order: Clupiformes, Family: Clupeidae) found in the northern hemisphere, *A. georgianus* is a perch (Order: Perciformes).

2.3 Description

The family Arripidae contains one genus, *Arripis* Jenyns, and four species. All species are endemic to areas within temperate Australian or New Zealand waters (Paulin 1993):

1. *Arripis georgianus* (Valenciennes 1831) – Australian herring
2. *Arripis truttaceus* (Cuvier 1829) – western Australian salmon
3. *Arripis trutta* (Bloch & Schneider 1801) – eastern Australian salmon / kahawai
4. *Arripis xylabion* (Paulin 1993) – northern kahawai/giant kahawai

Arripis georgianus can be distinguished from other species of the genus *Arripis* by the higher number of rakers on the lower limb of the first gill arch, lower soft dorsal ray count and rough scales (Paulin 1993). The species also differs from the other three species in having slightly smaller scales (lateral line count 54–59 cf. 49–56).

Meristic characters (Paulin 1993)	*A. georgianus*	*A. truttaceus*
Dorsal fin (spines, rays):	IX, 13–14	IX, 15–19 [1]
Anal fin (spines, rays):	III, 10	III, 10
Pectoral fin (rays):	16–18	16–18
Pelvic fin (spines, rays):	I, 5	I, 5
Caudal fin (rays):	17	28
Lateral line (scales):	54–59	49–56
Gill rakers (upper + lower):	16–18 + 28–32	7–11 + 16–17
Vertebrae:	25	25

Arripis georgianus colouration resembles that of juveniles of other *Arripis* species except for the prominent black tips on the caudal fin lobes of *A. georgianus* which are absent in the other *Arripis* species (Paulin 1993). In WA, recreational fishers often confuse juveniles of *A. truttaceus* with juveniles/adults of *A. georgianus*. *A. georgianus* have a larger eye and more rounded head than *A. truttaceus* (Fig. 2). Juvenile *A. truttaceus* have several rows of golden or brown spots on their back and sides, and scales are smooth to the touch. Adults of *A. truttaceus* are easily distinguished by their size – the maximum length of *A. truttaceus* (96 cm TL) is considerably larger than *A. georgianus* (41 cm TL) (Hutchins and Swainston 1986).

1 Paulin (1993) reported 15–16 dorsal rays, but 15–19 has since been observed (DoF unpubl. data).

3.0 Distribution and habitat

Arripis georgianus is endemic to southern Australia, occurring from Shark Bay (WA) southward to Port Phillip Bay (Victoria) (Hutchins and Swainston 1986) (Fig. 2). Abundance in eastern SA and western Victoria is relatively low compared to WA and western SA. Occasional specimens have been reported from New South Wales and Tasmania, although the accuracy of these identifications is disputed (WFRC 1973, Moore 2012).

Arripis georgianus is essentially an inshore marine species and mainly occurs in nearshore coastal waters, around offshore islands (including Rottnest Island) and in the lower reaches of estuaries. Adults and juveniles form pelagic schools over a range of habitats (reef/sand/weed). Juveniles grow to maturity in nursery areas, often near seagrass beds in protected embayments along the southern coast of WA (typically from Perth southwards), SA and Victoria. The role of the western Great Australian Bight as a nursery area is unknown.

Juvenile 0+ *A. georgianus* appear to benefit from nurseries containing some vegetation. At coastal sites along the west coast, the abundance of 0+ *A. georgianus* is positively correlated with the level of detached macrophytes, which appear to be an important source of shelter from predators and food (especially amphipods) for juveniles (Lenanton 1982, Lenanton *et al*. 1982). The recruitment by 0+ fish in late winter/spring occurs at the peak in the level of detached macrophytes in local surf zones and 0+ fish remain associated with detached macrophytes throughout summer on the west coast (Lenanton *et al*. 1982). This suggests that the level of marine vegetation adjacent to nurseries may partly determine recruitment success by *A. georgianus*.

Although 0+ *A. georgianus* have been recorded in small numbers in some south-west estuaries, it is more usual for *A. georgianus* to first enter estuaries as a relatively large adult rather than in the first or even second year of life (Lenanton and Potter 1987, Potter *et al.* 2011).

4.0 Stock structure

Arripis georgianus constitutes a single stock across its range. This has been demonstrated by three stock delineation methods: tag-recapture, analysis of otolith chemistry and genetics.

Since the 1950s, several large scale tagging studies have demonstrated extensive movement of adult *A. georgianus* from the southern coast of Australia (from SA and southern WA) to the lower west coast of Australia (Ayvazian *et al*. 2004, and see ‘Tagging’ below).

During 1997–1998, the stable oxygen isotope ratios in otolith carbonate were determined for *A. georgianus* collected from 10 sites located between Dongara (WA) and Port Adelaide (SA) (Ayvazian *et al*. 2004). Whole otoliths from older juvenile and adult fish (length range 155–358 mm) were analysed. At south-western sites, the oxygen isotope values of otolith carbonate did not have the same signature as the water from which they were captured, indicating that prior movement had occurred. Most otoliths had signatures characteristic of the colder water found in the south-east part of the species range, indicating westward migration. Overall, the isotopic composition of the otolith carbonate suggested that *A. georgianus* is generally a highly migratory species with a small proportion of individuals showing partial residency.

During 1997–1998, allozyme eletrophoresis was also conducted on fish collected from 11 sites located between the Jurien Bay (WA) and Port Phillip Bay (Victoria) (Ayvazian *et al*. 2004). The study found no evidence of population genetic subdivision in the population, although the conclusion was based on a test with limited power due to a very low level of allozyme polymorphism. Moore and Chaplin (2013) provided stronger evidence of genetic homogeneity in *A. georgianus.* They used fragment length polymorphisms at two to four nDNA intron loci in samples of *A. georgianus* collected from across their entire range. This study also found no evidence of genetic subdivision.

In combination, the above findings indicate that *A. georgianus* constitutes a single, genetically homogeneous stock across it's geographic range. This homogeneity is due to the aggregation of spawning adults over a relatively small area and short time period, which facilitates random mating, and the extensive adult migration and planktonic larval dispersal which both facilitate a high level of mixing.

5.0 Tagging

Several tagging studies have been conducted to examine movement patterns. In each study, movements by recaptured fish indicated a net westward (along the south coast) and northward (along the west coast) movement of the stock. Overall, tagging studies indicate that *A. georgianus* leave SA in summer, migrate along the southern coast in autumn and reach the south-west of WA during the winter. Nearly all recaptures indicate westward migration along the south coast, resulting in net movement of fish from SA to the SCB, and then from the SCB to the WCB. Evidence from tagging within the WCB suggested there is minimal movement after spawning. Post-spawning fish appear to remain within the WCB (i.e. there is no return migration to the SCB).

Tagging was conducted in SA between 1952 and 1954 at Ceduna, Kangaroo Island, Streaky Bay and Port Lincoln (WFRC 1973). A total of 6,693 fish were released in 9 events. In all cases white plastic internal tags were used. Only 26 of the tagged fish (0.39%) were recaptured – 19 in WA and 7 in SA (Fig. 3). The shortest distance travelled was 965 km and the longest distance was 2,189 km. One fish tagged at Kangaroo Island was recaptured near Rottnest Island 152–-181 days later and had travelled an estimated 2,189 km in 5–6 months (~12 km per day). Although the recapture rate was low, the results of these tagging studies suggested a large-scale movement from SA to WA.

In WA, tagging has occurred during three separate periods (1951–55, 1997–98 and 2012). Tagging was first conducted in WA from 1951 to 1955 (WFRC 1973). A total of 4,784 fish were released in 16 tagging events at Cheyne Beach, Bremer Bay, Hopetoun, Esperance and Parry's Inlet in the SCB and Geographe Bay, Garden Island and Rottnest Island in the WCB. Both internal and operculum clip-on tags were used. A total of 121 fish (2.53%) were recaptured – 101 recaptured locally and 20 recaptured to the west of the release site (Fig. 4).

Of 484 fish tagged during 1952–54 at Geographe Bay and Rottnest Island, 62 were recaptured locally after being at liberty for 2 to 526 days. Only one recapture was recorded to the south of its tagging location (tagged at Rottnest Island in June 1954, recaptured in Geographe Bay in November 1954).

Tagging was conducted in WA in 1997 (at Peaceful Bay and Bremer Bay in the SCB) and in 1998 (at Bremer Bay in the SCB and Geographe Bay in the WCB) (Ayvazian *et al*. 2004). External plastic T-bar tags were inserted at the base of the dorsal fin. A total of 18,754 tagged fish were released during these 4 tagging events. A total of 2.0% of fish tagged in the SCB were recaptured, after being at liberty for an average of 36 days (range 1 to 410 days). Most

(91.5%) of these recaptures occurred locally within a month of being tagged, while 4.3% were recaptured in the WCB and 0.9% were recaptured to the east (near Esperance in WA). A total of 1.0% of fish tagged in Geographe Bay were recaptured. All were caught locally after being at liberty for an average of 33 days (range 0 to 326 days).

Tagging was conducted at two sites (Canal Rocks and Castle Rocks) near Cape Naturaliste in the WCB in 2012 during May and at two sites (Woodman Point and Challenger Beach) within Cockburn Sound during November/December (DoF unpubl. data) (Figs. 5–7). External plastic T-bar tags were inserted at the base of the dorsal fin. A total of 3,597 tagged fish were released during these 2 tagging events (1,552 tagged at Cape Naturaliste and 2,045 tagged in Cockburn Sound). Of the fish tagged at Cape Naturaliste, 2.3% were recaptured, after being at liberty for an average of 52 days (range 5 to 331 days) (as of November 2013). The average distance travelled was 51 km. All recaptured fish had either been caught locally or moved northwards, including some recaptured in the Perth/Mandurah area (Figs. 5 and 6). Of the fish tagged in Cockburn Sound, 1.6% were recaptured, after being at liberty for an average of 76 days (range 7 to 162 days) (as of November 2013). The average distance travelled was 11 km. All were recaptured locally in Cockburn Sound, with the exception of a single fish recaptured at Rottnest Island (Fig. 7).

Tag recovery rates in each study were relatively low (0–3%). In the 1950s and 1990s, tags were found in *A. georgianus* after they had been sold for bait and human consumption, suggesting that the low recovery rates were partly due to commercial fishers and processing factories failing to detect (or report) tags. Rates of tag loss were not examined in the 1950s and 1990s studies, although the loss of internal tags used in the 1950s was presumably low. In 2012, preliminary results from an experiment using double tagging suggested a high tag loss (up to 50%) for external T-bar tags.

Tagging-induced mortality in *A. georgianus* associated with external T-bar tags has not been examined. Tagging-induced mortality in *A. georgianus* has only been examined using the small internal tags previously used for juvenile *A. truttaceus* (WFRC 1980). A total of 51 fish were tagged and maintained in an outside aquarium over a period of 225 days during 1979/1980. Over this time 13 individuals (25%) died from various causes: one fish died the day after tagging; 4 fish as a result of handling (up to 142 days after tagging); 1 fish of a broken jaw (169 days); 1 fish from unknown causes (187 days); 1 fish jumped out of the tank (212 days); and 5 fish died from an infection associated with tagging wound (152 days – 2 fish, 233 days – 1, 225 days – 2).

6.0 Migration

Juvenile *A. georgianus* occur in WA, SA and Victoria (i.e. throughout the entire geographic range of the species) whereas adults occur only in south-western WA (Fairclough *et al.* 2000a. No spawning occurs in SA or the eastern section of the south coast of WA (i.e. east of Esperance) (Fairclough *et al.* 2000b). In SA, the local *A. georgianus* population is comprised almost exclusively of 0–2 year old fish. Each year, the abundance of 2+ fish in SA declines markedly in January/February due to the onset of maturity in 2+ fish and their emigration from SA to the spawning area in WA (Fairclough *et al.* 2000a). Tagging studies indicate that maturing juveniles migrate to the south coast of WA and then to the west coast, where they spawn during autumn. There is no evidence of a post-spawning migration (unlike the 'back run' migration undertaken by *A. truttaceus*). Hence, adult *A. georgianus* remain within south-western Australia, with the spawning stock concentrated in the WCB.

Along the south-west coast of WA, the migratory pattern determines the timing of landings by the main commercial *A. georgianus* fisheries in the SCB and WCB. These beach-based fisheries target schools in autumn as they migrate westward and northward along the coast to the spawning area (Smith *et al.* 2013a).

After spawning, adults disperse and become resident in coastal and estuarine waters of the WCB, and to a lesser extent also the western part of the SCB, forming the basis for fishery landings that are taken there throughout the year. Post-spawning adults enter estuaries during spring and may remain until summer/autumn, after which they return to coastal waters to spawn during winter. In the Swan/Canning Estuary, this migratory pattern was reflected in the monthly landings by the former commercial fishery - catches peaked in spring, minor catches occurred in summer/autumn and negligible catches occurred in winter (Smith 2006).

7.0 Recruitment

Full details of recruitment dynamics of *A. georgianus* are given in Smith *et al.* (2013a) and references therein. Briefly, spawning by *A. georgianus* mainly occurs within the southern WCB and the timing in May/June coincides with the annual peak in flow by the Leeuwin Current. Modelling of larval dispersal suggests that larvae are transported to nurseries in the WCB, SCB and in SA by a combination of the Leeuwin Current, wind-driven surface currents and swimming behaviour (Ayvazian *et al.* 2000).

New recruits are first observed at nurseries in the WCB and in the South Zone of the SCB at 30–40 mm during June and are first observed at 50–60 mm in the South-east Zone of the SCB during August (Figs. 8–10). Juveniles are first observed in SA at about 60 mm in October/November (Jones *et al.* 1990, Jones 2008). Later arrival and a larger body size at settlement is consistent with the longer larval duration experienced by fish transported to south-east and SA nurseries from the spawning area in the WCB.

The strength of the Leeuwin Current influences the distribution of recruitment each year. During years of strong Leeuwin Current flow, higher levels of recruitment tend to occur in nurseries in the eastern region of the SCB and in SA. Conversely, during years of weak Leeuwin Current flow, higher levels of recruitment tend to occur in WCB nurseries (Smith *et al.* 2013a).

In the WCB, some recruitment occurs in all years, which indicates that some larvae are retained in the WCB irrespective of Leeuwin Current strength. It is likely that recirculating water in Geographe Bay plays an important role in retaining some *A. georgianus* larvae within the WCB (Feng *et al.* 2010).

In WA, monitoring of 0+ *A. georgianus* recruitment has occurred annually since 1993/94 and is ongoing at key sites within the WCB, the western SCB and the eastern SCB (Smith *et al.* 2013a). In SA, recruitment to Gulf St Vincent was measured annually from 1981 to 2000 (Jones and Westlake 2003).

Annual recruitment strength in the eastern SCB is positively correlated with the annual catch rate of *A. georgianus* by the herring 'trap net' fishery (the main commercial fishery for this species in WA) three years later (Smith *et al.* 2013a).

In WA, adult *A. georgianus* are occasionally found in the Gascoyne Coast Bioregion (GCB), at a much lower abundance than in the WCB. Juvenile recruitment to the GCB is believed to be very low and is not routinely monitored. Juvenile fish (of various species) were sampled monthly at 8 sites at Carnarvon (GCB) from August 1995 to November 1998. *A. georgianus* were captured on only one sampling occasion. In October 1995, 33 0+ juvenile *A. georgianus* were captured (DoF unpubl. data). They comprised two length cohorts, including 29 small fish (64–96 mm TL) and 4 larger fish (123–145 mm).

8.0 Maturity

Arripis georgianus is a gonochorist, *i.e.* individuals do not change sex. Females attain maturity at a greater size and age than males.

Fairclough *et al.* (2000b) calculated $L_{50\%}$ and $A_{50\%}$ values (i.e. the length and age at which 50% of individuals attain maturity) using pooled samples collected in the WCB and the western part of the SCB during the late 1990s. However, a reanalysis of data collected by Fairclough *et al.* (2000b) and some additional data collected by DoF over this period found some significant differences in maturity between Bioregions and yielded revised values for this sampling period (Smith *et al.* 2013a) (Tables 1 and 2).

Further sampling during 2009–2011 again found significant differences between Bioregions in the length- and age-at-maturity. Higher $L_{50\%}$ and $A_{50\%}$ values in the SCB during both sampling periods may be a consequence of slower juvenile growth in the SCB (see 'Growth' below). Some significant differences in the length- and age-at-maturity occurred between sampling periods. The cause of these differences is unknown but may include a change in growth in response to environmental variations or selective fishing pressure, or be an artefact of variations in sampling.

In 2009–11, females in the WCB attained maturity at an average of 194 mm TL, and almost all were mature at 251 mm (Table 1, Fig. 11). Males attained maturity at an average of 174 mm, and almost all were mature by 189 mm. In the SCB, maturity was attained at a larger average size by both females (220 mm) and males (196 mm).

In 2009–11, over 50% of females were mature by the end of their 3^{rd} year, and all were mature by the end of their 4^{th} year. Over 50% of males were mature by the end of their 2^{nd} year, and all were mature by the end of their 3^{rd} year (in WCB) or 4^{th} year (in SCB) (Table 2).

9.0 Spawning

Arripis georgianus are broadcast spawners. Egg fertilisation is external. Females/males release multiple batches of eggs/sperm during the spawning period. Spawning occurs between April and late June, with a pronounced peak in activity during late May/early June (Fairclough *et al.* 2000b, Smith *et al.* 2013a). This timing appears to be synchronised with the onset of the annual peak in flow by the Leeuwin Current, a strategy which allows maximum alongshore dispersal of the pelagic eggs and larvae.

The timing of spawning has been determined from macroscopic and microscopic developmental staging of gonads and monthly peaks in Gonadosomatic Index (GSI) (Fairclough *et al.* 2000b, Smith *et al.* 2013a). Back-calculated birth dates of small juveniles estimated from daily otolith increments also indicates spawning within a 12 week period between April and June, peaking in May (Ayvazian *et al.* 2000).

Spawning occurs in coastal waters of WA, potentially between the Abrolhos Islands and Bremer Bay (Fairclough *et al.* 2000b) but mainly north of Cape Leeuwin (WFRC 1973, Smith *et al.* 2013a). A high proportion of adults migrate to this area prior to spawning and so, in this sense, they form a broad aggregation in this region. At a smaller scale, schools of fish probably form multiple, small aggregations that spawn simultaneously throughout this area. Rottnest Island appears to be a key spawning area (Lenanton 1978). Pollard (1969) stated that "*Rottnest is famous as the spawning ground for herring. For as long as fisherman can remember, big herring schools that swim around from the Bight each autumn gather at Rottnest at the start of May in such numbers that the sea is often black over large areas.*" Such historical reports suggest that the density of *A. georgianus* aggregating around Rottnest Island during the spawning period was much higher than current levels.

10.0 Fecundity

Arripis georgianus is a multiple batch spawner with determinate fecundity. Fairclough *et al.* (2000b) estimated potential annual fecundity of individual females by counting the number of large vitellogenic oocytes in the pre-spawning ovaries of 37 fish in mid-May. Total lengths of sampled fish were 197–335 mm (mean 247 mm) and weights were 94–439 g (mean 179 g). The number of large oocytes ranged from ~32,000 to 207,000 (mean 84,700) per fish.

The relationships between these estimates of fecundity (F), total length in millimetres (TL), wet weight in grams (W) and age in years (A) of fish, are expressed by

$F = 4619.3 \times e^{(0.0114 \times TL)}$ ($r^2 = 0.84$, $n = 37$),

$F = 498.9W - 4501.3$ ($r^2 = 0.88$, $n = 37$) and

$F = 18519A + 13640$ ($r^2 = 0.71$, $n = 33$). (Fairclough *et al.* 2000b)

11.0 Eggs and larvae

Arripis georgianus eggs have not been observed in the field, but are assumed to be pelagic and similar in appearance to those of *A. truttaceus*, whose eggs are pelagic, 0.8 – 1.0 mm in diameter, with a single oil globule (Neira *et al.* 1998). *Arripis truttaceus* larvae hatch 40 hours after fertilisation and attain 4 mm SL four days after hatching (temperature unknown) (Munro unpubl data, cited by Fahlbusch 1995). All stages of *A. truttaceus* larvae have been formally described (Neira *et al.* 1998).

Limited aspects of *A. georgianus* larval morphology were described by Fahlbusch (1995). However, a complete, formal description of each egg and larval stage is not yet available. *Arripis truttaceus* and *A. georgianus* larvae are similar in appearance – older larvae of each species can be distinguished by fin ray and gill raker counts, but further work is needed to develop a morphological description of *A. georgianus* required to separate younger larvae.

Arripis georgianus larvae have been collected during daylight and at night from surface waters of the Leeuwin Current (temperature 16.5 – 18.5 ºC and salinity 35.6 – 35.8), at a range of sites between Bremer Bay (WA) and SA (Fahlbusch 1995). Subsurface waters were not sampled. Captured larvae ranged in size from 6 – 27.5 mm SL (i.e. from preflexion to post-larval stage). Their ages were estimated to be 43–81 days (determined from daily otolith increments), indicating spawning dates from late May to early June (Fahlbusch 1995).

During a daytime plankton survey around Rottnest Island during May 2005, pre-flexion, flexion and postflexion *Arripis* spp. larvae were caught at the surface but only preflexion larvae were caught in subsurface (2 m depth) samples (K. Smith, DoF, unpubl. data). The smaller (preflexion/flexion stage) larvae could not be identified to species level. Older larvae (postflexion stage) were identified and included both *A. georgianus* and *A. truttaceus*.

During night-time sampling off the eastern Australian continental shelf, preflexion *A. trutta* (eastern Australian salmon) larvae were not found at the surface but occurred in subsurface waters to depths of about 50 m (Smith *et al.* 1999).

In summary, limited evidence suggests that preflexion stage *Arripis* spp. larvae are typically dispersed throughout the water column, including the surface and upper mixed layer, whereas post-flexion larvae and early juveniles are concentrated in surface waters. This has implications for the dispersal of older larvae, which are likely to be affected by wind-driven surface currents.

The length of the planktonic larval phase experienced by new recruits probably varies significantly between regions. Ayvazian *et al.* (2000) developed a preliminary model of larval transport, incorporating the transport effects of the Leeuwin Current, swimming and wind-driven surface currents. Modelled recruitment patterns were in reasonable agreement with the three years of actual recruitment strength data available at the time. Assuming spawning off Perth, the model estimated a larval duration of ~40 d to reach Albany and ~60 d to Poison Creek (Esperance). Modelled recruitment strength to WA and SA followed an inverse relationship, i.e. if strong recruitment in WA, then weak in SA, and vice versa.

Arripis georgianus larvae appear to feed mainly at night (Fahlbusch 1995).

12.0 Age and growth

12.1 Larvae and Juveniles

Fahlbusch (1995) found a linear relationship between standard length of (preserved) larvae and age for *A. truttaceus* larvae and small juveniles. Sample size was insufficient to determine such a relationship for *A. georgianus*, but a similar relationship would presumably exist since it is closely related and morphologically similar. In this study, counts of increments in the lapillus were found to be lower than counts in the sagittal otolith for fish >10 mm SL, indicating that lapillus counts underestimate age and are unsuitable for ageing juveniles >10 mm SL. However, in smaller fish (<10 mm), lapillus and sagitta counts were the same. The lapillus requires much less preparation than the sagitta and so may be useful for ageing larvae.

A growth 'check' forms in otoliths at age 25–30 days, after which secondary primordia start to develop (Ayvazian *et al.* 2000). It is not known what event in life, if any, that this check coincides with.

The enumeration of daily increments in thin sections of sagittal otoliths (sectioned along sagittal plane) is the recommended method for ageing young juveniles (age 80–180 days old) (Ayvazian *et al.* 2000). Increments in the lapillus and in scales often underestimate age and are unsuitable for aging.

An attempt to validate the daily periodicity of otolith increments by tetracycline injection failed (Ayvazian *et al.* 2000). However, the estimated hatch dates of young juveniles correspond closely to the annual peak in gonadosomatic index (GSI), so daily periodicity is effectively validated. Daily increments have been validated in *A. trutta* (Stevens and Kalish 1998).

Length-at-age relationships indicate a decreasing gradient in juvenile growth rate from west to east - growth was fastest in the southern WCB (juveniles caught at Koombana Bay), intermediate in the eastern SCB (Poison Creek), and slowest in SA (Ayvazian *et al.* 2000). Juveniles (age range 80–180 days) sampled in WA and SA displayed the following average growth rates:

0.32 + 0.05 mm/day (95% CI, $r^2 = 0.42$) in WA

0.18 + 0.03 mm/day (95% CI, $r^2 = 0.35$) in SA.

Juveniles in the mid-west zone of the WCB (i.e. north of Perth) display slower growth than in the southern WCB or in the SCB (length-at-age, DoF unpubl. data). This suggests sub-optimal conditions for growth in the northern part of the species range, perhaps due to higher temperatures.

Analysis of length frequencies (modal progression) also indicates a decreasing gradient in the growth rate of juveniles from west to east (Fairclough *et al.* 2000a, Smith *et al.* 2013a). During the first 12-18 months of life, growth is faster in the southern WCB and western SCB, compared to slower growth in the eastern SCB and in SA (Fig. 12). For example, juveniles in the southern WCB attain an average length of 144 mm at 11 months and 214 mm at 22 months, whereas those in the eastern SCB attain an average length of 118 mm at 11 months and 156 mm at 22 months (Smith *et al.* 2013a).

12.2 Adults

On average, adult females have a higher length-at-age and attain a greater maximum length than males (Figs. 13, 14). Observations during two sampling period (1996-98 and 2009-11) suggest that the growth rate can vary spatially (growth is slightly faster in the WCB, than in the SCB) and temporally (growth was slower during the more recent sampling period) (Table 3, Fig. 14). The reasons for apparently slower growth in recent years are not known but may include environmental factors, variations in recruitment sources (juvenile growth rates vary between regions), selective fishing pressure or sampling artefacts.

The maximum reported total length of *Arripis georgianus* (unsexed) is 41 cm (Hutchins and Swainston 1986). The maximum lengths observed by the DoF since sampling commenced in the 1970s are 391 mm (unsexed), 390 mm (female) and 325 mm (male) (Smith *et al.* 2013a).

The maximum reported age of females and males is 12 and 11 years, respectively (Potter *et al.* 2011, Smith *et al.* 2013a). These individuals were captured in Wilson Inlet, which is a seasonally closed estuary on the south coast of WA. *Arripis georgianus* in Wilson Inlet tend to have higher average length- and weight-at-age than fish in adjacent ocean waters. Hence, growth of *A. georgianus* in this estuary appears to be atypical and the maximum ages seen here may not be representative of the majority of the stock, which resides in ocean waters. In ocean waters, the maximum reported age of females and males is 10 and 9 years, respectively (Fairclough *et al.* 2000a, Smith *et al.* 2013a).

12.3 von Bertalanffy growth parameters:

See Table 3.

12.4 Total length (TL, in millimetres) versus total weight (W, in grams):

No significant difference in this relationship between males and females. Relationship for both sexes is

$W = (1.0829 \times 10^{-5}) \times TL^{2.9990}$ (Fig. 15)

or in linear form:

$\text{Log } W = (2.990 \times \text{LogTL}) - 11.4382$ ($r^2 = 0.9848$, n = 6,542)

12.5 Total length (TL, in millimetres) versus fork length (FL, in millimetres):

No significant difference in this relationship between males and females. Relationship for both sexes is

$TL = (1.1716 \times FL) - 2.9123$ ($r^2 = 0.9949$, n = 10,027)

13.0 Mortality

Using the general regression equation method of Hoenig (1983) for all taxa, natural mortality (*M*) is estimated to be 0.42 per year, based on the maximum age of 10.5 years which has been observed in ocean waters (Smith *et al.* 2013a). If the maximum age in ocean waters was 12 years (as seen in the atypical case of Wilson Inlet, see discussion above), then *M* would be 0.37 per year.

14.0 Diet

Juveniles and adults of *A. georgianus* are carnivorous, feeding on a wide range of organisms at all levels of the water column (surface, mid-water and bottom). Highly opportunistic feeding behaviour leads to regional differences in diet (Greenwell 2001).

Juvenile *A. georgianus* feed mainly on small marine invertebrates, especially crustaceans, but also consume small fish and insects (Lenanton *et al.* 1982, Greenwell 2001). Along the lower west coast of WA, detached macrophytes in the surf zone of sandy beaches are an important source of food and shelter for 0+ year old juveniles. The amphipod *Allorchestes compressa* is the major prey consumed by juveniles associated with these detached plant accumulations (Lenanton *et al.* 1982). Other important food items for 0+ juveniles include bivalves and brachyuran crabs.

Adult *A. georgianus* consume small fish (e.g. whitebait, anchovies, garfish, pilchards) and invertebrates (Lenanton *et al.* 1982, Greenwell 2001). Some mature *A. georgianus* enter estuaries, perhaps to take advantage of higher productivity and more abundant food, such as shrimp (*Palaemonetes australis*) or insects.

15.0 Predation

Juvenile and adult *A. georgianus* are consumed by various large predators such as dolphins, seabirds, sharks, fur seals, western Australian salmon, tailor, yellowtail kingfish and mulloway (Kailola *et al.* 1993). Recent observations of predators include little penguins (*Eudyptula minor*)

(*A. georgianus* found in 2–8% of stomachs, Bool *et al*. 2007), crested turn (*Sterna bergii*) chicks (in 6% of stomachs, Ward *et al*. 2008) and southern bluefin tuna (in 10% of stomachs, Itoh *et al.* 2011).

It was previously suggested that an increase in the New Zealand fur seal population along the south coast in recent years may have led to increased predation of *A. georgianus* (R. Campbell, pers. comm.). However, a recent dietary study in WA found *A. georgianus* was a negligible component (<1% of prey biomass) of the New Zealand fur seal diet (Hara 2012).

The mass mortality of pilchards across southern Australia due to a herpesvirus in 1995 and 1998 probably negatively impacted on *A. georgianus*. Various predators of pilchards probably switched to targeting other species, including *A. georgianus*, which could have substantially increased the mortality rate of *A. georgianus* at this time. Additionally, loss of pilchards would have resulted in reduced prey availability to *A. georgianus*.

16.0 External influences on stock

The juveniles and adults of *A. georgianus* utilise coastal and estuarine habitats throughout south-western Australia for spawning, feeding and nursery areas. Some of these habitats are degraded and it is possible that the cumulative effects of various anthropogenic impacts on coastal and estuarine habitats could impact on the stock. For example, the removal of seagrass or macrophytes is likely to result in reduced prey availability and loss of shelter for juvenile 0+ *A. georgianus* (Lenanton 1982, Lenanton *et al*. 1982).

Annual variations in the strength of the Leeuwin Current are believed to influence the distribution of the spawning stock and the distribution of juvenile *A. georgianus*. Firstly, pre-spawning adults migrate against the Leeuwin Current, travelling westwards along the south coast of Australia and then northwards along the lower west coast of WA. In years of weak Leeuwin Current flow, it is possible that adults travel further northwards. Thus, the current may influence the annual location of spawning and the post-spawning distribution of adults. Secondly, the extent of southwards/eastward dispersal of pelagic eggs and larvae (and hence the distribution of recruitment to nursery sites across southern Australia) is largely determined by the strength of the Leeuwin Current each year.

Coastal water temperatures influence the distribution and catchability of adult fish. In 2011, a very strong Leeuwin Current resulted in unusually warm ocean temperatures in coastal waters of the WCB and the western SCB (Pearce *et al.* 2011). This 'heatwave' event altered the distribution and behaviour of *A. georgianus* and many other nearshore finfish species. In particular, *A. georgianus* in the SCB were discouraged from undertaking a pre-spawning migration to the WCB in autumn 2011. Most adults appear to have remained in the SCB or lower WCB, and spawning success in 2011 was poor (as measured by juvenile recruitment index). Recreational and commercial fishery catch rates in the WCB and SCB during the heatwave event were relatively low. In the subsequent months, catch rates in the WCB were low (due to the lack of SCB migrants that would normally arrive during the spawning period) but catch rates in the SCB were high due to the accumulation of fish that failed to migrate.

Fluctuating market demand is a significant factor affecting the annual commercial catch level. Limited demand and low wholesale prices paid for *A. georgianus* in recent years have limited commercial catch and effort levels. By purchasing only a limited quantity each year, fish processors effectively restrict the catch level. Commercial fishers sometimes elect not to capture a school of fish, or release part of their catch, when a market is not available.

17.0 Commercial fisheries

Arripis georgianus is targeted in WA and SA by multiple commercial fisheries which use shore-based or nearshore netting methods (beach seine, haul and gill nets). Minor quantities are also taken commercially in Victoria. Nationally, the largest commercial fishery is the beach-based, herring 'trap net' (or 'G-trap') fishery, which operates on various beaches near Albany (south coast of WA)[1]. The proportion of total commercial landings taken in WA was relatively constant, typically 70–80% per year, from the early 1970s until 2008. However, most recent (during 2008–2012) WA landings comprised 55–60% of the national commercial catch each year.

Since the 1970s, 80–90% of total commercial landings of *A. georgianus* landed within WA each year have been taken in the SCB, with the remaining 10–20% taken in the WCB.

Within the SCB, the majority of commercial landings have historically been taken by the herring 'trap net' fishery. The remainder of the commercial catch is taken in estuaries by the South Coast Estuarine Managed Fishery and in nearshore ocean waters under 'open access' arrangements. The proportion of commercial landings taken by the 'trap net' fishery has been gradually declining since the late 1990s, when the fishery contributed ~95% of the SCB annual catch. In 2012, this fishery reported 81% of the total commercial catch of *A. georgianus* in the SCB and 67% of the total commercial catch of *A. georgianus* in WA.

Within the WCB, approximately half of commercial landings have historically been taken by beach seine nets in the Geographe Bay/Bunbury area (known as the 'south-west beach seine fishery'). The remainder has been taken by seine, haul and gill nets in nearshore ocean waters and estuaries by various small fisheries including the Cockburn Sound (Fish Net) Managed Fishery and the West Coast Estuarine Managed Fishery.

In WA, the majority of commercial landings are taken in autumn (February–April) during the pre-spawning period when migrating schools are targeted.

Nationally, commercial landings of *A. georgianus* peaked at approximately 1,800 t per year in the late 1980s and early 1990s and steadily declined thereafter. National landings were approximately 262 t in 2012, the lowest level since the start of reliable catch records in 1950. Commercial landings within WA and in SA each followed a similar downward trend. In WA, landings peaked at 1,537 t in 1991 and reached an historical low of 147 t in 2011. In 2012, total WA landings were 163 t. In SA, landings peaked at 498 t in 1987/88 and reached an historical low of 99 t in 2011/12 in SA (Fowler *et al.* 2012).

In the SCB, the total annual commercial catch reached an historical peak of 1,427 t in 1991 and then steadily declined to an historical low of 110 t in 2011. Landings were 135 t in 2012. Recent low catches in the SCB reflect declining catches by the 'trap net' fishery. In the WCB, the total annual commercial catch of *A. georgianus* reached an historical peak of 211 t in 1988 and attained a similar level of 191 t in 1992. Annual landings then steadily declined to reach an historical low of 28 t in 2012.

The declines in each region are believed to be primarily due to the reduced availability of fish due to a declining stock level (Smith *et al.* 2013a).

1 'Trap nets' are specifically used to target herring. Usually set in a '6' or 'G' shape off a beach, this fishing method herds and traps fish migrating along the beach. The seaward end of the net is pulled to the shore after an overnight set. In mid-1991, the use of herring trap nets was restricted to licensed fishers using a fishing boat with the appropriate condition (i.e. *Fishing Boat Licence Condition 42*) at 10 separately nominated south coast ocean beaches.

18.0 Recreational fisheries

Arripis georgianus is targeted by recreational fishers in WA and SA using line fishing methods. Historically, *A. georgianus* has been the most commonly retained species of finfish taken by shore- and boat-based recreational fishers in the WCB and SCB (Smith *et al.* 2013a). It is also one of the most common species in the SA recreational catch (3rd most common in 2007/08, Jones 2009).

In WA, the majority of recreational landings of *A. georgianus* are taken in the warmer months (January–June). This period reflects the months of highest recreational effort (i.e. the most popular fishing months).

A precise estimate of the current retained recreational catch in WA is not available due to the lack of recent catch estimates for the shore-based fishery. Shore-based fishers in WA are estimated to take the majority (60–70%) of the total WA recreational catch of *A. georgianus* (Smith *et al.* 2013a and references therein). The largest share of the total WA recreational catch (50–55%) is taken by shore-based fishers in the WCB. WCB boat-based fishers take the next largest share (25–30%). Overall, approximately 80% of the WA recreational catch is estimated to be taken in the WCB, mainly within the popular Metropolitan Zone (Fig. 1).

Within the WCB, *A. georgianus* comprise about 65% of all finfish retained by shore-based recreational fishers and 25–30% of finfish retained by boat-based fishers (Smith *et al.* 2013a and references therein). Approximately 10–12% of all *A. georgianus* caught by recreational fishers in the WCB are released.

Limited available data suggests recent annual recreational landings of *A. georgianus* have been approximately 100–150 t in the WCB and 30–70 t in the SCB. At these levels, the total recreational catch was approximately equal to the total commercial catch in WA in recent years (Smith *et al.* 2013a).

In SA, the total recreational catch was estimated to be 93 t in 2007/08 (Jones 2009), which is similar to recent commercial catch levels in SA.

19.0 Age and length composition of fishery landings

The majority (~70%) of WA recreational landings of *A. georgianus* are estimated to be taken within the Metropolitan Zone of the WCB. In this zone, sampling during three periods (1996–1998, 2004–2006 and 2009–2011) found that the majority of recreationally caught fish ranged from 190 to 270 mm TL in size and 1 to 6 years in age (Smith *et al.* 2013a). Between 1996–1998 and 2009–2011, the average length declined from 24 to 23 cm, and the proportion of older fish (aged >3 years) declined from 24% to 15%.

The majority (~60–70%) of WA commercial landings of *A. georgianus* are taken by the 'trap net' fishery within the South Zone of the SCB. In this fishery, sampling during three periods (1983–1985, 1994–1996 and 2008–2011) found that the majority of fish ranged from 200 to 300 mm TL in size and 2 to 6 years in age (Smith *et al.* 2013a). Between 1983–1985 and 2008–2011, the average length declined from 25 to 23 cm, and the proportion of older fish (aged >3 years) declined from 27% to 4%.

For further details of the composition of landings, including spatial and temporal variations, see Smith *et al.* (2013a).

20.0 Legal possession limits and size limits in WA

See Table 4.

21.0 Sex ratio in fishery landings

In WA, the sex ratio (female:male) of fishery landings of *A. georgianus* varies depending on the location, age and method of capture.

WRFC (1975) reported that SCB commercial fishery landings exhibited an overall ratio of approximately 1:1, although the proportions varied during the fishing season.

Lenanton (1978) reported strong biases in the sex ratio of recreational catches at Rottnest Island during the spawning period (March-June). The ratio apparently varied according to location. At the western tip of the island, males usually dominated but elsewhere on the island females usually dominated.

Fairclough *et al.* (2000a) reported that *A. georgianus* caught by commercial netting in south-western WA (i.e. southern WCB and western SCB) exhibited a sex ratio of approximately 1:1 for all age classes from 0 to 5+, except for the 1+ age class which had a ratio of 66:34. In recreational landings in south-western WA, the ratio was strongly biased towards females (68:32).

Long-term monitoring of WA fishery landings conducted by DoF between 1977 and 2011 indicates a consistent bias towards females in landings of *A. georgianus* by both sectors, in both the WCB and SCB. The bias is greatest in recreational landings. For the period 1977–2011, the average ratio (female:male) was 57:43 for SCB commercial landings, 60:40 for WCB commercial landings, 75:25 for SCB recreational landings and 68:32 for WCB recreational landings (Smith *et al.* 2013a).

During extensive sampling in 2009–2011, there was a positive relationship between age of fish and the bias towards females. For example, in WCB recreational landings, the ratio was 57:43 in the 1+ age class, and progressively increased to reach 82:18 in the 5+ age class (Smith *et al.* 2013a).

In SA, sampling during 1996–1999 observed the same sex ratio of 75:25 in recreational angling and commercial netting landings (Ayvazian *et al.* 2000). This indicates a strong bias towards females in total fishery landings in SA.

22.0 Stock status

At the time of writing, a biomass estimate was not available for this stock. A ‘weight-of-evidence’ assessment of the stock was completed in 2012 (Smith *et al.* 2013a). The assessment found evidence of a substantial decline in stock abundance since the late 1990s and a steady increase in fishing mortality (F) over the same period. During the sampling period 2009–2011, the estimated F was approximately two times higher than natural mortality (M), which was well above the limit reference point used in the management of this species (F_{limit} = 1.5 x M). Relatively low annual recruitment was also observed in most years over the previous decade. For many years, during and prior to the assessment, total national fishery landings (commercial and recreational) comprised predominantly young fish, with 50–75% of annual landings comprised of fish that are yet to spawn for the first time. Also, total national landings comprised predominantly (~70%) females. The assessment concluded that the stock level was inadequate and recommended a reduction of at least 50% in the total catch of *A. georgianus* to ensure the sustainability of the stock.

Low recruitment may partly be a consequence of the declining breeding stock level due to overfishing but is also likely to be partly due to environmental factors, including the fluctuations in the strength of the Leeuwin Current. Low recruitment along the southern coast of WA tends to occur in years of weak current. In 2011, extremely unusual oceanographic conditions occurred along the south-western coast of WA, including summer temperatures >3°C above average in some areas (a 'heatwave' event, Pearce *et al.* 2011). These conditions were believed to be unfavourable for successful spawning by *A. georgianus*. Recruitment was relatively low in 2011. Recruitment improved in 2012 and was the highest level observed in 13 years.

Acknowledgements.

Dave Fairclough, Chris Dowling, Amber Howard, Paul Lewis, Martin Holtz.

23.0 References

Ayvazian SG, Jones GK, Fairclough D, Potter IC, Wise BS and Dimmlich WF. 2000. Stock assessment of Australian herring. Fisheries Research and Development Corporation, Project No. 96/105. Department of Fisheries, Western Australia. Fisheries Research Report, 163. 130 pp.

Ayvazian SG, Bastow TP, Edmonds JS, How J and Nowara G. 2004. Stock structure of Australian herring (*Arripis georgiana*) in southwestern Australia. Fisheries Research 67:39-53.

Bool NM, Page B and Goldsworthy SD. 2007. What is causing the decline of little penguins (*Eudyptula minor*) on Granite Island, South Australia. SARDI Research Report Series No. 217. South Australian Research and Development Institute, Adelaide.

Department of Fisheries DoF. 2011. Resource Assessment Framework (RAF) for Finfish Resources in Western Australia. Fisheries Occasional Publication No. 85. Department of Fisheries, Western Australia.

Fahlbusch V. 1995. Early life history of Western Australian salmon, *Arripis truttaceus* (Cuvier) and Australian herring, *Arripis georgianus* (Cuvier and Valenciennes): morphology, aging, ecological distribution and feeding ecology. Unpublished B.Sc. (Hons) thesis. School of Biological Sciences, Flinders University, South Australia. 114 pp.

Fairclough DV, Dimmlich WF, and Potter IC. 2000a. Length and age compositions and growth rates of the Australian herring *Arripis georgiana* in different regions. Marine and Freshwater Research 51, 631–640.

Fairclough DV, Dimmlich WF and Potter IC. 2000b. Reproductive biology of the Australian herring *Arripis georgiana*. Marine and Freshwater Research 51:619-630.

Feng M, Slawinski D, Beckley LE and Keesing JK. 2010. Retention and dispersal of shelf waters influenced by interactions of ocean boundary current and coastal geography. Australian Journal of Marine and Freshwater Research 61:1259-1267.

Fowler AJ, McGarvey R, Steer MA and Feenstra JE. 2012. South Australian Marine Scalefish Fishery. Stock Status Report 2011/12. Report to PIRSA Fisheries and Aquaculture South Australian Research and Development Institute (Aquatic Sciences), Adelaide. F2007/000565-7. SARDI Research Report Series No. 681. 44pp.

Greenwell C. 2001. A diet study of *Arripis georgianus* from the south-west of WA Unpublished report. Department of Fisheries, Western Australia.

Hara A. 2012. Diet and habitat use of New Zealand fur seals at the western margin of their population expansion. Unpublished MSc thesis. University of Western Australia, Perth.

Hoenig JM. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82: 898-903.

Hutchins B, and Swainston R. 1986. Sea fishes of southern Australia. Swainston Publishing, Perth.

Itoh T, Kemp H and Totterdell J. 2011. Diet of young southern bluefin tuna *Thunnus maccoyii* in the southwestern coastal waters of Australia in summer. Fisheries Science 77:337-344.

Jones GK and Westlake M. 2003. Marine scalefish and miscellaneous fisheries. South Australian Fisheries Assessment Series Report No. 01/18. SARDI Aquatic Sciences, Adelaide. 47 pp.

Jones GK, Hall DA, Hill KL and Staniford A.J. 1990. The South Australian marine scalefish fishery. Stock Assessment, Economics, Management. Green Paper. South Australian Department of Fisheries. 187 pp.

Jones GK. 2008. Australian salmon and herring. Chapter 30. In: Natural History of Gulf St. Vincent. (eds: Shepherd SA, Bryars SM, Kirkegaard I, Harbison P and Jennings JT). Publications of the Royal Society of South Australia (Incorporated) pp. 415 – 436.

Jones K. 2009. South Australian Recreational Fishing Survey 2007/08. South Australian Fisheries Management Series Paper No. 54. PIRSA Fisheries, Adelaide. 84pp.

Kailola PJ, Williams MJ, Stewart PC, Reichelt RE, McNee A and Grieve C. 1993. Australian fisheries resources. Bureau of Resource Sciences, Department of Primary Industries and Energy and the Fisheries Research and Development Corporation, Canberra.

Lenanton RCJ. 1978. Age, spawning time and fecundity of Australian herring (*Arripis georgianus* C. and V.) (Pisces: Arripidae) from the waters around Rottnest Island, Western Australia. Australian Journal of Marine and Freshwater Research 29:599-612.

Lenanton RCJ. 1982. Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of south-western Australia. Australian Journal of Marine and Freshwater Research 33:881-900.

Lenanton RCJ, Robertson AI and Hansen JA. 1982. Nearshore accumulations of detached macrophytes as nursery areas for fish. Marine Ecological Progress Series 9:51-57.

Lenanton RCJ and Potter IC. 1987. Contribution of estuaries to commercial fisheries in temperate Western Australia and the concept of estuarine dependence. Estuaries 10:28-35.

Moore G. 2012. Aspects of the evolutionary history of a pair of fish species (Arripidae: *Arripis*) on either side of a biogeographic barrier in southern Australian seas. Unpublished PhD thesis. Murdoch University, Perth.

Moore GI and Chaplin JA. 2013. Population genetic structures of three congeneric species of coastal pelagic fishes (*Arripis*: Arripidae) with extensive larval, post-settlement and adult movements. Environmental Biology of Fishes 96:1087-1099.

Neira FJ, Mishiewicz AJ and Trnski T (eds). 1998. Larvae of temperate Australian fishes, laboratory guide for larval fish identification, 1st edition. University of Western Australia Press, Nedlands.

Paulin C. 1993. Review of the Australasian fish family Arripidae (Percomorpha), with the description of a new species. Australian Journal of Marine and Freshwater Research 44:459-471.

Pearce A, Lenanton R, Jackson G, Moore J, Feng M and Gaughan D. 2011. The ‘marine heat wave’ off Western Australia during the summer of 2010/11. Fisheries Research Report No. 222. Department of Fisheries, Western Australia. 40 pp.

Pollard J. 1969. Australian and New Zealand Fishing. Paul Hamlym, Sydney. 952 pp.

Potter IC, Chuwen BM, Hesp SA, Hall NG, Hoeksema SD, Fairclough DV and Rodwell TM. 2011. Implications of the divergent use of a suite of estuaries by two exploited marine fish species. Journal of Fish Biology 79:662-691.

Smith KA. 2006. Review of fishery resources and status of key fishery stocks in the Swan-Canning Estuary. Fisheries Research Report No. 156. Department of Fisheries, Western Australia.

Smith KA, Gibbs MT, Middleton JH and Suthers IM. 1999. Short term variability in larval fish assemblages of the Sydney shelf: tracers of hydrographic variability. Marine Ecological Progress Series 178:1-15.

Smith K, Brown J, Lewis P, Dowling C, Howard A, Lenanton R and Molony B. 2013a. Status of nearshore finfish stocks in south-western Western Australia. Part 1: Australian herring. Final NRM Report - Project No. 09003. Fisheries Research Report No. 246. Department of Fisheries, Western Australia. 200 pp.

Smith K, Brown J, Lewis P, Dowling C, Howard A, Lenanton R and Molony B. 2013b. Status of nearshore finfish stocks in south-western Western Australia. Part 2: Tailor. Final NRM Report – Project No. 09003. Fisheries Research Report No.247. Department of Fisheries Western Australia. 112 pp.

Stevens DW and Kalish JM. 1998. Validated age and growth of kahawai (*Arripis trutta*) in the Bay of Plenty and Tasman Bay. NIWA Technical Report 11. 33 pp.

Ward TM, Goldsworthy S, Rogers PJ, Page B, McLeay LJ, Dimmlich WF, Baylis A, Einoder L, Wiebkin A, Roberts M, Daly K, Caines R and Huveneers C. 2008. Ecological importance of small pelagic fishes in the Flinders Current System. Report to Department of the Environment and Water Resources. SARDI Research Report Series No. 276. South Australian Research and Development Institute, Adelaide.

Western Fisheries Research Committee (WFRC). 1973. Documents relating to scientific workshop on salmon and herring at Waterman on December 14 and 15, 1972. Department of Fisheries and Fauna, Western Australia. 66 pp.

Western Fisheries Research Committee (WFRC). 1975. Documents relating to the second scientific workshop on salmon and herring at Waterman on October 16 and 17, 1974. Department of Fisheries and Wildlife, Western Australia. 110 pp.

Western Fisheries Research Committee (WFRC). 1980. Documents relating to the twenty-first meeting held at Waterman from July 1 to 3, 1980. Department of Fisheries and Wildlife, Western Australia.

White T. 1980. Herring and tailor: their exploitation and utilization in Western Australia. Fishing and Allied Industries Committee, Perth. 64 pp.

Table 1. Length-at-maturity (+ 95% confidence interval) (in millimetres) for 50% ($L_{50\%}$) and 95% ($L_{95\%}$) of female and male *Arripis georgianus* in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB), sampled during various periods (adapted from Smith *et al.* 2013a).

Year	Bioregion	Sex	$L_{50\%}$ (95% C.I.)	$L_{95\%}$ (95% C.I.)	Sample size
1996-99*	Pooled	F	196.9 (193.8-199.9)	241.0 (n/a)	1042
		M	179.0 (175.0-184.4)	203.9 (n/a)	544
1996-98	Pooled	F	207.2 (206.0-208.4)	243.1 (239.7-246.5)	723
		M	188.1 (183.9-192.2)	213.6 (202.0-225.1)	387
1996-98	WCB	F	202.6 (201.5-203.7)	233.2 (230.1-236.2)	650
		M	185.0 (182.8-187.3)	201.0 (194.7-207.5)	282
1996-98	SCB	F	228.3 (224.9-231.8)	255.7 (246.2-265.2)	164
		M	216.7 (205.9-227.4)	265.4 (234.2-296.6)	105
2009-11	Pooled	F	198.9 (194.4-203.4)	254.2 (241.3-267.0)	2,099
		M	181.0 (174.5-187.5)	217.8 (199.1-236.5)	1,279
2009-11	WCB	F	194.1 (171.8-216.3)	250.8 (189.0-312.7)	1,781
		M	174.4 (170.9-177.8)	188.8 (178.7-198.9)	971
2009-11	SCB	F	219.6 (215.4-223.7)	265.3 (253.5-277.1)	318
		M	196.4 (188.0-204.9)	231.1 (206.5-255.6)	308

*from Ayvazian *et al.* (2000) and Fairclough *et al.* (2000b)

Table 2. Age-at-maturity (+ 95% confidence interval) (in years) for 50% ($A_{50\%}$) and 95% ($A_{95\%}$) of female and male *Arripis georgianus* in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB), sampled during various periods (adapted from Smith *et al.* 2013a).

Year	Bioregion	Sex	$A_{50\%}$ (95% C.I.)	$A_{95\%}$ (95% C.I.)
1996-99*	Pooled	F	1.7 (1.6 – 1.7)	n/a
		M	1.4 (1.35 – 1.5)	n/a
1996-98	Pooled	F	1.99 (1.93-2.05)	2.86 (2.57-3.16)
		M	1.85 (1.70-2.00)	2.40 (2.02-2.79)
1996-98	WCB	F	1.88 (1.79-1.97)	2.51 (2.15-2.86)
		M	1.81 (1.35-2.26)	2.25 (1.67-2.82)
1996-98	SCB	F	2.58 (2.47-2.68)	3.45 (3.25-3.66)
		M	2.37 (2.37-2.38)	2.99 (2.98-3.00)
2009-11	Pooled	F	2.35 (1.12-3.58)	4.07 (0.65-7.49)
		M	1.80 (1.49-2.10)	2.44 (1.81-3.06)
2009-11	WCB	F	2.19 (1.93-2.44)	3.97 (3.24-4.70)
		M	1.76 (1.08-2.45)	2.27 (1.47-3.07)
2009-11	SCB	F	2.77 (2.75-2.78)	3.81 (3.77-3.85)
		M	1.90 (1.81-2.00)	3.47 (3.19-3.76)

*from Ayvazian *et al.* (2000) and Fairclough *et al.* (2000b)

Table 3. von Bertalanffy growth parameters (± standard error) for female and male *Arripis georgianus,* sampled in 1996–98 and 2009–11. L_∞ – mean asymptotic length (total length, in mm); K – growth coefficient (per year); t_0 – hypothetical age (in years) at zero length (adapted from Smith *et al.* 2013a).

Year	Bioregion	Sex	L_∞	K	t_0	Sample size
1996-98	Pooled	F	263.6 (±0.7)	0.81 (±0.01)	-0.04 (±0.01)	2412
		M	239.4 (±0.6)	1.02 (±0.01)	0.02 (±0.01)	1708
1996-98	West Coast	F	262.8 (±0.8)	0.82 (±0.01)	-0.04 (±0.01)	1954
		M	238.0 (±0.6)	1.04 (±0.02)	0.02 (±0.01)	1479
1996-98	South Coast	F	266.2 (±1.5)	0.78 (±0.02)	-0.03 (±0.02)	458
		M	249.8 (±2.2)	0.89 (±0.04)	-0.01 (±0.02)	229
2009-11	Pooled	F	272.8 (±1.1)	0.57 (±0.01)	-0.26 (±0.03)	5157
		M	237.3 (±0.7)	0.87 (±0.02)	-0.06 (±0.02)	3210
2009-11	West Coast	F	271.5 (±1.1)	0.57 (±0.01)	-0.30 (±0.03)	4565
		M	236.7 (±0.8)	0.86 (±0.02)	-0.08 (±0.02)	2731
2009-11	South Coast	F	295.8 (±6.2)	0.48 (±0.03)	-0.20 (±0.08)	592
		M	246.0 (±3.2)	0.79 (±0.05)	0.02 (±0.05)	479

Table 4. Changes to legal daily bag limits and size limits for *Arripis georgianus* in Western Australia (LML = Legal Minimum Length, WCB = West Coast Bioregion, SCB = South Coast Bioregion).

Date	Regulation
1913	LML 6 inches
1937	LML 7 inches
1975	LML 180 mm
Jun 1991	LML removed for recreational fishers; recreational daily bag limit 40 (WCB & SCB only)
Oct 2009	Recreational daily bag limit 40 in SCB, 30 in WCB.
Mar 2011	LML removed for commercial fishers.
Feb 2013	State-wide recreational daily bag limit 30, as part of a mixed species daily bag limit of 30.

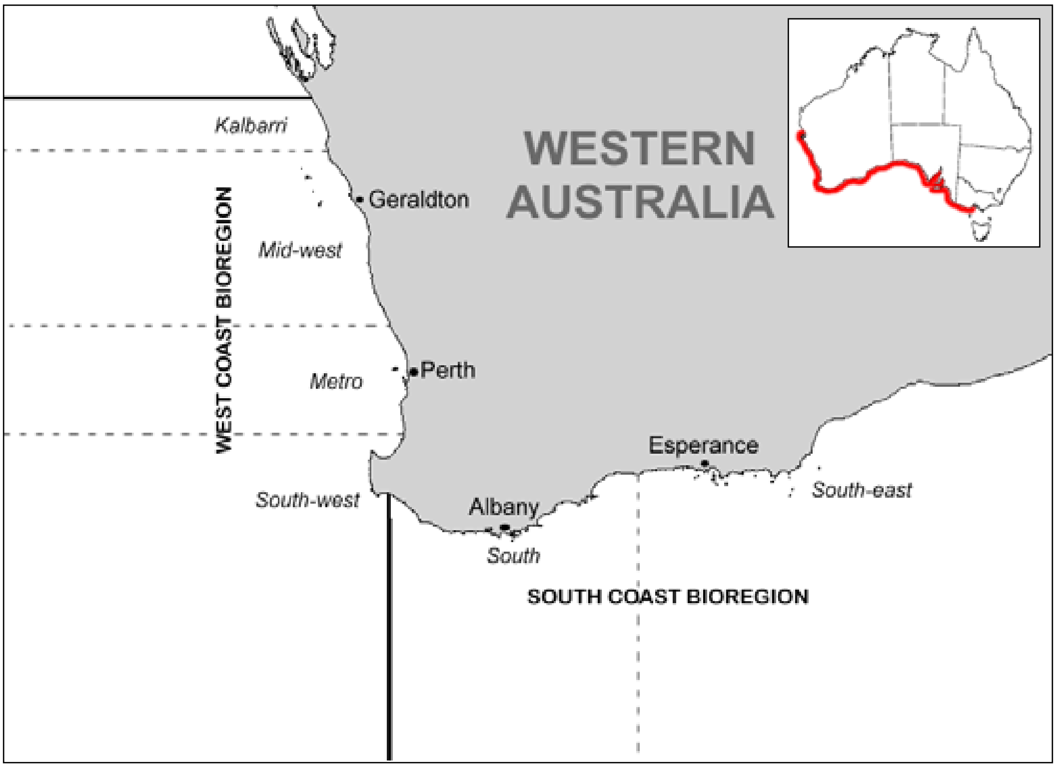

Figure 1. Boundaries of Bioregions (West Coast, South Coast) and Zones within Bioregions (Kalbarri, Mid-west, Metro, South-west, South, South-east) in Western Australia. Inset – distribution of *Arripis georgianus* across southern Australia.

Figure 2. Comparison of juvenile *Arripis truttaceus* (197 mm TL) (top) and adult *A. georgianus* (188 mm TL) (bottom).

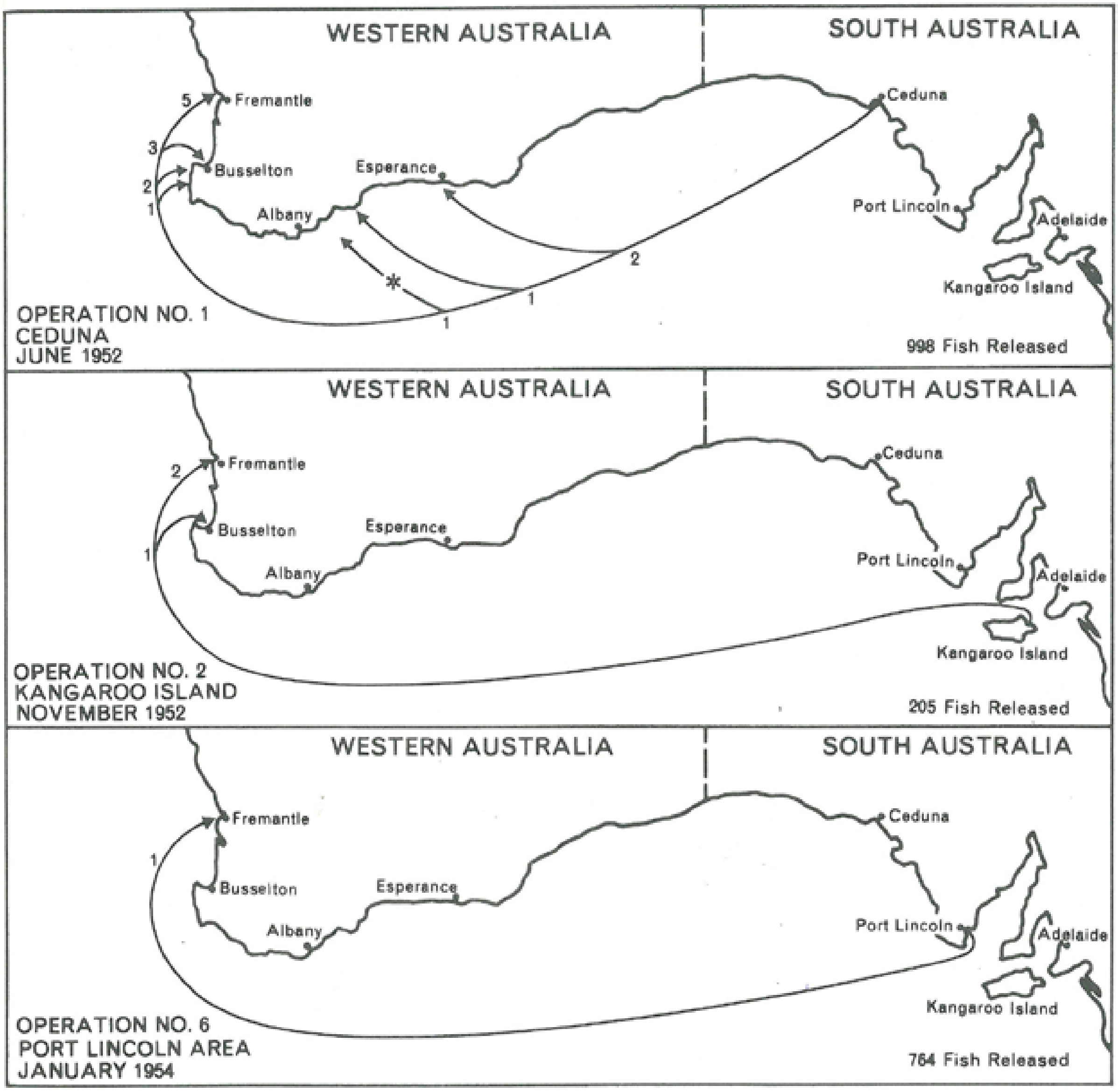

Figure 3. Movements of recaptured *Arripis georgianus* from South Australia to Western Australia tagged in 1952 and 1954. Numbers indicate number of recaptures in each location. *indicates recapture without precise location data (reproduced from WFRC 1973).

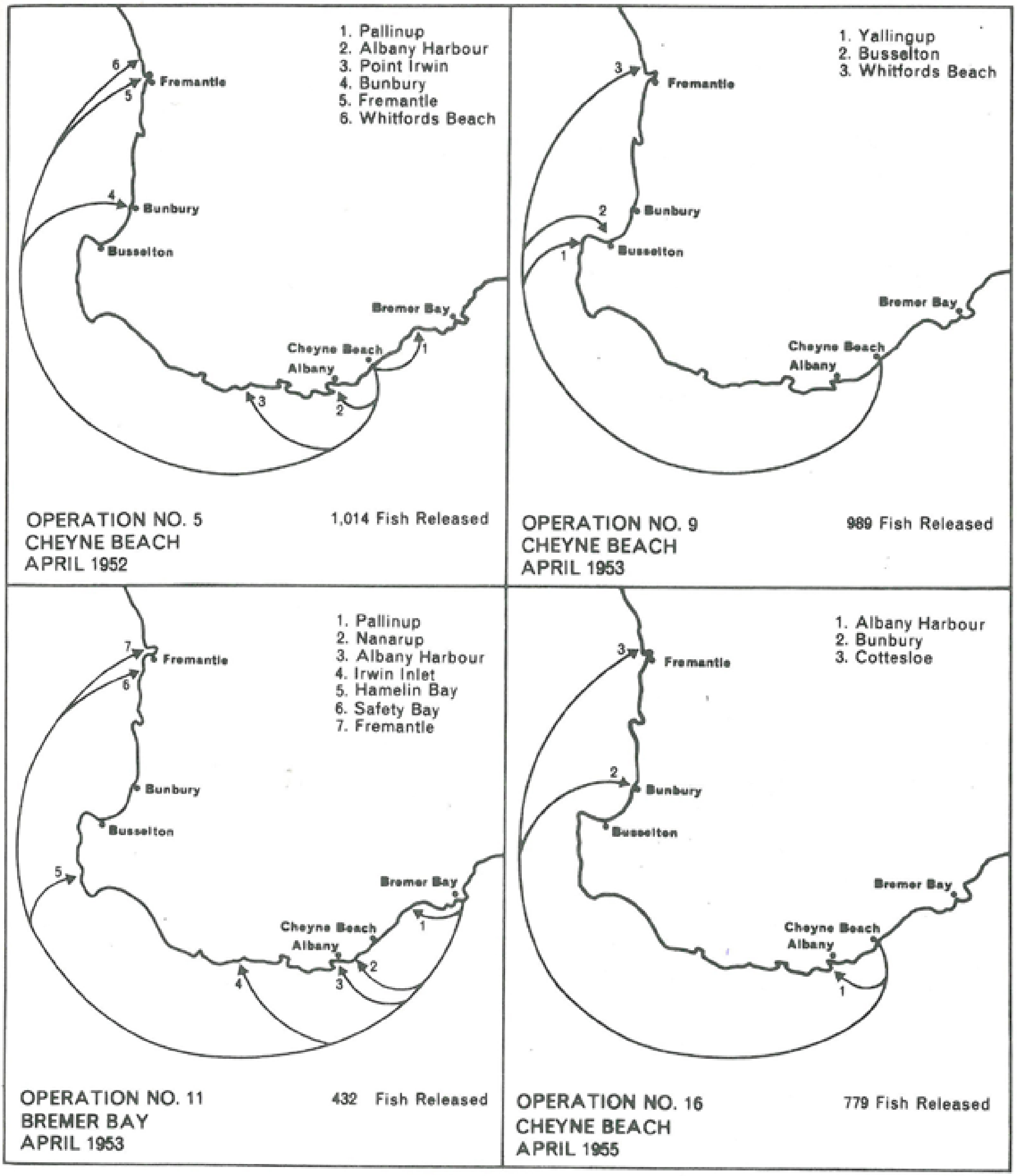

Figure 4. Movements of recaptured *Arripis georgianus* tagged on the south coast of Western Australia in 1952 and 1953. Numbers indicate number of recaptures in each location. (reproduced from WFRC 1973).

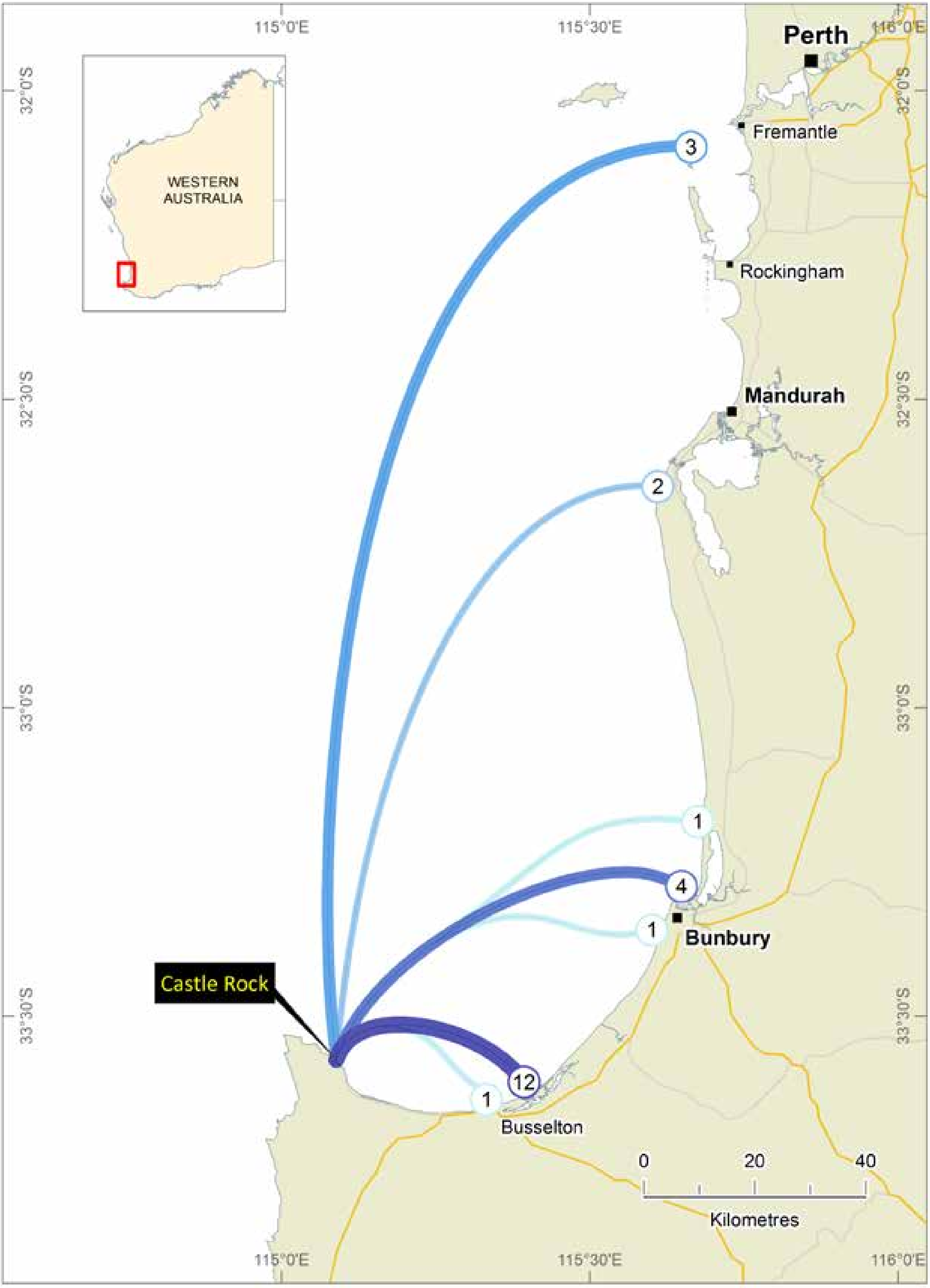

Figure 5. Movements of recaptured *Arripis georgianus* tagged on the west coast of Western Australia at Castle Rocks (near Dunsborough) in May 2012. Numbers within circles indicate number of recaptures at each location. (recaptures as of November 2013)

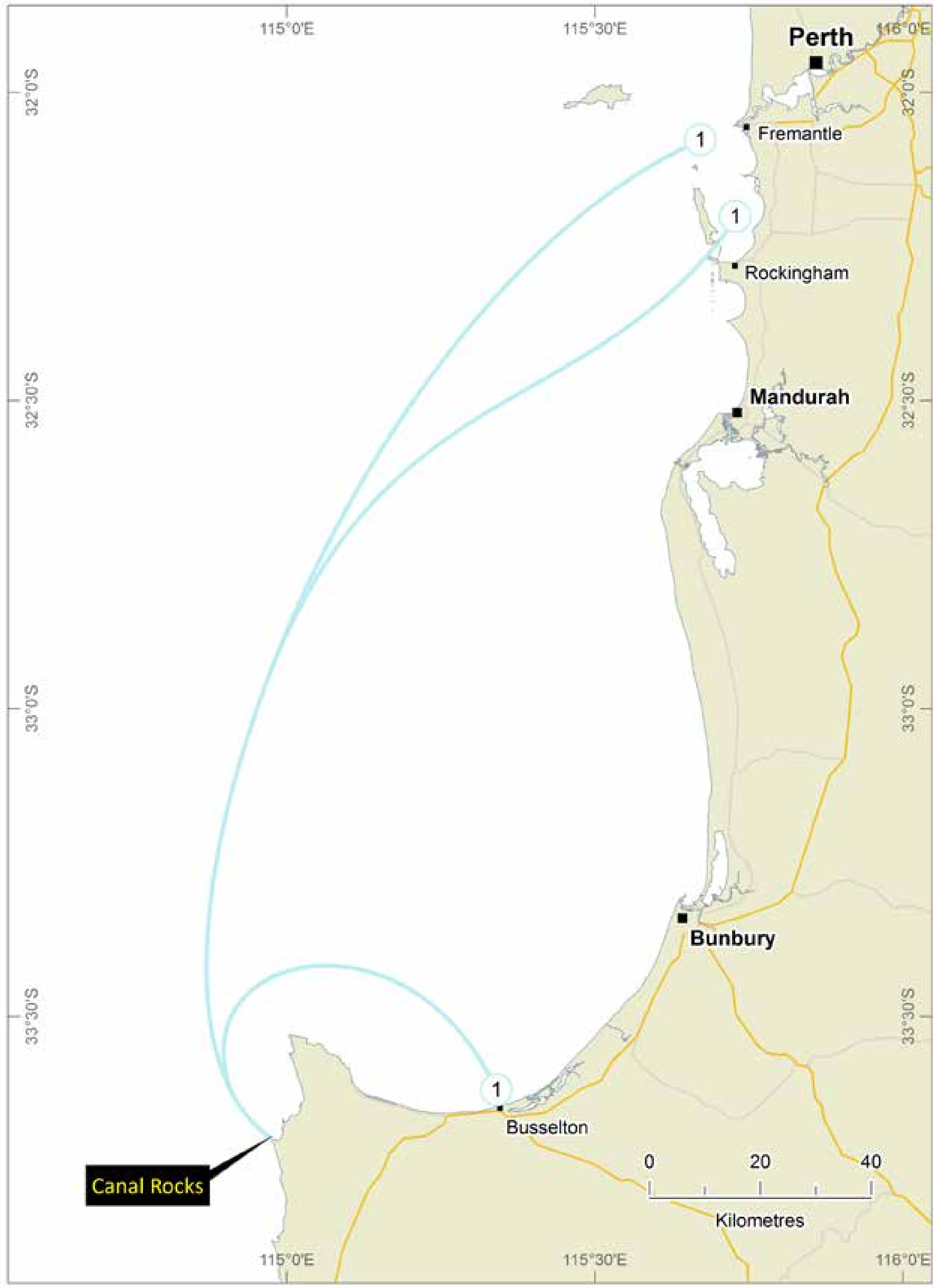

Figure 6. Movements of recaptured *Arripis georgianus* tagged on the west coast of Western Australia at Canal Rocks in May 2012. Numbers within circles indicate number of recaptures at each location. (recaptures as of November 2013)

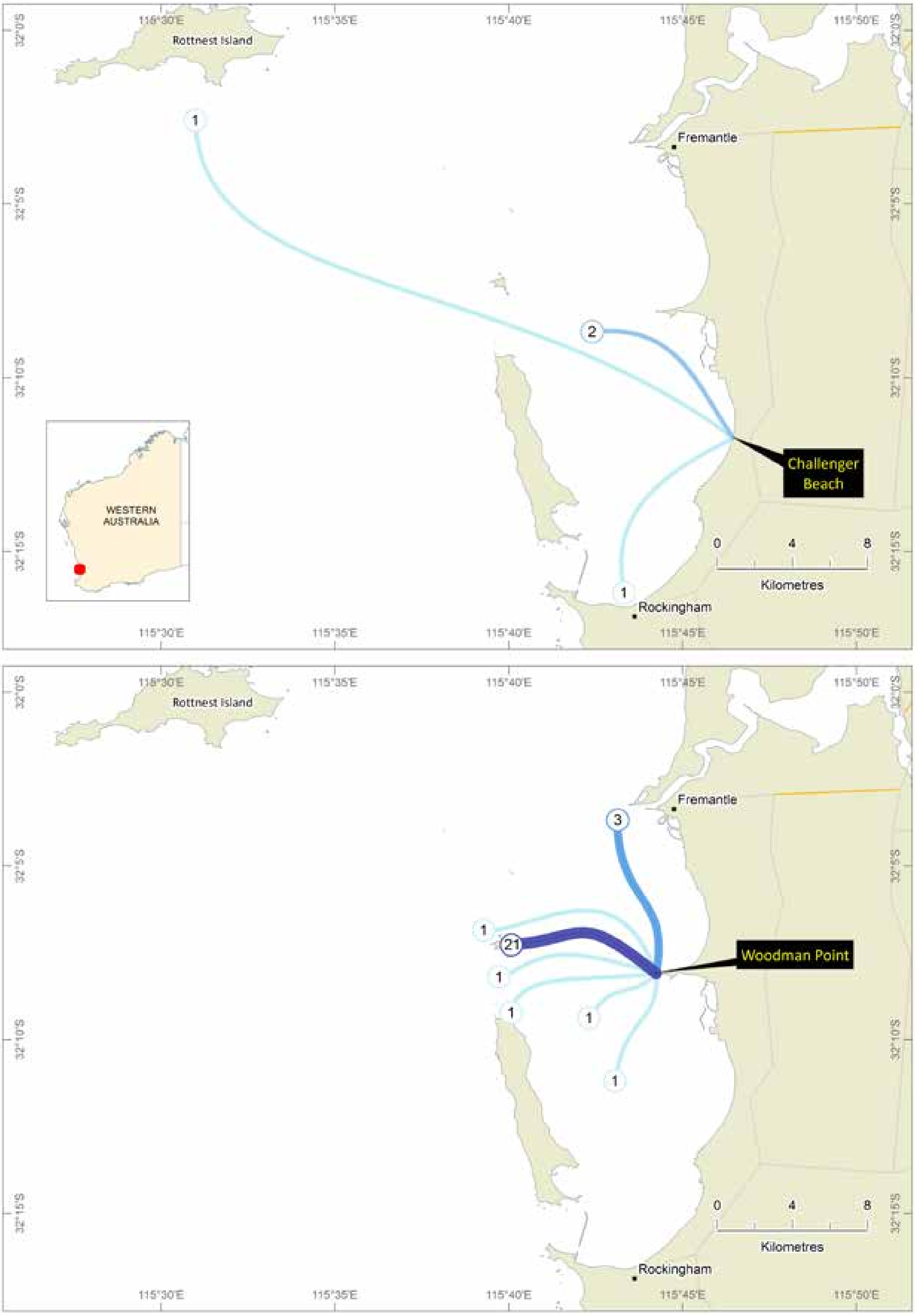

Figure 7. Movements of recaptured *Arripis georgianus* tagged on the west coast of Western Australia in Cockburn Sound (at Woodman Point and Challenger Beach sites) in November/December 2012. Numbers within circles indicate number of recaptures at each location. (recaptures as of November 2013)

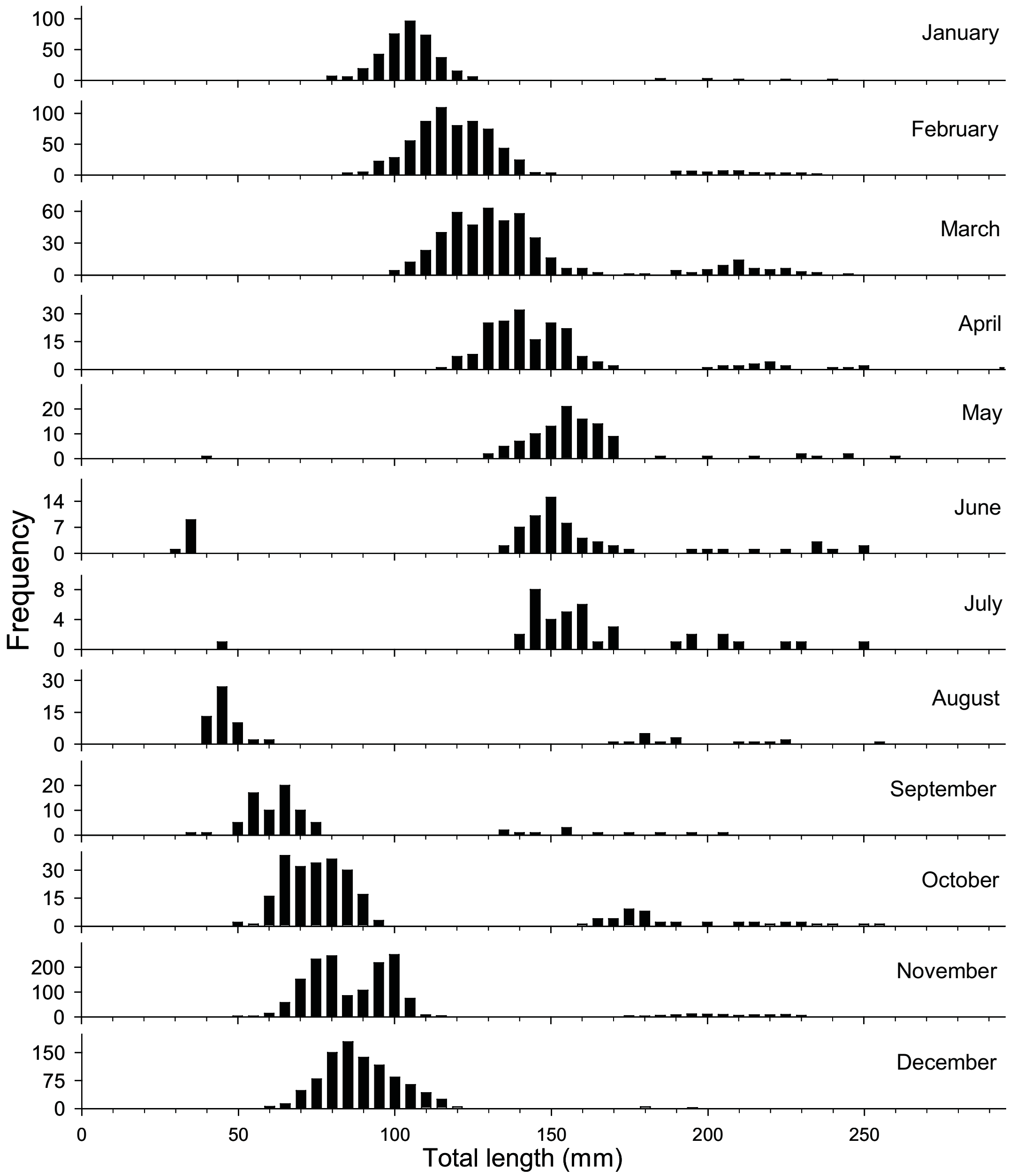

Figure 8. Monthly length frequency distributions of *Arripis georgianus* in the West Coast Bioregion (Zones pooled), summed from all samples taken 1993/94 to 2009/10 (reproduced from Smith *et al.* 2013a).

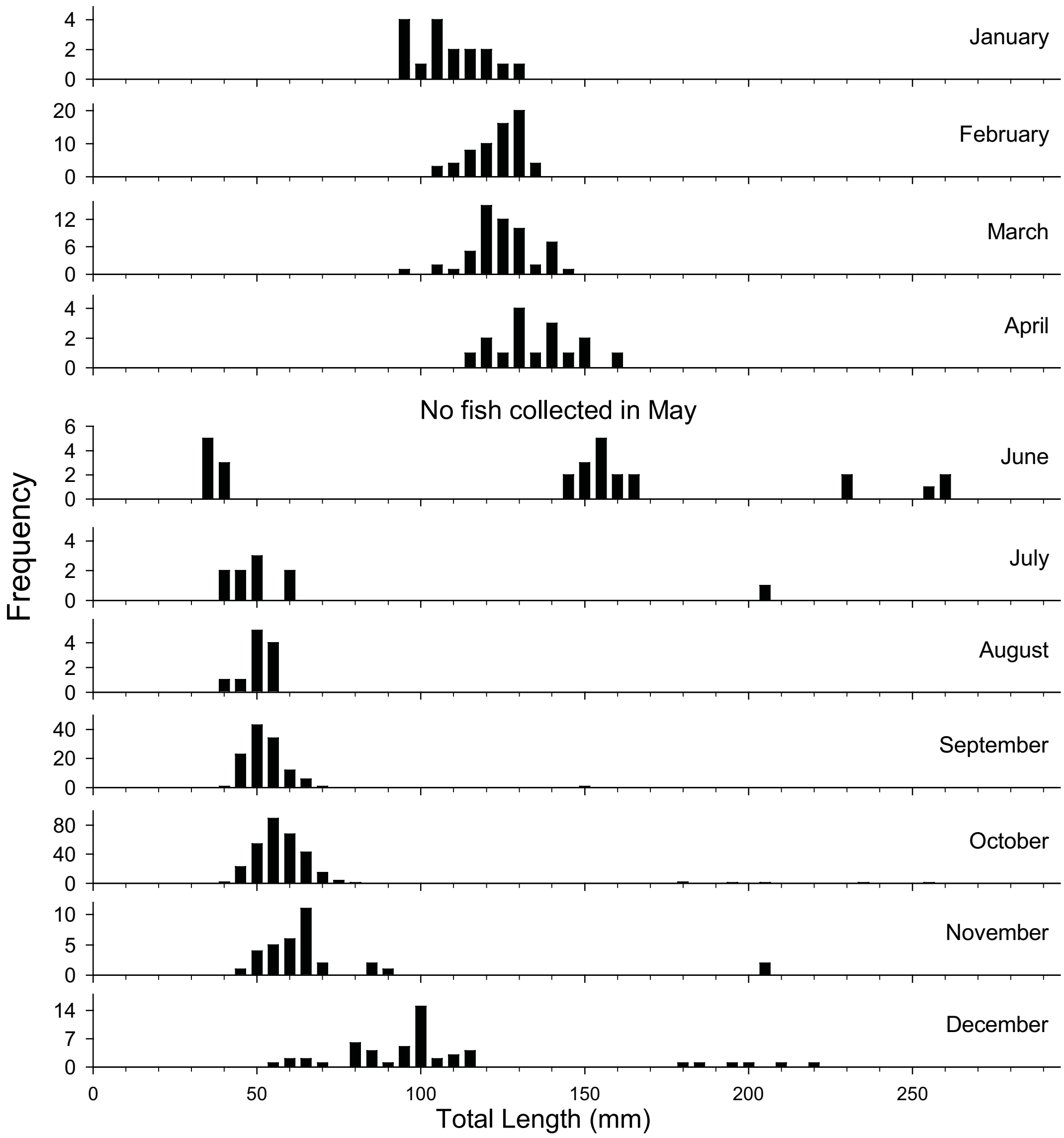

Figure 9. Monthly length frequency distributions of *Arripis georgianus* in the South Zone of the South Coast Bioregion, summed from all samples taken 1993/94 to 2009/10 (reproduced from Smith *et al.* 2013a).

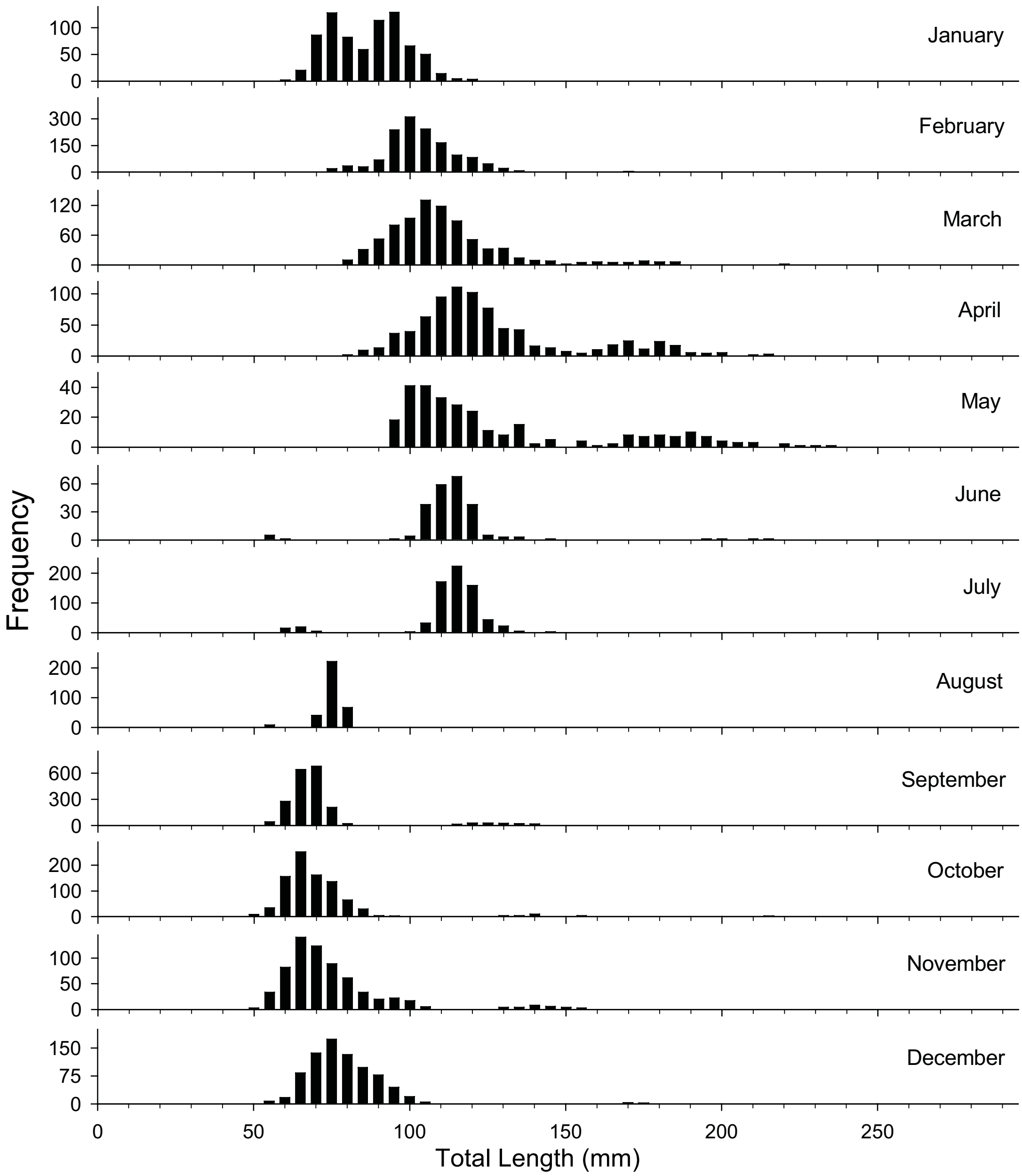

Figure 10. Monthly length frequency distributions of *Arripis georgianus* in the South-east Zone of the South Coast Bioregion, summed from all samples taken 1993/94 to 2009/10 (reproduced from Smith *et al.* 2013a).

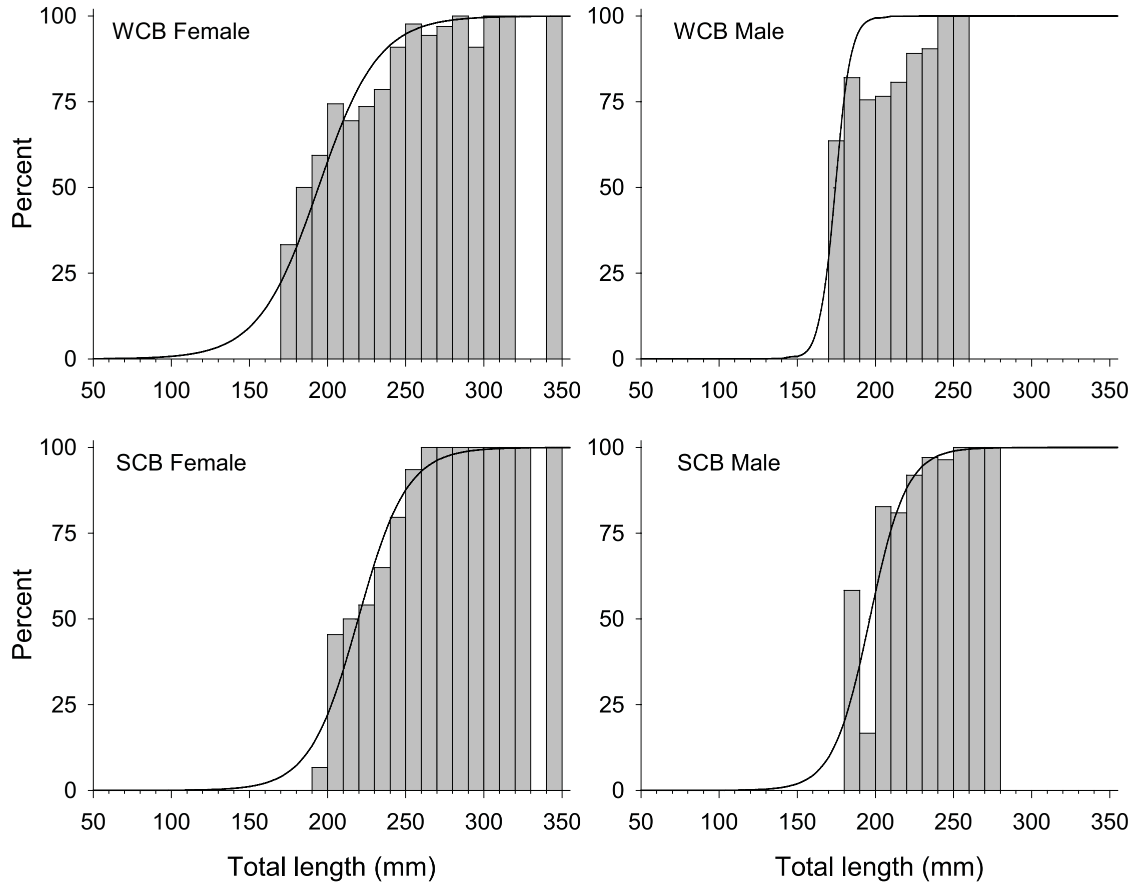

Figure 11. Proportion of mature individuals within each size class, with logistic curves fitted, for female and male *Arripis georgianus* sampled in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) in 2009–11.

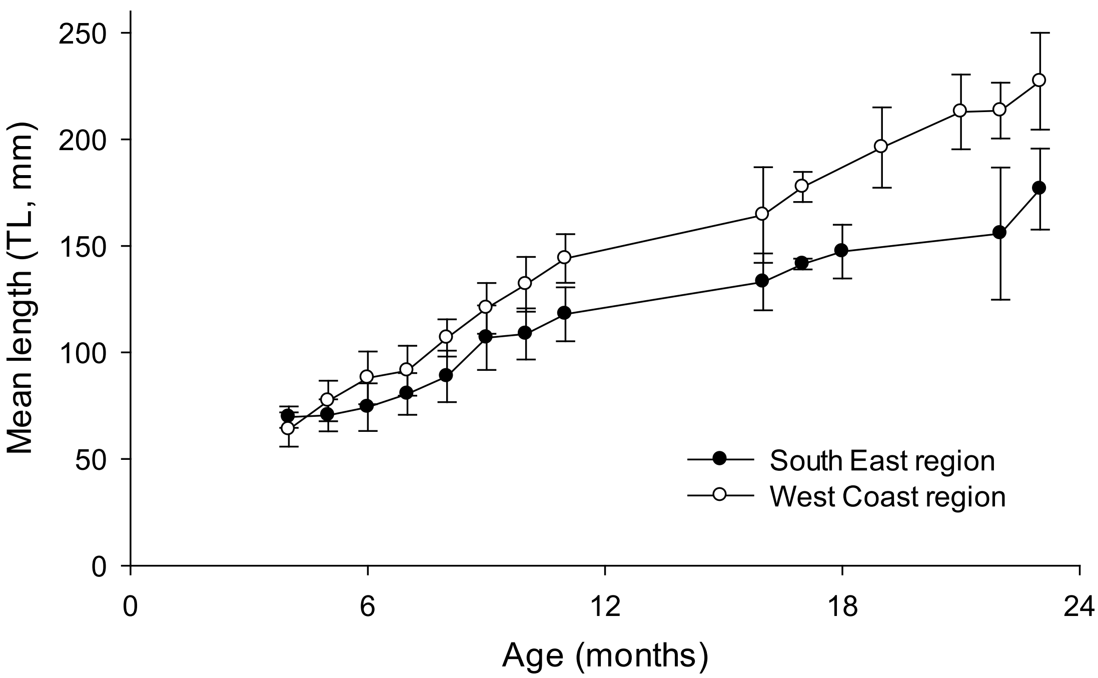

Figure 12. Mean (+ s.d.) length-at-age of juvenile *Arripis georgianus* in the West Coast Bioregion and the eastern part of the South Coast Bioregion (south-east zone) in 2009–11, estimated from progression of modes in length frequency data (reproduced from Smith *et al.* 2013a).

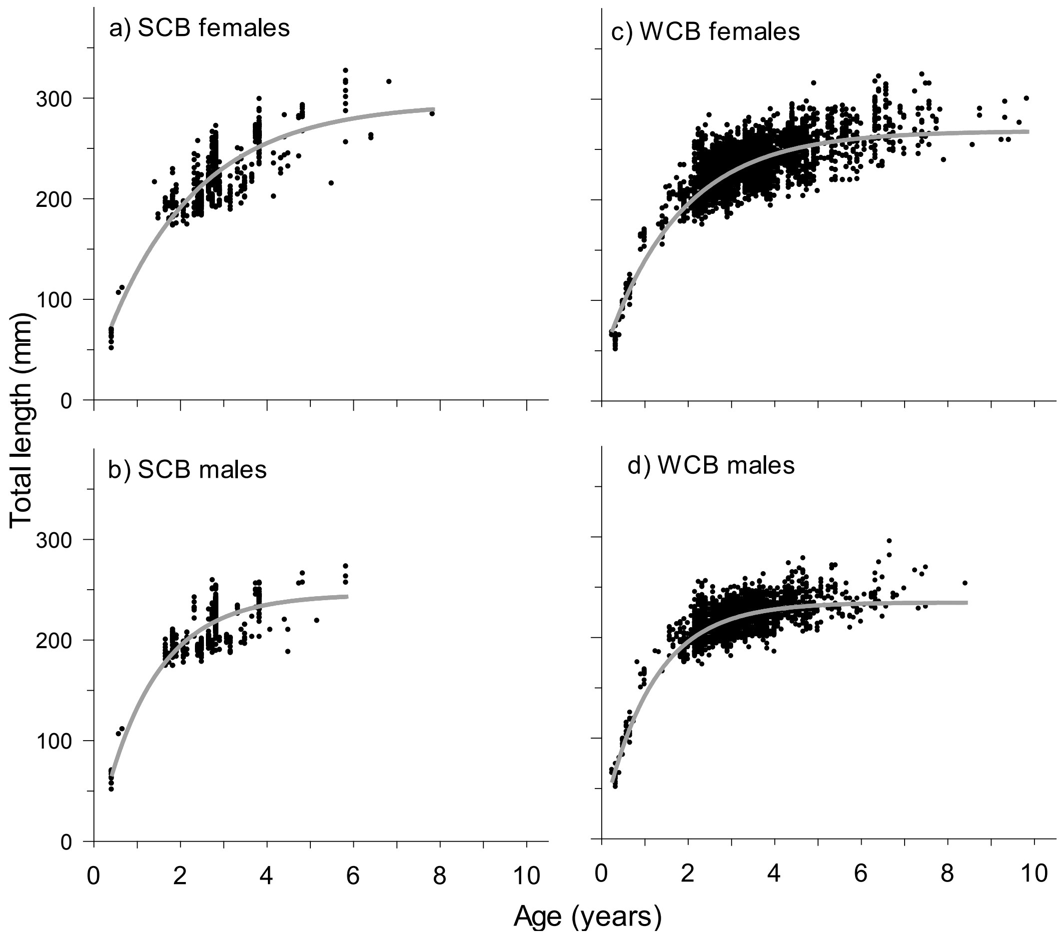

Figure 13. Total length versus age, with von Bertalanffy growth curves fitted, for female and male *Arripis georgianus* sampled in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) in 2009–11 (reproduced from Smith *et al.* 2013a).

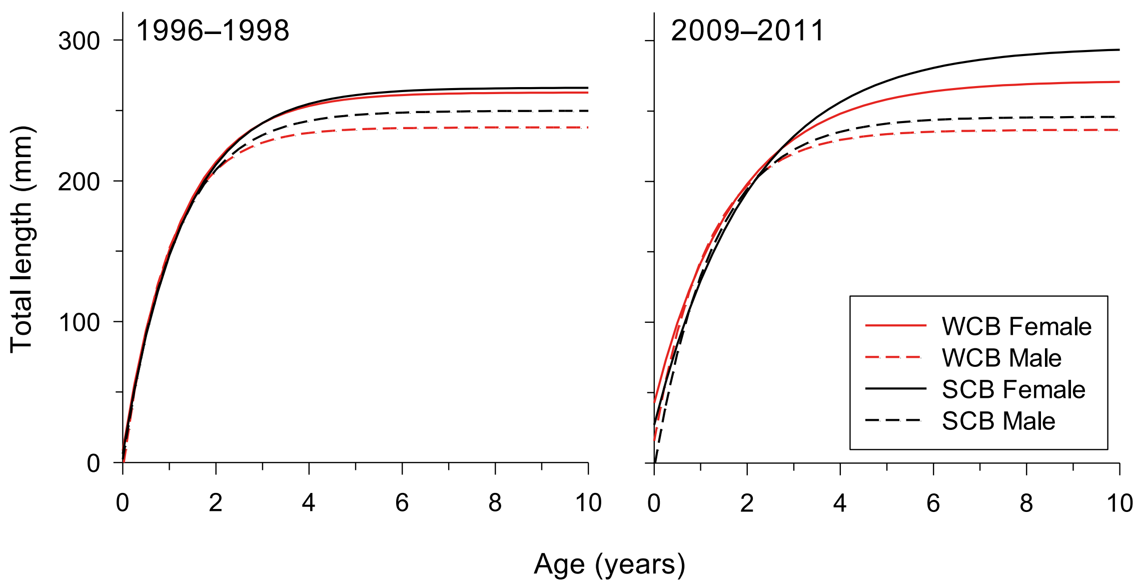

Figure 14. Comparison of von Bertalanffy growth curves for female and male *Arripis georgianus* sampled in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) during 1996–98 and 2009–11 (using growth parameters in Table 3).

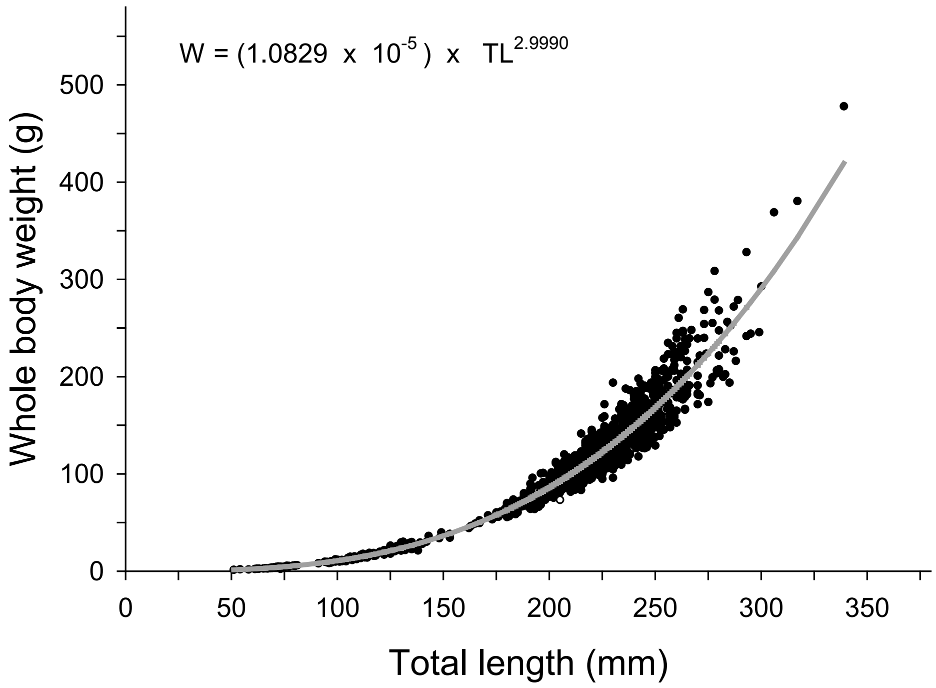

Figure 15. Whole body weight (W) versus total length (TL) for *Arripis georgianus,* females and males pooled.