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FRDC Project 96/105

STOCK ASSESSMENT OF AUSTRALIAN HERRING

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96/105. STOCK ASSESSMENT OF AUSTRALIAN HERRING

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OBJECTIVES:

1. Determine the age structure, growth, and reproductive biology of Australian herring and the source of recruitment to the Western Australian fishery.
2. Determine whether fishing or factors independent of fishing (i.e. Leeuwin Current) have caused the decline in commercial catches currently being experienced across the range of this species.
3. Develop a more useful, ongoing index of recruitment of immediately post settled juvenile Australian herring (and other recreationally and commercially valuable species, i.e. Australian salmon) that settle into shoreline nursery areas between Geographe Bay in Western Australia and the Coorong estuary in South Australia.
4. Determine the movement patterns of Australian herring and their vulnerability to capture by Western Australian commercial and recreational fishers.
5. Develop an age structured spatial model to assess the status of Australian herring stock, using the biological and tagging information gathered during this study.

NON-TECHNICAL SUMMARY

Australian herring (*Arripis georgiana*) is an important finfish resource to both the commercial and recreational sectors in Western Australia and South Australia. A decline in the commercial catches in both states during the early 1990s and ever increasing recreational fishing pressure alerted fisheries scientists in both states to a potential problem. Despite the popularity of this species there was little validated information on which to develop stock assessment models. Therefore the objectives of this research, stated above, were to collect pertinent biological and fisheries information and to use the information to develop a stock assessment model.

Australian herring were collected from along the Western Australian and South Australian coastlines between January 1996 and June 1999 for age, growth and reproductive biology analyses. Reproductive examination showed trends during the year of gonadosomatic indices, gonadal maturity stages and oocyte stages demonstrate that spawning is restricted to south-western Australian waters as far east as Esperance and that it occurs mainly during May. Evidence of recent spawn, mature and maturing eggs in some ovaries examined during the spawning period indicate that Australian herring is a multiple spawner. The mean number of maturing eggs in the ovaries of fish caught just prior to spawning was estimated to be 84700. Maturity was first reached by 50% of females and males at about 197 and 179 mm, respectively, and by about 54% of females and about 80% of males at the end of the second year of life.

Since the opaque zones on the otoliths of Australian herring were shown to be formed annually, their number could be used to age this species. Although catches of Australian herring in south-western Australia, where spawning occurs, were dominated by the 0+ to 5+ age classes, they did contain females and males up to ten and nine years of age, respectively. The asymptotic lengths for female and male Australian herring derived from the von Bertalanffy growth equation are 262 and 239 mm, respectively. In contrast to the situation in south-western Australia, the catches of Australian herring in the south eastern region of WA and SA, where spawning does not occur, were dominated by the 0+ to 2+ age classes. The marked decline that occurs in the number of 2+ fish in South Australia during summer implies that, at this time, many Australian herring start migrating towards their spawning areas in south-western Australia.

The use of otolith microstructure analysis proved successful in providing data on the hatching period and growth of late-juvenile stages of Australian herring. Hatch dates peaked in the early half of May which was consistent with the reproductive study on adult females. The growth rate for these late-juvenile stages was approximately 0.32 mm per day and 0.18 mm per day for Western Australian and

South Australian waters, respectively. There was variability in the individual age estimates of fish, possibly due to the influence of transitional levels during egg, larval and post-larval stages on otolith microstructure.

The determination of whether fishing or factors other than fishing have influenced the commercial catches, an analysis of commercial Australian herring catch data, fishing effort and CPUE data from the southern states; WA, SA and Victoria, linked with environmental factors, the index of recruitment and market demand was conducted. It was concluded that for the Western Australian south coast trap net fishery the CPUE was related to recruitment strength in the Gulf St. Vincent (SA) nursery areas up to 4 years prior. The SA hauling net fishery declines in the 1990's have been due to a decline in targeted and non targeted effort. Additionally, targeted CPUE is affected by interannual variation in the recruitment at Barker Inlet. The fluctuations in Victoria also reflect the interannual variation in the index of recruitment.

In order to assess annual variation in juvenile recruitment, an index of recruitment of immediately post settled juveniles was developed and used to model juvenile transport to explain the movement of juveniles from spawning to nursery areas. While the spawning areas for Australian herring are in Western Australian waters, juveniles recruit and settle in coastal and estuarine habitats along the Western Australian, South Australian and western parts of the Victorian coastline. Monthly seine netting for juvenile Australian herring in inshore nursery habitats between Perth and Adelaide was conducted for three years. The data on the numbers of Australian herring were used to develop an index of juvenile recruitment and to place the results in the context of a transport model. The apparent factors that determine the degree of recruitment success, measured as the strength of the index of recruitment, are oceanic and wind induced currents and the swimming ability of the post larval fish. In general, the transport model indicated that in years of stronger transport there is greater recruitment and settlement of juvenile Australian herring east of the Great Australian Bight; while in weaker years there was a stronger pulse of juveniles collected west of the Great Australian Bight. This exploratory model provides the first attempt to develop an index of recruitment for Western Australia and South Australia and to bring together the influences which account for recruitment success.

As a part of the juvenile Australian herring monthly recruitment sampling program the influence of diel variation was examined at two key locations, Koombana Bay in Western Australia and James Beach in South Australia. The day and night sampling program indicated that in Western Australia the young of the year fish are more abundant during the day and there are few 1+ and older fish. In contrast, there was no difference in the abundance of young of the year between the day and night samples at James Beach and the 1+ and older fish were more abundant during the night. The day-night pattern of habitat use may be site specific.

The movement pattern of Australian herring and the underlying stock structure was examined using three techniques. These techniques are mark/recapture, allozyme electrophoresis and stable isotope analysis of otolith carbonate. Approximately 10,000 Australian herring were tagged in the autumn of 1997 and 1998. Fish were tagged at two sites on the south coast of Western Australia in 1997 and one site on both the south coast and west coast of Western Australia in 1998. The fish showed both local movements with recaptures from the site of release, or large movements to the west and northward along the WA coastline. The allozyme electrophoresis was conducted on Australian herring sampled from sites along its geographic range and revealed only one polymorphic locit, supporting a premise of little genetic subdivision. Stable oxygen isotope analysis of otolith carbonate demonstrated that the fish did not have the chemical signature of the water where they had been captured, but were similar to fish which had spent their lives in colder water such as found in the south part of Australia. This indicates that Australian herring are migratory and probably move from the south east to the south west of Australia. These three techniques suggest that Australian herring form one biological stock across their geographic range.

The stock assessment of Australian herring relies on data collected and collated from the present study, as well as other historic fishery information. The vulnerability of Australian herring to capture was investigated in the stock assessment models as selectivity functions. From all available data two models have been developed, one for the west coast of Western Australia and one for the southern coast of Australia. It was recognised that further enhancement of the models were necessary as the results from testing the models with data were inconclusive. Further development of the models will be undertaken by Fisheries Western Australia. The models will be used by Fisheries Western Australia and South Australia Research and Development Institute on an annual basis to assess the status of Australian herring.

BACKGROUND

Australian herring supports a valuable commercial and recreational fishery along the extensive Western Australian and South Australian coasts. During the past four years, the average annual value of the annual commercial catch of Australian herring in Western Australia was $0.6 m, and in South Australia it was $0.3 m. Historically, most of the commercial Western Australian catch has been taken to supply the Western rock lobster fishers with bait, while the South Australian catch goes to the fresh fish market. Further, Australian herring is the most sought after recreational species in Western Australia, and is amongst the top recreational species in South Australia in general, and the most important for the jetty and wharf recreational fishers. The recreational catch is currently valued at $112 m in Western Australia (Lindner and McLeod 1991; FRDC WA 93/080). Australian herring has been identified as the first research priority species by the Western Australian Recreational Fishing Advisory Committee (RFAC).

The Western Australian commercial fishery for Australian herring involves 21 licensed fishing teams, who operate trap nets along the south coast, and a further 13 teams which operate beach seines along the lower west coast. Historically, the status of the Australian herring fishery in Western Australia has been evaluated using commercial catch data. The annual Western Australian commercial catch from the Australian herring trap net fishery along the south coast represents about two-thirds of the total commercial catch of Australian herring in Western Australia. The commercial catch from the trap net fishery decreased from a peak of *ca* 1,600 tonnes in 1991 to *ca* 600 tonnes in 1994/95. A similar dramatic decline was experienced in both the South Australian and Victorian commercial haul net and gill net fisheries. The South Australian commercial catch declined from a peak of 500 tonnes in 1987/88 to 275 tonnes in 1994/95. This fishery supports 150 hauling net fishers who take Australian herring as part of their multi-species catch mainly in the Spencer Gulf and Gulf St. Vincent. In Victorian waters, catches of Australian herring fell from 35 tonne in 1965/66 to 5 tonne in 1994/95.

Preliminary analyses of recreational catch data from our FRDC Australian salmon and herring creel assessments (FRDC WA 93/39) have determined that Australian herring comprise *ca* 50% of the overall catch taken by recreational anglers on the south-west coast of Australia. The recreational component of the Western Australian catch of Australian herring was 25.6 % and 15.3% of the total Australian herring catch during 1994 and 1995 respectively. The estimated recreational catch from Gulf St Vincent in South Australia from boat anglers during 1994/95 was 50 tonnes. Since the mid 1990's the annual commercial catch from Western Australia increased to approximately 1000 tonnes before declining to 700 tonnes in 1998. South Australian annual commercial catches have remained below 350 tonnes through 1998. Declines in the annual commercial catch from each state and rising recreational fishing participation raised concern over the sustainability of the stock and prompted the development of the present collaborative research study.

At the outset of this research project, the biological paradigm we were investigating was researched originally by Lenanton (1978) and researchers at Fisheries Western Australia. (WFRC 1973).[1] Research suggested that Australian herring spawn off the lower south-western corner of Australia, and possibly as far east as the waters off South Australia. Many larvae settle on the lower west coast of Western Australia, while the majority are transported eastwards by the Leeuwin Current, with some larvae being transported as far as Victorian waters. A 15 year juvenile recruitment survey of Australian herring into South Australian waters (Adelaide region) has shown that the variability in the recruitment strength may be explained in part by the strength of the Leeuwin Current (see Report on 1995 National Workshop on Australian salmon and herring). This is consistent with the results of earlier work that showed that the strength of recruitment of juveniles of the closely related Australian salmon into South Australian waters is also related to the timing and strength of the Leeuwin Current and differing meteorological conditions (Lenanton *et al.* 1991). Australian herring remain in these waters until they approach maturity, at which time some Australian herring migrate westwards from South Australian waters to the south and lower west coast of Western Australia (Western Fisheries Research Committee 1973). In this regard, the extent to which Australian herring stocks off the lower west coast of Western Australia are dependent on the movement of fish from the south coast has always been a key management issue.

The approach of this research was to collect data on biological variables and stock characteristics, such as age and size composition, reproductive biology, fecundity and source of recruitment, in order to develop a stock assessment model for this popular fish species

NEED

As a consequence of the recent significant pilchard mortality experienced throughout the waters off southern Australia, the supply of imported fresh bait to sectors of the fishing industry, such as the Western rock lobster industry, may cease due to the need for more stringent quarantine regulations. This would exert a huge additional pressure on existing local bait supplies, the key one of which is Australian herring. Since commercial catches have declined in Western Australia and South Australia, and the fishing pressure exerted by the large and expanding population of recreational fishers across south-western and southern Australia has increased, there is an urgent need to more precisely determine the status of the Australian herring stock.

It has not been possible to develop a predictive stock assessment model for Australian herring due to the high levels of uncertainty surrounding important model parameters, such as age structure, growth and reproductive variables. Refining model parameters will involve collecting the appropriate biological information in both Western Australia, South Australia and, to a lesser extent, Victoria.

[1] This is based on information contained in a restricted publication entitled 'Documents Relating to a Scientific Workshop on Salmon and Herring at Watermans on December 14 and 15, 1972' which was

A large part of the stock assessment exercise is the need to determine whether fishing or factors independent of fishing, i.e. environmental factors such as the Leeuwin Current and meteorological conditions, have caused the declines in commercial catches currently being experienced throughout the range of this species. Additionally, an ability to be forewarned of the likelihood of poor recruitment to the fishable stock, and how it might subsequently affect the breeding stock would be most beneficial to managers. Because of the varied exploitation strategies, an index of the magnitude of the breeding stock may be difficult to determine. Quite apart from the modelling process, an index of juvenile recruitment is a useful management tool in its own right. Juvenile recruitment indices for Australian herring (and Australian salmon) developed by the South Australian Research and Development Institute (SARDI) over recent years are promising forecasters of subsequent recruitment into the fisheries. The development of a more useful ongoing index of recruitment of immediately post-settled juveniles, first requires rigorous evaluation of methodology; including site evaluation, sampling design and statistical analysis.

Within Western Australian waters, areas of peak juvenile abundance have been well established from about 1200 beach seine samples taken over recent years at marine shoreline sites throughout the range of the distribution of the species. Before a long-term cost effective sampling strategy can be developed, a few years must be spent on rigorous evaluation of all available design options.

Although Australian herring is known to migrate from South to Western Australian waters, the extent to which this migration extends up the lower Western Australian coast is not known. There is thus a need to determine the degree to which fish originating from the south coast contribute to the fishery on the lower west coast. Such data would help elucidate if the trap net fishery on the south coast is having a deleterious effect on that of the lower west coast. Our proposed research follows directly from our current FRDC-funded Australian salmon and herring creel assessment project, which is elucidating the degree to which Australian herring and salmon are important to the recreational fishing sector.

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prepared to meet the needs of the Western Fisheries Research Committee, Department of Fisheries and Fauna, Western Australia, and issued in Perth in 1973.

OBJECTIVES

1. Determine the age structure, growth, and reproductive biology of Australian herring and the source of recruitment to the Western Australian fishery.

2. Determine whether fishing or factors independent of fishing (i.e. Leeuwin Current) have caused the decline in commercial catches currently being experienced across the range of this species.

3. Develop a more useful, ongoing index of recruitment of immediately post settled juvenile Australian herring (and other recreationally and commercially valuable species, i.e. Australian salmon) that settle into shoreline nursery areas between Geographe Bay in Western Australia and the Coorong Estuary in South Australia.

4. Determine the movement patterns of Australian herring and their vulnerability to capture by Western Australian commercial and recreational fishers.

5. Develop an age structured spatial model to assess the status of Australian herring stock, using the biological and tagging information gathered during this study.

RATIONALE AND APPROACH

The present study was designed as an extensive examination of the biology and fishery for the Australian herring throughout most of its geographic distribution. As such, a collaborative research program was designed between Fisheries Research, Fisheries Western Australia; South Australian Aquatic Sciences Division of the South Australian Research and Development Institute (SARDI) and Murdoch University.

This report is presented in 8 chapters each dealing with one or more of the stated objectives. Each chapter begins with the objective and a short abstract. Chapter 1 is an historic overview of the commercial and recreational fishery in Western Australia and South Australia. This chapter was prepared to provide the background for the rest of the report.

CHAPTER 1. A DESCRIPTION OF THE COMMERCIAL AND RECREATIONAL FISHERY FOR AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*) IN SOUTHERN AUSTRALIAN WATERS – HISTORY OF DEVELOPMENT, METHODS OF CAPTURE AND VALUES

G. K. Jones and S. G. Ayvazian

Western Australia.

Description of the commercial fishery and its history of development

Ever since the early years of colonisation, small catches of Australian herring (*Arripis georgiana*) have been made in WA using set and haul nets in the estuaries and off the beaches of the west and south coast of Western Australia (see review of the development of the WA Australian herring fishery; Walker and Clarke 1987). In 1947 the first regulations concerning the commercial take of Australian herring were instigated, and these were operating rules for the hauling net fishery around the Bunbury Breakwater (Walker and Clarke 1987). Up to 4 netting teams had operated there at any one time and had come into conflict. Rules were introduced as a condition on the licence concerning the priority of netting (shots) and the operation of the shots.

However, it was not until the mid 1940's when a beach seine fishery for Australian salmon between Bremer Bay on the south coast and Perth was begun, that Australian herring catches started to increase, as they were taken as part of this fishery in varying amounts depending on the size of the Australian salmon catch. Thus, in years of high Australian salmon catches, Australian herring catches were low, and vice versa. During the 1950's and 60's, the major proportion of Australian herring caught in these beach seines was canned and the remainder sold on the fresh fish market. Canneries operated at Mandurah and Albany during these years, and the demand for canned Australian herring was considered to control the size of the Australian herring catch during these years (Walker and Clarke 1987). In 1953, the first Australian herring trap was used at Cheynes Beach.

It was also during this time that rock lobster fishers began to net Australian herring for bait around Rottnest Island, but there are no records of their catches. In the early 1960's, conflict between these fishers and recreational fishers began in this area, and between 1964 and 1973 the net fishery was restricted to a seasonal one, occurring between May and July. After 1973, however, netting was totally banned around Rottnest Island, resulting in a geographical shift in the location of the bait fishery for Australian herring to the south coast. Both beach seine and trap nets were used during this period, however, trap nets slowly increased in their importance.

In the early 1970's, an important marketing factor caused fishing effort for Australian herring to increase along the south coast. The price differentials between cleaned Australian salmon, (which occurred on the beaches), and whole Australian salmon declined, thus providing an incentive for Australian salmon/herring fishers to spend more time fishing for Australian herring and using their traps at night. In 1983, it was deemed necessary to control fishing effort on the Australian herring trap net fishery, and the following regulations were put in place.

A) Australian herring trap net useage. Australian herring trap nets were restricted to certain beaches. These were: Bettys, Trigelow, Peaceful Bay, Cheynes, Pallinup, Shelley, Nornalup, Gull Rock, Boat Harbour East, Drage, Goodes, House, Cape Riche, Bremer Bay, Cosy Corner, Parrys, Fisheries, Nanarup, Benderg, Two Peoples Bay, Doubtful Island, Boat Harbour West, McGearys Cove and Dillon Bay Beaches (see Figure 1.1). Also, a ban was placed on the use of trap nets in February and March, and all trap net fishing was restricted to night fishing.

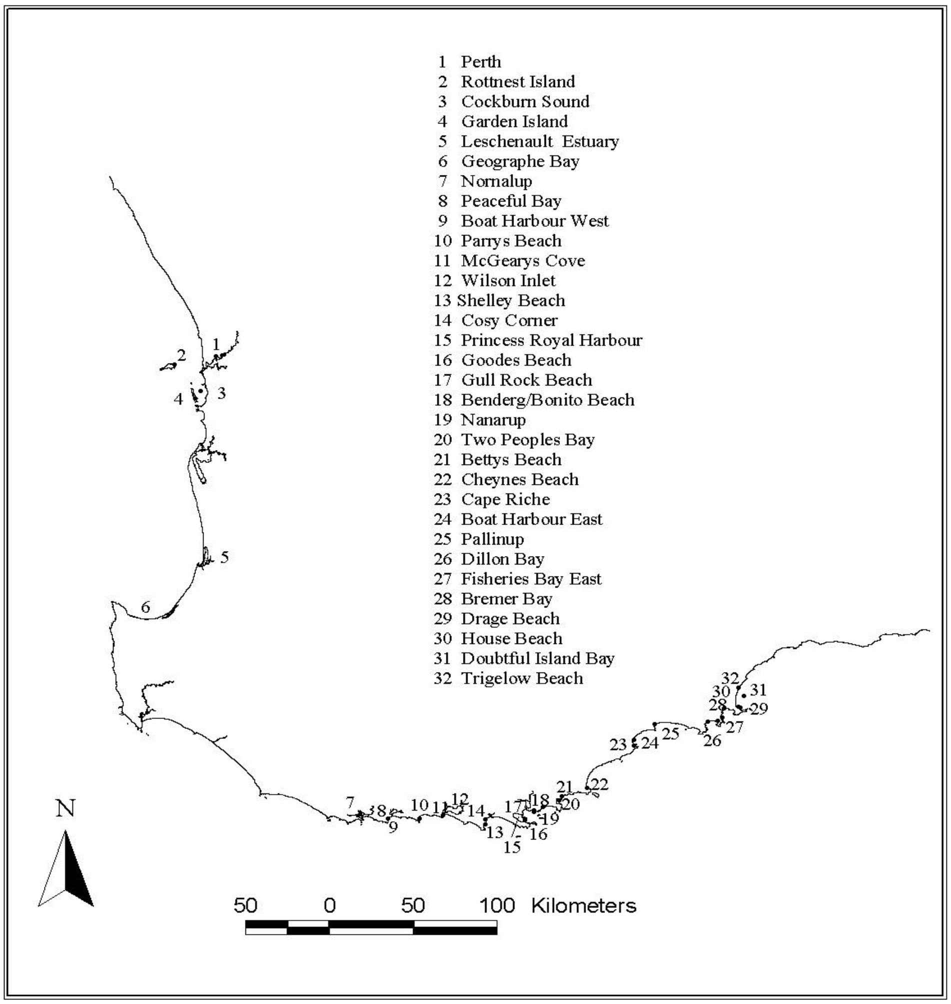

Figure 1.1 Locations of places in Western Australia mentioned in Chapter 1.

B) Entry of fishers into the trap net fishery and a restriction in movement of fishers after the Australian salmon migration to take Australian herring. The commercial capture of Australian herring on a specific Australian salmon beach was permitted only to an authorised holder to April 20th, with only 1 team per beach to operate with a headland between each. Cheyne Beach, Albany was to have a reciprocal agreement between two teams to work as one or work alternate days. However, it was at this time, that the average price for Australian herring increased and Australian salmon prices decreased. Also, the Australian herring season was extended to throughout the year (except February -March for traps). In 1985/86 there were 6 processors in Albany freezing and packaging Australian herring for rock lobster bait.

In 1973, a size limit of 180 mm (total length) was set for Australian herring for the commercial fishery only, and in 1991, a tightening of the regulations applying to Australian herring trap net endorsements took place, with only those fishers with a herring trap net endorsement being permitted to fish with Australian herring trap nets.

In the last several years, 1995/96 – 97/98, there has been a significant decline in the price of Australian herring, possibly due to the increased importation of relatively low priced North Sea herring (*Clupea harengus*) for use as rock lobster bait. In 1999, there are currently reports of Australian herring being discarded from trap nets, and frozen material remaining in the Geraldton freezers from the previous year, thus indicating a current very low demand for commercially caught Australian herring (see Chapter 7).

Methods and areas of capture

Four types of gear are used to take Australian herring by commercial fishers in WA.

A) Set Nets. These vary in mesh size between 54 and 58 mm, and are set overnight predominantly in sheltered bays and estuaries along the west and south coast (Leschenault and Wilson Inlets and Princess Royal Harbour). More recently, they have been deployed in protected ocean waters as well. On occasions, Australian herring schools are encircled by these nets, with the Australian herring becoming enmeshed. Usually it is possible for one fisher to operate and haul a set net.

B) Beach Seines. These are shot from the shore using rowed dinghies. The nets range in length between 200 and 500 m and their depth varies according to the depth of beach fished. Mesh sizes are similar to those used in the Australian herring trap nets. Netting teams (usually consisting of two or more persons), wait for schools to move to pre-determined positions, or the teams move along beaches with 4WD, searching for the schools and carrying their gear with them.

C) Hauling Nets. These are modified beach seine nets which are used in Geographe Bay, and are set and hauled onto a boat. The haul net units (usually consisting of two persons) travel along the shore of the sheltered part of Geographe Bay, and the nets are hauled over sand or seagrass beds.

D) Herring Trap Nets. Walker and Clarke (1987) provide an excellent description of the Australian herring trap net and the method of deployment and hauling as far as 1985, and anecdotal information indicates no major changes in the method of operation since then. Usually between 4 and 6 persons operate as a fishing unit. The dimensions (length, greatest depth) vary between different units, depending on the particular beach fished. Between 1982 and 1985, the lengths of the nets varied between 290 and 680 metres, and the greatest depths ranged between 8 and 13 m. Mesh size of the trap nets varied between 2.8 – 4.6 cm. Trap nets are set about sunset and hauled after sunrise, and only are worked in favourable weather conditions. The nets are shot from the beach and set (anchored) in the shape of "6" or "G", with the opening of the "G" towards the migrating school of Australian herring. Usually, about 10 – 20 settings per team occur each season and these occurred in the central region of each bay, however, during the early 1980's, a number of innovations occurred which improved the efficiency of these nets. These innovations included: the introduction of pockets at the end of the trap net, thereby allowing accessibility to smaller sandy beaches, and the ability to fish over rocky bottom.

Description of the recreational fishery and its history of development

There is no single account of the early development of the recreational Australian herring fishery in Western Australia, although it is clear that this species has been a staple of the catch for most anglers. The reason for this is because Australian herring are generally abundant and widespread along much of the lower west and south coasts. Australian herring occur on metropolitan beaches, adjacent to high population areas and are easy to catch by anglers fishing from the beach, rock groynes and jetties. In 1987, it was estimated that 300,000 individuals or 26% of the state's population aged 15 years and over fished with approximately 30 – 39% of anglers targeting Australian herring (Anon. 1987; Van Bueren *et al.* 1996).

The importance of Australian herring as a recreational species has long been recognised. They are categorised as "bread and butter" species by Fisheries WA, along with sea garfish, yellow eye and sea mullet and whiting species. A household survey conducted in 1976 into the seafood eating habits of Australians determined that in metropolitan Perth, Australian herring received the highest score for a fish species eaten during the survey period. The Australian herring had either been caught by a family member or received as a gift from a recreational fisher (Anon. 1976).

The importance of Australian herring to the recreational sector was evident from the early 1960's when conflict arose with commercial fishers netting for Australian herring around Rottnest Island. This lead to the declaration of a complete netting ban around Rottnest Island in 1973. In response to the growing conflict between the two fishing sectors and increased fishing pressure, Lenanton and Hall (1976) studied the recreational fishery in the north and south Perth metropolitan region as well as on Rottnest Island during April through June, 1973. This survey provided the first real indication of the recreational catch and effort for Australian herring. Resource sharing issues over the catch of Australian herring continued through the 1980's and 1990's when the Australian Salmon and Herring Advisory Committee was formed to discuss options to resolve some of the issues. It was felt that the first task was to better understand the recreational catch of Australian herring. The 1994/95 Australian salmon and herring creel survey (Ayvazian *et al.* 1997) surveyed anglers along the south-western coastline. The 1994 and 1995 catch from the recreational sector comprised approximately 5 to 10 percent of the state total catch and Australian herring accounting for 49% of the recreational catch. A recent boat based anglers survey along the west coast during 1996/7 indicated Australian herring were ranked second overall in the total numbers of fish caught, behind all whiting, except King George whiting (Sumner and Williamson 1999).

Australian herring is predominantly a line caught species from shore or boat, with little recreational netting targeting herring. Lenanton *et al.* (1996) conducted an assessment of the effects of recreational netting in selected estuaries from January 1994 to June 1995. This study found that Australian herring comprised less than 1% of the catch in recreational gill nets, with the main target species sea mullet comprising 22% of the catch.

Methods and areas of capture

Rod and line fishing is the most common method used by shore based recreational anglers to catch Australian herring. When fishing from groynes , breakwaters, reefs, rocks and beaches etc. a small float or berley cage is used approximately 2 m above the hooks. Prawns, whitebait, blue sardines, blowfly maggots ("wogs") and even coloured plastic straws are commonly used as bait. Small lures are also popular terminal tackle from boats and rocky headlands. Small chemical lights (cyalume sticks or "glowies") are becoming increasingly popular with fishers targeting Australian herring at night. The chemical light is usually attached to the line 30 to 50 cm above the hook, and are thought to increase the catch of Australian herring while fishing at night from beaches or jetties. Australian herring are caught in WA from the SA/WA border all around the south coast to as far north as Shark Bay, although they are not commonly caught north of Geraldton. The Perth metropolitan beaches, Cockburn Sound and around Rottnest and Garden Islands are very popular fishing spots, in part reflecting their proximity to the comparatively large population of Perth.

Recreational catch, effort and CPUE

A number of recreational surveys specifically aimed at estimating the Australian herring catch in WA waters have been undertaken over the past 25 years. Lenanton and Hall (1976) undertook the first recreational creel survey during April – June, 1973 along the Perth metropolitan (between Two Rocks and Mandurah) coastal waters and Rottnest Island for both shore and boat fishers. Approximately 142 tonnes (711,000 fish) were estimated to have been caught throughout the period, at average catch rates ranging between 2.9 fish / angler hr for shore fishers and 10.9 fish / angler / hr for boat fishers off Rottnest Island. Ayvazian *et al.* (1997) carried out a roving creel survey along the southern and western coast of WA to estimate the catch, effort and CPUE's on Australian herring and salmon by boat and shore based fishers between February, 1994 and June,1996. Table 1.1 provides details of the estimated catch and CPUE's, respectively for Australian herring by region and year for shore and boat based fishers. For 1994 and 1995 the WA recreational herring catch was estimated at 246.9 and 177.2 tonnes, respectively. For both years the major proportion of the catch was taken by shore based fishers, with the west coast waters being the most important area, in terms of catch. With progressive distance from Perth, the catch decreased. Autumn was the main season when highest catches occurred, and this was consistent for both shore and boat based fishers, and winter and summer seasons being the next most important periods.

The catch rates (fish / angler hr) in the fishery were generally the highest along the south coast, with the only exception being during 1995 in the shore based fishery (Table 1.1). For west coast waters, the catch rates between the three years were generally similar (ranging between 0.62 and 1.47 fish / angler hr). However, along the south coast the average catch rates in 1996 for both shore and boat fishers were substantially higher (3.04: shore, 1.65: boat), compared with the two previous years (range 1.21 – 1.6: shore; 1.24 – 1.34: boat).

Between September, 1996 and August, 1997, a recreational survey of the boat based fishery for west coast waters between Kalbarri and Augusta was undertaken, and the results of this survey indicated that 68 tonnes of Australian herring were taken by boats (Sumner and Williamson 1999).

Table 1.1 Summary of catches (tonnes, live wt) and average CPUE (±SE)(kg / angler / hr) of Australian herring by recreational fishers in WA, 1994 – 96 (adapted from Ayvazian *et al.* 1997).

Year	Fishing Platform	West Coast Catch (t)	South Coast Catch (t)	South-east Coast Catch (t)	Total Catch (t)
1994 (Feb – Dec)	Shore	99.9	49.1	19.2	168.2
"	Boat	58.6	13.2	6.9	78.7
1995 (Jan – Dec)	Shore	108.1	37.3	4.2	149.6
"	Boat	24.6	2.5	0.5	27.6
1996 (Jan – June)	Shore	23.8	11.2	NA	35.0
"	Boat	25.7	1.4	NA	27.1

Year	Fishing Platform	West Coast CPUE	South Coast CPUE	South-east Coast CPUE
1994 (Feb – Dec)	Shore	1.40 (0.06)	1.61 (0.08)	1.1
"	Boat	1.23 (0.07)	1.34 (0.12)	1.6
1995 (Jan – Dec)	Shore	1.47 (0.07)	1.21 (0.10)	0.6
"	Boat	0.62 (0.65)	1.24 (0.31)	1.0
1996 (Jan – June)	Shore	1.33 (0.11)	3.04 (0.36)	NA
"	Boat	1.00 ((0.19)	1.65 (0.55)	NA

Value of the recreational fishery

Surveys estimating the expenditure by the recreational fishers have been undertaken in WA (Lindner and McLeod 1991), however, these surveys are considered to be of limited use, especially when comparisons are attempted between recreational and commercial values. Van Bueren *et al.* (1999) carried out a pilot economic survey of the shore based recreational fishery along the Perth metropolitan coastline during the summer of 1997. The aim of the survey was to determine the economic value of the recreational fishery, based on an estimate of the expenditure anglers were willing to pay over and above their trip expenses, (which is comparable to the profits made by commercial fishers). For the purpose of the survey, Australian herring were classed as one of several "bread and butter" species, and the values for this group of species was estimated at 94 c / trip and 14 c / fish.

South Australia

Description of the commercial fishery and its history of development

Australian herring has been an important component of the multi-species net fishery in SA since colonisation. Because of its schooling nature, Australian herring has always been caught commercially by nets, with insignificant landings by line. In the years following colonisation, the net fishery was mainly a beach seine fishery, and there are reports of Australian herring caught in beach seine nets during the mid 1800's from both gulfs (e.g. Moonta Bay in Spencer Gulf and Glenelg, Gulf St.Vincent) as well as Kangaroo Island (K.I.) waters (Wallace–Carter 1989) (Figure 1.2).

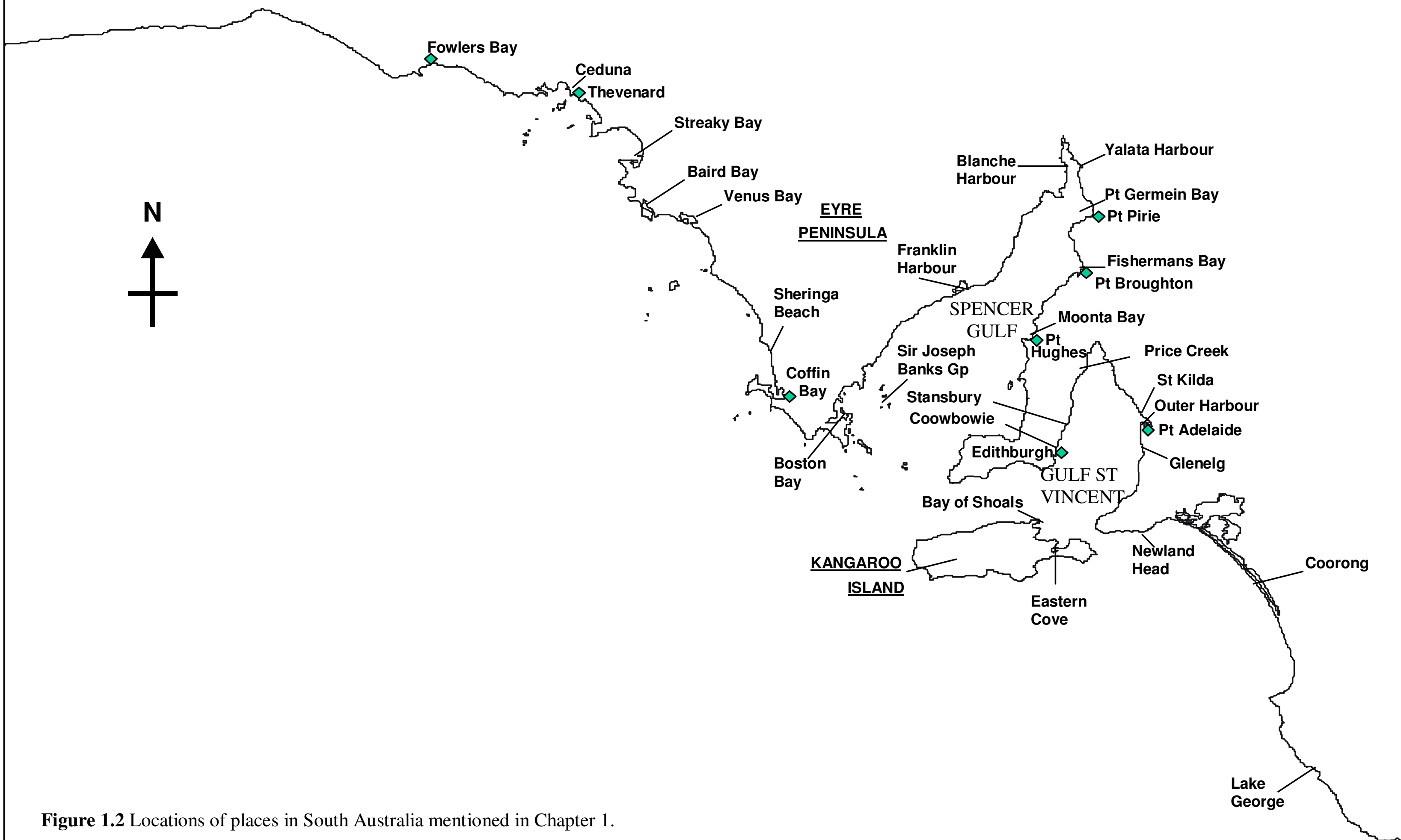

Figure 1.2 Locations of places in South Australia mentioned in Chapter 1.

In 1889, a cannery existed at Eastern Cove, (K.I.) and a number of species including Australian herring were canned; however, there are no records of the total quantities landed throughout the state in the 1800's. Fish caught throughout the state were used to supply local and the Adelaide markets, and fishing cutters initially used to transport fish to the main Adelaide market. During the 1870's railways became important means of transport of fish, not only to the Adelaide, but also Broken Hill (NSW) and Melbourne (Victoria) markets. The relative sizes of the Australian herring catch sent interstate or remaining in SA are not known.

On 12/12/1889, a minimum weight limit of 2 oz (approx. 56 gms) was set for Australian herring for all fishers. Based on current length/weight relationship information this weight is equivalent to a fish of 18 cm, total length. During the 1950's, regulations for minimum lengths replaced those for minimum weights, and a minimum legal length of 15 cm, T.L. was instigated for Australian herring for both commercial and recreational fisheries in SA.

With the decline in the stocks of the native oyster (*Ostrea angasi*) during the early 1900's, many of SA fishers who used to dredge for the oysters transferred their fishing effort to net and line fishing activities (Wallace-Carter 1989). The types of netting used during this period included set netting in shallow water and beach seining. Most of these netting techniques were ones which had already been developed in southern England, from where a substantial number of the SA fishers had emigrated. It was during this time that beach seines began to be hauled in a different manner, with the net being hauled onto a small boat which had originally been used only for setting the net (Wallace-Carter 1989).

Further developments in the net fishery occurred during the 1930's and early 1940's, where there was a dedicated promotion by the government to promote the netting of many of the lower valued species, including Australian herring. This was considered necessary as a means of reducing fishing effort on the more highly valued species such as King George whiting (*Sillaginodes punctata*), and diversifying the operations of commercial fishers. Beginning in the late 1800's, but more importantly, from the 1930's onwards, there was an influx of immigrant fishers from Greece and southern Italy to South Australia, bringing their traditional netting techniques. The lampara net was introduced in the 1920's to take schooling fish species such as Australian herring and garfish. Towns such as Port Pirie (Spencer Gulf), and Thevenard (West Coast) and Port Adelaide (Gulf St. Vincent) were important fishing ports for these fishing communities.

It was in 1936/37 when records of catches of Australian herring were first collected by the Government on a regular basis. For example, the quantity of Australian herring passing through the Adelaide Fish Market varied between 23,500 and 94,000 kg in 1945/46 and 1936/37 respectively, however, it is not known what was the cause of this variation. It was only from 1951/52 onwards that records of the total commercial Australian herring landings in SA were collected. Between 1951/52 and 1971/72, records from fish processors, the Adelaide fish market and railway consignments to interstate markets were used to compile the annual landings for each species, and thereafter, the records from commercial fishers by way of compulsory catch and effort forms were used.

With the development of net fishing throughout west coast and gulf waters during the 1930's and 40's, and the building of a cannery for Australian salmon and herring in Port Lincoln in the early 1940's, Australian herring catches began to rise during the 1950's, and it is suspected that fishing effort also increased. During the 1950's, annual catches in west coast waters (Ceduna – Streaky Bay) were as high as 52 tonnes, with catches in this area comprising up to 30% of the state catch. These levels of landings continued in this area till 1961/62, at which time netting bans were put in place in a number of west coast bays (Ceduna, and parts of Baird Bay and Venus Bay) to protect the livelihoods of line fishers targeting King George whiting. The waters of Coffin Bay, upper Venus and Baird Bay and Streaky Bay continued to be important netting areas, however, because of the relatively low value of Australian herring, and the relatively high costs of transporting fish to the main Adelaide market, catches of Australian herring generally declined in west coast waters. Netting of the higher valued species including King George whiting and snapper and to a lesser extent garfish continued in these bays.

During the mid 1950's, net fishers in the northern Spencer Gulf (Pt. Broughton) developed two more efficient methods of net fishing which caused increased catches of Australian herring in these areas. These methods were called "power hauling", and motorised "drain-off" shots. Before this time, nets were deployed and hauled by a number of methods. These included set nets, where the capture was dependent on moving fish becoming enmeshed – fish were often "splashed", (i.e. the oars were hit on the surface of the water adjacent to the nets, thereby frightening the fish into the nets). Although this method is still used in some areas, the hauling of nets using the power of the vessel's motor is now the main method for capturing netted fish, including Australian herring.

In the northern areas of both gulfs, which are characterised by extensive tidal flats, another method of set netting took place. Nets over 1000 m in length were set in lines on the edges of channels at high waters, and were staked with poles every 100 or so metres. With the ebbing tide, fish moved off the inter-tidal flats and became enmeshed in the set nets. With the development of more powerful motors in the fishing vessels, this method of set netting gradually was replaced by the "double drain-off shot".

In the 1970's a regulation to not allow hauling and small mesh set netting in waters greater than 5 m depth was set, thereby limiting the potential area where Australian herring nets could be used. Also, in the late 1970's, a limited entry policy for managing the marine scalefish fishery in SA was adopted. At about the same time, maximum lengths of hauling nets were set (600 m), as well as minimum mesh sizes (3 cm) for hauling nets and 5 cm mesh size for set and "bait" nets. It was also during this time that further netting closures were put in place – these included the waters of Streaky Bay and seasonal netting closures in Coffin Bay (November – March, inclusive) and upper Spencer Gulf (November – January, inclusive).

As a result of the limited entry policy and non-transferability of netting endorsements in the Marine Scalefish Fishery, there was a decrease in the number of licence holders from 876 in 1977 to 673 in 1988, with a 23 % decrease in netting endorsements.

Some waters of the state had been closed, re-opened and then re-closed to netting on a number of occasions, e.g. the Bay of Shoals, K.I. since the 1920's, with the changes mainly for changing resource sharing reasons.

In 1983, the minimum legal length of 15 cm for Australian herring was abolished by the government, because it was considered that there was little biological reason for it, in the first place. It was also at this time that further netting closures were implemented. These included partial closure of Coffin Bay, Franklin Harbour, Boston Bay, upper Spencer Gulf, Fisherman's Bay, Price Creek and Outer Harbour in Gulf St. Vincent and Eastern Cove, KI. Also, Aquatic Reserves in Yatala and Blanche Harbours and St. Kilda – Chapman's Creek were put in place. All these closures have resulted in a decline in the area where inshore netting can take place.

In 1995, further netting closures were put in place (i.e. all of Coffin Bay and Franklin Harbour), as well as areas adjacent to key recreational fishing areas – Pt. Germein Bay, Edithburgh, Coobowie, Stansbury, Fowlers Bay.

Methods and areas of capture in 1996-98

The largest quantities of herring caught in the net fishery are taken as by-catch to the more highly valued species, including KG whiting, sea garfish, where relatively small quantities are targeted. Therefore the netting methods described are those which apply in general to all netted species in the SA Marine Scalefish Fishery. By legislation, all nets of mesh size less than 15 cm, the maximum length of the net must be 600 m, with a maximum drop of 5 m in the wings and 10 metres in the bunt or pocket. These nets may only be used in water 5 metres deep or less. Further, the use of nets are restricted under licence conditions, where no more than one, mesh, gill, haul or bait net shall be used at any one time. There is no restriction on the use of mono-filament or multi-filament mesh.

A) <u>Hauling nets (including ring, power-hauled and "drain-off" shots).</u>

The main mesh sizes used are 3 cm (multi-ply) and 5 cm (multi-ply and mono). Nets of 3 cm mesh are mainly used for targeting garfish, and a large size range of Australian herring are often taken during these operations. Nets of 5cm mesh are mainly used for targeting on King George whiting and, although no mesh selectivity experiments have been undertaken for Australian herring, observations on the sizes of fish caught in these nets, reveal larger average sizes than those for the garfish small mesh nets. When Australian herring are targeted, and because of the high size dependent schooling behaviour of Australian herring, fishers tend to avoid situations when small Australian herring have the potential for enmeshing in large numbers in either the small or large mesh size nets.

The method setting and hauling nets varies considerably according to environmental conditions, the relative abundance and tightness of schools of fish and the experience of the netter. Power hauling of nets is undertaken by hauling the net through the water with the aid of the engine power of the net boat. First, the bunt end of the net is anchored in water less than 5 m depth, with the remainder of the net being set in a semi-circle. The wing end of the net is then slowly towed by the vessel until the net is closed to a circle. This operation takes about 45 minutes during which time fish caught in the previous net shot are washed, graded and packed in ice. During the towing operation approximately half of the net (nearest the towing vessel) is clear of the seafloor. Once the net has been closed to a circle, the bunt end of the net is then secured to the bow of the vessel, and the net is then retrieved either by hand or through a hydraulic power block or onto a powered drum. As the area inside the circle of the net diminishes, the fish are herded until they swim into the pocket at the bunt end in the case of a 3 cm mesh net, or are meshed when the shot is being completed in the case of a 5 cm mesh net. The total shot takes about 2.5 hours to complete.

Ring shooting, on the other hand (see Figure 1.3) completely surrounds a sighted school of Australian herring and the method of retrieving the net is similar to the power-haul shot. As a ring shot takes less time to complete than a power haul shot, a greater number of shots per day is often possible. Ring shots are generally used for sighted schooling fish whereas power-hauled shots are normally “blind” shots conducted in conditions when fish are not easily sighted. Some net fishers have adapted their nets to become modified purse seine nets, and schools of small Australian herring are targeted using this type of net. Both ring and power haul netting are carried out throughout the state in waters where netting is permitted. A double drain-off shot is carried out by two separately licenced net fishers, who anchor or stake the bunt end of two nets adjacent to each other. The shot is dependent on the movement of the fish off the inter-tidal banks on the ebbing tide, and at the completion of the shot, the nets are hauled in a similar fashion to the power-hauled method. Only one drain-off shot is permitted per day. The drain off shots are generally used by fishers working in the northern waters of Spencer Gulf and Gulf St. Vincent.

B) Gill or set nets.

Set gill nets of 5 cm mesh size continue to be used in a traditional manner by a relatively small number of net fishers to catch Australian herring for bait (either for their long lining or rock lobster potting operations. The maximum length of the nets are 75 m. Nets are usually shot near the shore, and left for up to one hour, while the netter drives the fish into the net by splashing with oars. The fish become enmeshed, and the netter then hauls the net by hand or mechanical means. The quality of the fish taken by set nets are often inferior to that taken by hauling net methods. This method is used in northern Spencer Gulf, Gulf St. Vincent, Kangaroo Island and the south-east of SA.

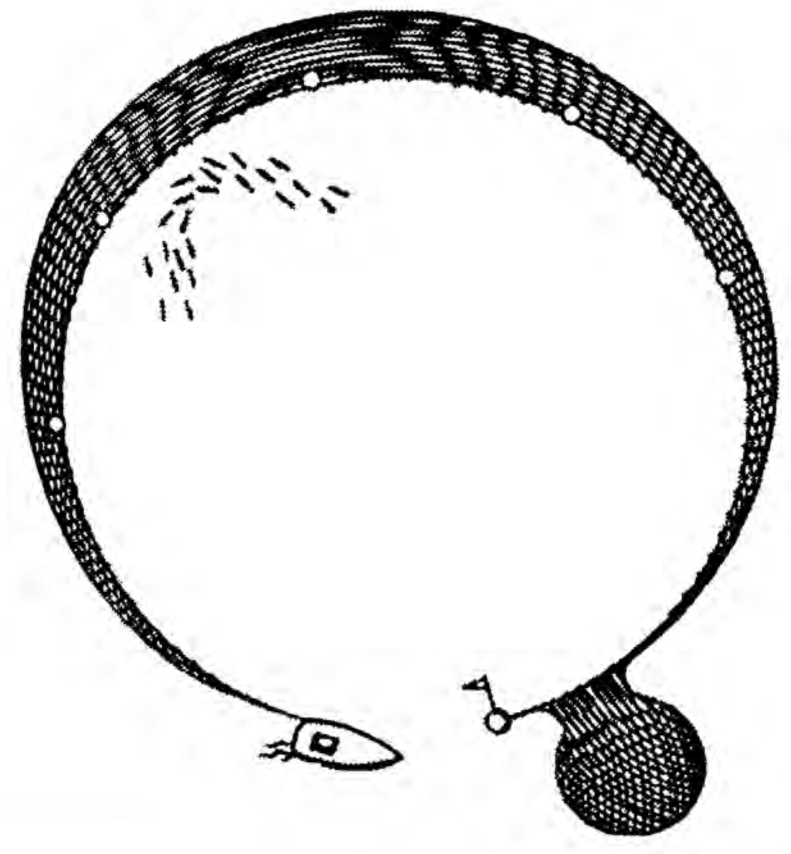

Figure 1.3 Method of ring shooting a sighted school of Australian herring in the SA hauling net fishery

Gross value of production of the commercial fishery

The majority of the Australian herring caught in the commercial fishery in SA has always been for human consumption on the local market. It is generally a relatively low valued species, in comparison with other major species caught predominantly in the net fishery (e.g. sea garfish). It is marketed as whole fresh fish, fresh fillets, or smoked fish. There is often a price differential between small (< 20 cm) and large (> 20 cm) fish, with higher prices for the latter size group. Often, small fish are also sold for commercial and recreational bait for snapper line fishing operations, and there is a minor market for small fish for feeding seabirds (pelicans, penguins, cormorants) and marine mammals (sea lions and fur seals) at Zoos and conservation parks in the vicinity of Adelaide.

While a net fishery existed in Coffin Bay and other west coast bays, a large proportion of the Australian herring caught in these areas was exported to the Melbourne market, where average values always exceeded those on the local market. However, with the closure of the net fishery in Coffin Bay in 1995, this market opportunity ceased. Currently, there is interest in the enhanced grow-out of wild caught Australian herring retained in sea cages, for the development of a gourmet smoked fish market.

Figure 1.4 shows the fluctuations in the total catch, value and average price of Australian herring between 1978/79 and 1997/98, based on wharf prices for fish sold within the state, and therefore, are an underestimate of the true value, as fish sold interstate are not taken into account. Note also that the CPI is not included. During the period, 78/79 – 90/91, the total catch and value generally fluctuated in unison, and the average prices ranged between 56 and 82 c / kg. Thereafter, and until 1995/96, the average price steadily increased to $ 1.30 / kg but has dropped again in the last two years to 98 c / kg in 1997/98 and 1998/99. It is not known how the changes in the average size have influenced the fluctuating values. The value in 1998/99 was $ 314,000.

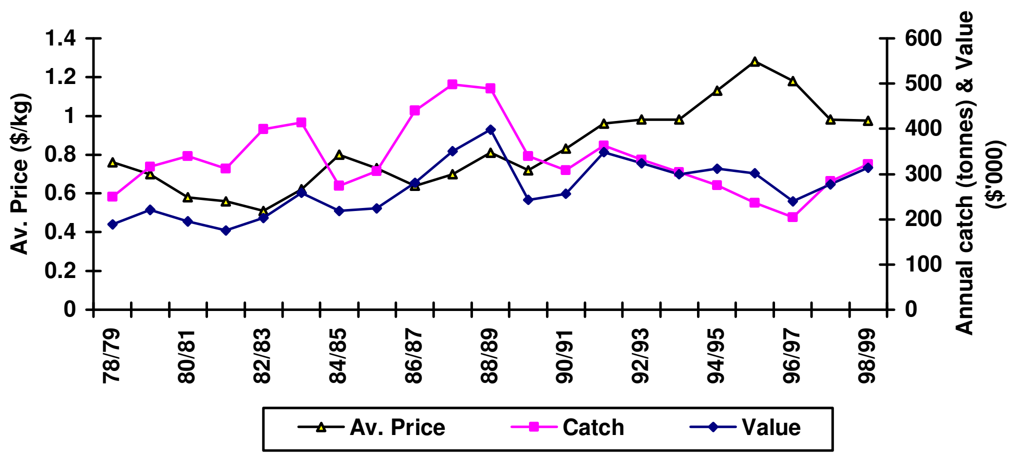

Figure 1.4 Total catch, value and average price of Australian herring caught in the SA commercial fishery, 1978/79 – 98/99.

Description of the recreational fishery and its history of development

Recreational fishing for Australian herring has been reported as early as the late 1800's, when anglers were reportedly taking them from the numerous jetties and piers situated around the SA gulfs.

The species is considered by recreational fishers as one of the four "bread and butter" species taken by the fishery (the others being Australian salmon (salmon trout), garfish and mullet). A number of regional surveys throughout the state during the 1980's highlighted the importance of Australian herring to recreational fishers, and especially to jetty fishers. In a survey of the recreational fishery off the Adelaide metropolitan coast during 1980, Jones (1981) found that Australian herring made up 17% of the catch (numbers) by boat fishers, 43.5% by jetty fishers, and only 2.6 % by shore based anglers. Similarly, in a survey of the Moonta Bay / Port Hughes area of Spencer Gulf in 1986, the Australian herring catch by jetty fishers ranged between 49 and 75% of the total catch on weekends, weekdays and public holidays, whereas the Australian herring catch by boat fishers was less important (2.7 – 13.5%) (Hill 1986). The recreational survey in the Port Lincoln bays during 1985/86 resulted in estimates of the Australian herring catch by boat fishers to be only 9.5% of their total catch, but for recreational net fishers, Australian herring amounted to 47% of their total catch.

For many years there has been an active recreational net fishery in SA marine waters. Before 1983, apart from mesh size regulations (minimum mesh size of 5 cm), and maximum length regulations (75 m), recreational net fishers could utilise their nets both off shore, as well as using them traditionally adjacent to the shore. However, in 1983, regulations were changed to permit fishers with registered netting permits to have one end of the net attached to the shore line, in all waters west of Newland Head. East of Newland Head, essentially the south east of SA, fishers were permitted to use two nets at any one time and away from the shoreline. During the 1980's and early 1990's, there were up to 12,000 recreational nets registered in this state, however, there are no estimates of the total fishing effort expended and catch composition by this sector. From the one survey (Jones 1986), and other anecdotal information, Australian herring were believed to be one of the more numerous species taken. In September 1995, recreational nets were banned from being used in all marine waters of South Australia. The remaining waters permitted for recreational nets now include the Coorong Estuary and Lake George, and anecdotal information from these fisheries indicates that Australian herring are of little significance in catches dominated by yellow-eye mullet (*Aldrichetta forsteri*).

Although the relative proportion of recreational fishers belonging to angling clubs is relatively small in this state (Philipson *et al.* 1986; Cierpicki *et al.* 1997), Australian herring is regarded as an important species taken by this sector. In Southern Eyre Peninsula waters during the national Angling Club Championships during Easter 1981, Australian herring were the second most commonly caught species in the "estuary" (Coffin Bay) and shore (Sheringa Beach) based competitions, but was of minor importance in the offshore (Sir Joseph Banks Gp.) competition. Figure 1.5 shows the differences in the size composition of Australian herring caught in these three areas.

In 1983, the minimum length limit of 15 cm (T.L.) for Australian herring was abolished, and there has never been any bag or boat limit for this species in SA waters.

Current methods and areas of capture

Rod and line fishing is now the only method employed by recreational fishers to capture Australian herring, whether it be from jetties, boats or shore. In jetty and boat fishing operations, because of their relatively small size, the most popular type of gear used to capture Australian herring includes light lines (up to 15 lb BS), up to three hooks (size 8 – 4), a small float approximately 2 m above the hooks and a "berley" spring at the end of the line. The berley spring usually contains a mixture of bread and bran soaked in fish oil. The most common bait used is blowfly maggots, commonly known as "gents". Usually, best catches from jetties are made at night, when the bright lights on the jetties are known to attract schools of Australian herring. Boat fishers with sport fishing inclinations use small lures, and this is also the method most often used by shore based anglers fishing the high energy beaches along the west coast of SA.

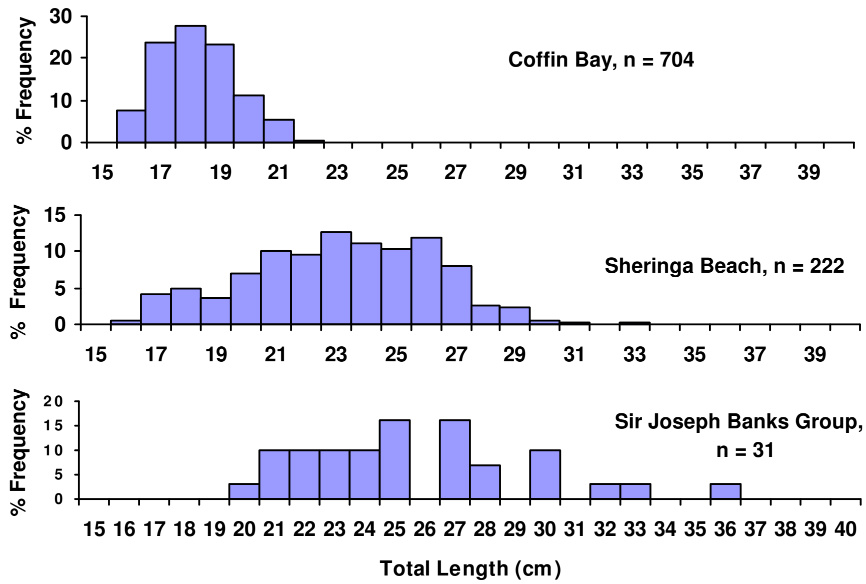

Figure 1.5 Length frequency distributions of herring caught in an inshore bay (Coffin Bay), a high energy beach (Sheringa Beach) and an offshore area (Sir Joseph Banks Group), Southern Eyre Peninsula waters, April, 1981.

Recreational catch, effort and CPUE

During the 1980's and early 1990's, several recreational surveys were undertaken in specific areas of the state. These included short surveys during public holidays to those lasting 12 months, and were aimed mainly for determining resource sharing arrangements within the specific area. The surveys were carried out using a range of methods, including creel surveys at boat ramps and questionnaire surveys to selected fishers. Although they were not aimed solely at estimating Australian herring catch and effort, there were sufficient data on this species to provide some indication of the relative importance of the species within the overall recreational fishery, as well as providing catch rate data for specific areas. Table 1.2 shows the results of these surveys.

The best overall information is available from the 1994 – 96 recreational boat fishing survey (McGlennon and Kinloch 1997) which estimated the annual Australian herring catch by boat fishers for most of South Australia at 35.6 tonnes. There are no comparable estimates for the shore based fishery.

Table 1.2 Summary of the recreational surveys undertaken in specific areas of S.A., with special reference to Australian herring. Data includes catch (tonnes), catch rates (No. fish/angler/hr or No. fish/boat/hr). Key to symbols: /a/hr = No. fish/angler/hr; /b/hr = No. fish/boat/hr; /n/hr = No. fish/net/hr.

Area	Period of Survey	Catch, catch rates in shore fishery	Catch, catch rates in boat fishery	Reference
West Coast.				
Coffin Bay	Easter, 81.	0.36 a/hr	1.23 a/hr	Jones, 1981
Coffin Bay	Jan - Jun. 90	-	1.6 tonnes	Staniford and Siggins, 1992
Coffin Bay	Apr. 95 – Jun. 96	-	1.4 tonnes	McGlennon and Kinloch, 1997
All West Coast	Apr. 95 – Jun. 96	-	5.0 tonnes	McGlennon & Kinloch, 1997
Spencer Gulf				
Pt. Lincoln	Jul. 85 – Jun. 86	7.1 n/hr	0.3 a/hr	Jones, 1986
Pt. Hughes	Mar. – May 85	2.1 a/hr	0.22 a/hr	Hill, 1986
All Spencer Gulf	Apr. 94 – Jun. 95	-	10.0 tonnes	McGlennon & Kinloch, 1997
Gulf St. Vincent				
Adelaide metro	Jan – Dec, 80	0.30 a/hr	0.27 a/hr	Jones, 1980
Adelaide metro	Jul. 90 – Jun. 91	-	0.31 a/hr	McGlennon, 1991
Adelaide metro	Jul. 94 - Jun. 95	-	0.34 b/hr	McGlennon & Kinloch, 1997
All Gulf St. Vincent	Jul. 94 – Jun. 95	-	20.6 tonnes	McGlennon & Kinlock, 1997

Expenditure in the recreational fishery

In similarity with WA, there have been studies on the expenditure by the recreational fishery in SA (see Philipson *et al.* 1986; Cierpicki *et al.* 1997), however, these provide limited information on values of the recreational fishery which can be compared with that of the commercial fishery. Staniford and Siggins (1992) estimated the marginal value of the Coffin Bay recreational boat fishery for the period January – June, 1990 at 29.2 c / fish, with the daily trip costs of 58.1 c / fish. Although the recreational fishery in this area was mainly related to King George whiting, Australian herring made up a significant proportion of the total recreational catch (19%).

Victoria

The commercial fishery

Netting surveys undertaken in the estuaries along the entire coast of Victoria indicate that Australian herring are mainly distributed in waters west of Port Phillip Bay, and are only occasionally observed in eastern waters (McCarraher 1986a–d). The commercial fishery for marine scalefish has been carried out for many years in the Victorian bays and inlets; and in Port Phillip Bay, the most intensively fished of all Victorian bays, for at least 140 years (MacDonald and Hall 1987). As Australian herring in Port Phillip Bay are at their easternmost end of their distribution, they have seldom been the subject of target fisheries, and so the development of the fishery has never been closely associated with this species.

The changes in the catches in the commercial fishery are described in Chapter 7. As Australian herring are a minor by-catch species taken in the predominantly haul net fishery within Port Phillip Bay, effort specifically relating to Australian herring cannot be determined, and so estimates of catch rates are not available for this species in Victoria.

Gross value of production of the fishery

The average price of Australian herring on the Melbourne market between 1990/91 and 1996/97 was $ 1.68 / kg (range $ 2.00 - $ 1.00 / kg). The total value of the commercial landings ranged between $ 34,000 and $ 2,000 during this same period. The figures on the average prices indicate the relatively high average prices at this market compared with the SA and WA markets.

The recreational fishery

The marine fin fish recreational fishery with the largest rate of participation in Victoria occurs in Port Phillip Bay (MacDonald and Hall 1987), with the main target species being sand flathead, King George whiting and garfish. Reports from two series of recreational catch and effort surveys of selected embayments and estuaries in Victoria indicate that Australian herring have rarely been an important species taken by this sector. Surveys were undertaken during the early - mid 1980's in the Gippsland Lakes (Hall and MacDonald 1985), Corner Inlet (Hall and MacDonald 1986), and Port Phillip Bay (MacDonald and Hall 1987), and subsequently followed up approximately 10 years later by similar surveys in the same areas (Conron and Coutin 1995a,b; Coutin *et al.* 1995, respectively). In all these surveys, Australian herring was mentioned only twice: (a) in the Gippsland Lakes : 1979 – 82 and (b) by shore and boat fishers in Port Phillip Bay during 1989 – 94. In the latter case, the catches were so relatively low, the authors amalgamated the Australian herring catches with those of "other species" which in turn comprised 10.6% of the total recreational catch. There are no catch rate data available specifically for Australian herring.

No recreational surveys have been carried out along higher energy coastal or offshore areas of Victoria, and so an estimate of the total Victorian catch of Australian herring by recreational fishers cannot be provided.

Expenditure in the recreational fishery

There are no known economic surveys available for Victorian waters which estimate the economic value of the recreational catch of Australian herring which are comparable with those carried out in WA and SA.

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CHAPTER 2. REPRODUCTION, AGE AND GROWTH OF AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*)

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Objective: To determine the reproductive biology and age and growth of *Arripis georgiana* and the source of recruitment to the Western Australian fishery.

The trends exhibited by reproductive variables demonstrate that the spawning of *Arripis georgiana* is restricted to south-western Australia and that it peaks between late May and early June. This occurs at the time when the Leeuwin Current is strongest, and thus facilitates the dispersal of some larvae and juveniles into nursery areas eastwards along the southern coast of Western Australia and into South Australia. Female and male *A. georgiana* typically first reach maturity at the end of the second or third years of life, when they have reached *ca* 197 and 179 mm, respectively. *Arripis georgiana* is a multiple spawner, producing between *ca* 32000 and 207000 eggs per annum. In south-western Australia, the catches obtained by netting contained an approximately equal number of females and males, whereas those obtained by rod and line contained a marked excess of females, implying that females are more voracious. While the assemblage in south-western Australia contained fish up to ten years of age, it was dominated by the 0+ to 5+ age classes. In contrast, the assemblage in the eastern part of Western Australia and in South Australia consisted mainly of 0+ to 2+ fish. The marked decline that occurs in the number of 2+ fish in South Australia in summer, together with the results of earlier tagging experiments, imply that many two year old *A. georgiana* start migrating towards their spawning areas in south-western Australia at this time. Most of the growth in south-western Australia, where all life cycle stages are present, occurred in the first two years of life. The growth coefficients (k) and asymptotic lengths (L_∞) for female and male *A. georgiana*, derived from the von Bertalanffy growth equation, are 0.813 and 0.992, respectively, and 262 and 239 mm, respectively. The fishery for *A. georgiana* in south-western Australia contains fish that have spent their whole life cycle in that region and also fish that have returned from spending the early part of life further east in Western Australia and in South Australia.

Introduction

The Australian herring *Arripis georgiana* (Valenciennes) constitutes a single stock over the full range of its distribution (see Chapter 6) in coastal marine waters and estuaries between Shark Bay on the west coast of Australia southwards and eastwards to Port Phillip Bay in Victoria (Fig. 2.1; Hutchins and Swainston 1986). This species is highly regarded as an angling fish by recreational fishers and is caught commercially for human consumption and for use as a bait by the fisheries for the rock lobsters *Panulirus cygnus* and *Jasus edwardsii* (Lenanton 1978; Walker and Clarke 1987; Kailola *et al.* 1993; Tregonning *et al.* 1995). From the results of sampling and tagging carried out in the 1950s, it was concluded that *A. georgiana* spawns predominantly to the north of Cape Leeuwin (34°23'S; Fig. 2.1) on the lower west coast of Australia and that the early life cycle stages are transported eastwards to nearshore waters in South Australia and Victoria, which then constitute the main nursery areas for this

species (unpublished data 1973[2]). That work also indicated that the *A. georgiana* found in South Australian and Victorian waters commence their migration back to Western Australia before they become sexually mature. Subsequently, Lenanton (1978) used the gonadal status of the relatively large individuals of *A. georgiana* caught during a four month period by anglers around Rottnest Island (Fig. 2.1), on the lower west coast of Australia, to estimate the peak spawning time and fecundity of this species in those waters. During that study, Lenanton found that the overall catch of anglers was dominated by male fish. However, the reproductive status of *A. georgiana* elsewhere in its wide distribution was not investigated.

The only previous attempts to age *A. georgiana* were those undertaken by Fisheries W.A.[3] (1975) and Lenanton (1978), who, for this purpose, used the number of annuli on the scales of *A. georgiana*. However, it should be recognised that work by Eggleston (1975) on the eastern Australian salmon *Arripis trutta* showed that, while the number of growth zones on the otoliths could be used to age this congeneric species, those on their scales did not produce reliable estimates of the ages of older fish. This raises the possibility that the number of annuli on the scales of individual *A. georgiana* may not always provide reliable estimates of the age of such fish.

The overall aim of the present study was to collect samples of *A. georgiana* regularly from along the coastlines of Western Australia and South Australia in order to elucidate important aspects of the reproductive biology, age composition and growth of this species. In terms of reproductive biology, the aims were to determine (i) the location and timing of spawning and their implications for the patterns of dispersal and migration exhibited by this species, (ii) whether *A. georgiana* is a multiple spawner *sensu* de Vlaming (1983), *i.e.* spawns more than once in a breeding season, (iii) whether there is evidence that the numbers of vitellogenic oocytes in the ovaries of fish just prior to the onset of spawning provide a reasonable approximation of fecundity, (iv) the sex ratios of *A. georgiana* in different regions and whether they are the same in samples obtained by netting and angling and in each of the main age classes, (v) the length and age at first maturity, and (vi) the implications of the results for managing the fishery for *A. georgiana*.

The aims of the present study, in terms of elucidating the age compositions and growth of *A. georgiana*, were to determine (i) whether the number of growth (opaque) zones on the otoliths of *A. georgiana* can be used to age the individuals of this species and whether or not it is necessary to section otoliths to reveal all of those growth zones, (ii) whether the number of annuli on the scales of *A. georgiana* can be used to ascertain consistently the age of the individuals of this species, (iii) the length and age compositions and growth rates of *A. georgiana* in the different regions, (iv) the timing of recruitment of the juveniles of *A. georgiana* into the different regions of Western Australia and

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[1]Data extracted from 'Documents relating to a scientific workshop on salmon and herring at the Waterman laboratory of Fisheries W.A. on December 14 and 15, 1972', prepared for the Western Fisheries Research Committee, Department of Fisheries and Fauna, Western Australia, issued in 1973.

South Australia, and (v) the time of year that the South Australian members of this species typically commence their migration back to Western Australia and the length and age at which this occurs.

Materials and methods

Sampling locations and methods

Arripis georgiana was collected between January 1996 and June 1999 from 143 sites in nearshore, shallow waters along the coastlines of Western Australia and South Australia (Appendices 2.1-2.3). For convenience, sites that were located close to each other have been grouped together and these now constitute the 36 areas shown in Fig. 2.1. Initially, Western Australia and South Australia were each regarded as comprising three regions. In Western Australia, the regions were (i) the lower west coast, with areas 1 to 12, (ii) the western south coast, with areas 13 to 17 and (iii) the eastern south coast, with areas 18 to 23 (Fig. 2.1). In South Australia, the regions were (i) the western region, with areas 24 to 27, (ii) the central region, with areas 28 to 33 and (iii) the eastern region, with areas 34 to 36 (Fig. 2.1). However, analysis of the data obtained for those different regions in Western Australia demonstrated that the trends exhibited by the gonadal variables for the assemblages of *A. georgiana* in the lower west and western south coast regions were the same, but that they differed from those in the eastern south coast region (see Results). Furthermore, the gonadal variables for *A. georgiana* in each of the three regions in South Australia were essentially the same. Thus, for the purposes of this study, the lower west and western south coast regions and the three regions in South Australia are now regarded as comprising just two regions, which are subsequently referred to as the south-western Australian and South Australian regions, respectively.

The juveniles of *A. georgiana* were collected from nearshore, shallow waters using seine nets. The lengths and mesh sizes of the small seine nets that were used in the different regions and the months in which they were employed are given in Table 2.1. Adult *A. georgiana* were obtained by research staff and recreational fishers through angling and by commercial fishers through the use of haul nets, gill nets and long trap nets, the last of which are laid outwards from the beach in the form of a G. Attention was paid to obtaining substantial samples of juvenile and adult *A. georgiana* from each of the three main sampling regions in each month of the year.

The total length and wet weight of each fish caught in each region were recorded to the nearest 1 mm and 0.1 g, respectively, except when the catch was large, in which case the lengths and weights of fish in a large randomly-selected subsample were recorded.

Sea surface temperatures

Mean monthly sea surface water temperatures are provided for four areas on both the lower west and western south coasts of Western Australia between 31°57'S, 115°44'E and 33°56'S, 120°06'E, one

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[2]Data extracted from 'Documents relating to the second scientific workshop on salmon and herring at the Waterman laboratory on October 16 and 17, 1974', prepared for the Western Fisheries Research Committee, Department of Fisheries and Fauna, Western Australia, issued in 1975.

area on the eastern south coast of Western Australia at 33°52'S, 121°54'E and four areas in South Australian waters between 34°44'S, 135°52'E and 35°07'S, 137°44'E. Each of the mean monthly temperatures for an area, which were obtained from the Australian Oceanographic Data Centre (http://www.AODC.gov.au), represent the mean of the water temperatures recorded daily within a 1 km radius in that area.

Reproduction

Gonadal variables

The sex of each *A. georgiana* was recorded, when its gonad could be identified macroscopically as either an ovary or testis. Gonads were removed, weighed to the nearest 0.01 g and, on the basis of criteria similar to that used by Laevastu (1965), assigned to one of the following eight stages: I-virgin, II-maturing virgin/resting adult, III-developing, IV-partially developed, V-prespawning, VI-spawning, VII-spent and VIII-recovering spent. A description of the morphological characteristics of each of the above stages of ovaries and testes and the histological characteristics of the ovaries (modified from Wallace and Selman 1981) are given in the Results (see Table 2.2). Gonadosomatic indices (GSI) were determined for female and male fish ≥ their respective L_{50}s at first maturity (see Results for L_{50}s), using the equation $W_1/W_2 \times 100$, where W_1 = wet weight of the gonad and W_2 = total wet weight of the fish.

Since *A. georgiana* does not become sexually mature in either the eastern south coast region of Western Australia or in South Australia (see Results), the histological studies of ovaries were restricted to samples collected in south-western Australia, where *A. georgiana* does spawn. Ovaries were removed from a random subsample of up to 10 large females from south-western Australia in each month between July 1996 and June 1998. These fish were selected so that they were > 230 mm TL and thus well above the L_{50} for females at first maturity (see Results). The ovaries were placed in Bouin's fixative for 24 h, dehydrated in a series of increasing concentrations of ethanols and embedded in paraffin wax. The mid-region of each ovary was cut into 6 µm thick transverse sections, which were then stained with Mallory's trichrome. The circumferences of 30 randomly-selected oocytes in each ovary were recorded to the nearest 0.1 µm using the computer imaging package Optimas 5.1a, which obtained the image via a Panasonic WV-CD20 video camera attached to an Olympus BH-2 compound microscope. These circumferences, which were recorded only for oocytes that had been sectioned through their nuclei, were then used to calculate the diameters of the oocytes. The stages of the oocytes in sectioned ovaries in sequential monthly samples were examined to ensure that ovaries were assigned to appropriate macroscopic stages. Sections of ovaries from fish caught during the spawning period were examined to ascertain whether individual ovaries that contained post-ovulatory follicles also possessed yolk granule and hydrated oocytes and thereby provided evidence that *A. georgiana* is a multiple spawner *sensu* de Vlaming (1983).

A Chi-squared goodness of fit test (Zar 1984) was used to determine whether or not the overall sex ratios in samples collected by netting and angling and in the different age classes were significantly different.

Table 2.1 Sampling regime for juvenile *Arripis georgiana* conducted by Fisheries Western Australia, the South Australian Research and Development Institute (S.A.R.D.I.) and Murdoch University Fish Research Group during the *A. georgiana* stock assessment project between July 1996 and December 1998. Note: The sampling regimes shown in this table for Fisheries Western Australia and S.A.R.D.I. are those included in their respective juvenile recruitment surveys and the regions and sites referred to are shown in Fig. 2.1 and listed in Appendices 2.1-2.3.

	Recruitment survey	**Additional sampling**
	Fisheries Western Australia	
Region	1, 2 and 3	1 and 3
Sites	All recruitment survey sites	Pinnaroo Point, Warnbro Sound, Koombana Bay and Poison Creek
Sampling frequency	Monthly	Monthly
Sampling period	August 1996 to January 1997, June to December 1997, July to December 1998	August 1996 to December 1998
Method of capture	60.6 m seine*	60.6 m seine
	S.A.R.D.I.	
Region	4, 5 and 6	
Sites	All recruitment survey sites	
Sampling frequency	Monthly	
Sampling period	August 1996 to January 1997, July 1997 to January 1998, July 1998 to January 1999.	
Method of capture	60.6 m seine	
	Murdoch University	
Region		1
Sites		Koombana Bay
Sampling frequency		Monthly
Sampling period		January 1997 to March 1998
Method of capture		102.5 m[#] and 21.5 m[♣] seine

Note: The dimensions of the nets used are as follows:
[*] The 60.6 m seine net comprises two 29.1 m long wings of 22 mm mesh and a 2.4 m long bunt of 8 mm mesh and fishes to a maximum depth of 2 m.
[#] The 102.5 m seine net comprises two 50 m long wings (44.5 m of 25.4 mm mesh and 5.5 m of 19 mm mesh) and a 2.5 m bunt of 9.5 mm mesh, with a drop of 2 m.
[♣] The 21.5 m seine net comprises two 10 m long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m long bunt of 3 mm mesh, with a drop of 1.5 m.

Length and age at first maturity

The lengths at which 50% (L_{50}) of female and male *A. georgiana* became mature and their 95% confidence intervals, were estimated by fitting the logistic function to the percentage contributions of females and males which, in each 10 mm length interval, possessed gonads at stages III to VIII during the spawning period. Fish with gonads at these stages were therefore either undergoing sexual maturation or in spawning condition or had recently spawned. The curve was fitted using a non-linear subroutine in SPSS (SPSS Inc. 1988). The logistic equation is $P_L = 1/[1+e^{(-\ln 19 \times (L-L_{50})/(L_{95}-L_{50}))}]$, where P_L is the proportion of fish with mature gonads at length interval L, and L_{50} and L_{95} are the lengths at which 50 and 95% of fish, respectively, become mature.

The ages at which 50% (A_{50}) of female and male fish first became mature, and their 95% confidence intervals, were determined using the parameters t_0, k and L_∞, derived from the von Bertalanffy growth function and the L_{50}s and their respective 95% confidence intervals (Stergiou 1999). The equation is $A_{50} = t_0 - (1/k)\ln(1 - L_{50}/L_\infty)$.

Fecundity

Whole ovaries, which were macroscopically designated as prespawning, *i.e.* stage V, were removed from 37 female fish caught in south-western Australia during the early part of the spawning seasons of 1997, 1998 and 1999 and whose lengths ranged from 197 to 335 mm. They were placed in Gilson's fluid for three months and shaken weekly to facilitate the breakdown of ovarian connective tissue. The contents of the two ovaries were passed through sieves of 600 and then 212 µm mesh to remove undissolved tissue and small previtellogenic oocytes. The combined wet weight of the yolk granule and large yolk vesicle oocytes retained on the sieve was recorded. The number of these vitellogenic oocytes in three random subsamples of approximately 0.1 g were then recorded and, in conjunction with the total wet weight of these oocytes and the wet weight of the two ovaries, then used to estimate the total number of these oocytes that would have been present in the ovaries. The relationships between this number and the total length, wet weight and age of fish were then determined.

Age and growth

Determination of the appropriate structure for ageing Arripis georgiana

Initially, both of the sagittal otoliths, together with a few scales from an area adjacent to the dorsal fin, were removed from a subsample of 120 *A. georgiana* that covered a wide size range. The otoliths and scales were cleaned, dried and stored in envelopes. Subsequently, the otoliths were placed in a small black dish and covered with methyl salicylate, while the scales were mounted between two glass microscope slides. They were both viewed under a dissecting microscope using reflected light. The otoliths contain a large central opaque core and, in larger fish, one or more opaque annuli, which are subsequently referred to collectively as opaque zones. In contrast, the scales of *A. georgiana* do not possess a comparable central core. The number of opaque annuli on both the otoliths and scales were recorded. Each otolith was then mounted in clear epoxy resin and cut transversely through its primordium into 0.4 mm sections using an Isomet low speed diamond saw. The sections were ground using fine wet and dry carborundum paper (Grade 1200), attached to microscope slides using DePX mounting adhesive and viewed in the same way as the whole otoliths and scales. The number of opaque annuli that could be seen in each sectioned otolith was recorded.

The results of those preliminary studies showed that the number of annuli visible in the otoliths of 120 fish, which covered a wide size range, were the same after sectioning as prior to sectioning. Thus, validation that the opaque zones on otoliths, *i.e.* opaque core and opaque annuli, were formed annually was carried out on whole otoliths. For this purpose, otoliths were removed from all fish, except for those < 80 mm which, from their discrete size distribution, clearly belonged to the 0+ age class. The number of opaque zones were counted in those otoliths in which such zones were clearly defined, which represented 88.7% of all otoliths.

The large central core of the otoliths of *A. georgiana* is laid down during late autumn/early winter, just after the fish have been spawned (see Results) and, for the purposes of validation procedures, is regarded as the first opaque zone. The marginal increment, *i.e.* the distance between either the single or outermost opaque zone (when more than one zone was present) and the periphery of each otolith, was measured. N.B. The marginal increment was only measured when a translucent zone could clearly be seen on the outer edge of the otolith. The marginal increment is expressed as a proportion of the distance between the primordium and the outer edge of the central opaque zone (= core), when this was the only opaque zone present, and as a proportion of the distance between the outer edges of the two outermost opaque zones, when two or more such zones were present. All measurements were made to the nearest 0.05 mm along a straight line extending from the primordium to the posterior edge on the concave surface of the otolith (Kalish *et al.* 1995). The opaque zones on the 120 randomly selected otoliths of *A. georgiana*, that were used for determining the most appropriate hard structure for ageing this species, were so well defined that, in a series of repeat counts, the senior author always recorded the same number of opaque zones for each otolith. However, the number of opaque zones recorded by the senior author in the sample of whole otoliths used above was compared with those recorded for the same otoliths independently by an inexperienced reader of otoliths, to test the degree to which the counts recorded by the author were reproducible by another worker.

Analysis of data

Since the trends shown by the length compositions of the different age classes of *A. georgiana* in each region in each year were essentially the same, the length-frequency data for the different age classes in the corresponding months of each year for each of the three regions have been pooled. The trends exhibited by gonadosomatic indices, the prevalence of the various gonadal stages and the pattern of oocyte development demonstrated that the spawning activity of *A. georgiana* peaked towards the end of May (see Results and Discussion). Thus, a birth date of 1 June was assigned to this species. von Bertalanffy growth curves were fitted to the individual lengths of females and males at their estimated ages at capture by a non-linear technique (Gallucci and Quinn 1979), using a non-linear sub-routine in SPSS (SPSS Inc. 1988). Since fish < *ca* 80 mm TL could not be sexed macroscopically, the lengths at age of these small fish were randomised and allocated alternately to the female and male data sets that were used for constructing length-frequency histograms and for determining von Bertalanffy growth equations. The von Bertalanffy growth equation is $L_t = L_\infty[1-e^{-k(t-t_0)}]$, where L_t is the mean length at age t (years), L_∞ is the mean of the asymptote predicted by the equation, k is the growth coefficient and t_0 is the hypothetical age at which fish would have zero length, if growth followed that predicted by the equation.

The parameters for the von Bertalanffy growth curves of female and male *A. georgiana* in south-western Australia, where all life cycle stages are present, were compared using a likelihood ratio test (see Cerrato 1990). The test statistic for two data sets with sample sizes n_1 and n_2 is given by $-2\log(\Lambda)$, where

$$\Lambda = \left(\frac{\hat{\sigma}^2_{1\,\omega}}{\hat{\sigma}^2_{1\,\Omega}}\right)^{-n_1/2} \left(\frac{\hat{\sigma}^2_{2\,\omega}}{\hat{\sigma}^2_{2\,\Omega}}\right)^{-n_2/2}$$

The null hypothesis is rejected at the α level of significance when $-2\log(\Lambda) > \chi^2$ (q), where q is the number of linear constraints.

Results

Sea surface temperatures

In each region, the mean monthly sea surface water temperature was greatest in February or March, *i.e.* late summer and early autumn, and least in August or September, *i.e.* late winter and early spring (Fig. 2.2). Water temperatures in each month were always higher on the lower west coast of Western Australia than in the western or eastern south coast regions of Western Australia or in South Australia. Although mean monthly water temperatures in the western and eastern south coast regions of Western Australia and in South Australia were similar in December to March, they subsequently diverged. This divergence is reflected in the fact that, by May, they had declined to lower levels in South Australia, *i.e.* 17.1°C, than in either the western or eastern south coast waters of Western Australia, where they were 19.0 and 17.8°C, respectively (Fig. 2.2).

Reproduction

South-western Australia

Gonadosomatic indices and maturity stages

In south-western Australia, the mean monthly GSIs for female *A. georgiana* ≥ the L_{50} at first maturity, *i.e.* 197 mm (see later), rose sharply from ≤ 0.5 between August 1996 and February 1997 to *ca* 1.8 in April 1997 and then to a very pronounced peak of *ca* 3.7 in May, before declining precipitously to *ca* 1.2 in June and 0.7 in July (Fig. 2.3). The same trends were exhibited by the mean monthly GSIs for the corresponding period in 1997/98. Furthermore, while the data were not as comprehensive for the first half of 1996, it is relevant that the mean GSI in May 1996 was at a similarly very elevated level as the mean GSI in that month in both 1997 and 1998. Although the mean monthly GSIs of male *A. georgiana* ≥ the L_{50} at first maturity, *i.e.* 179 mm (see later), displayed very similar trends to those of female fish, they tended to reach their very pronounced peaks slightly earlier, *i.e.* in April in 1997 and in April and May in 1998 (Fig. 2.3). The mean GSI was at a similarly high level in April 1996 as in the same month in 1997 and 1998.

Since the mean monthly GSIs of females and males each followed very similar trends in 1996, 1997 and 1998, and the same was also true for the prevalence of the various gonadal maturity stages of each sex (data not shown), the data for the gonadal maturity stages of fish in the corresponding months in the different years were pooled. The ovaries of all female *A. georgiana* caught in January and February

were at stages I and II (Fig. 2.4). Stage III ovaries, which first appeared in March when they constituted *ca* 44% of all ovaries, were also found in April and May. Stage IV ovaries were relatively most abundant in April and were absent after May, while stage V ovaries were most numerous in May and absent after June. Stage VI ovaries, *i.e.* spawning, were found between April and June. Stage VII ovaries, *i.e.* spent, were present from May to July and, while stage VIII ovaries, *i.e.* recovering spent, were found between May and October, they were only relatively abundant in June and July (Fig. 2.4). Ovaries of all fish in November and December were at stages I or II. Furthermore, the ovaries in samples of large female and male fish collected weekly during May 1999 (data not shown) shifted from belonging mainly to stage V at the beginning of this month to comprising mainly stage VII and VIII at the end of this month. The progressive changes exhibited by the developmental stages of the testes throughout the year paralleled those of the ovaries (Fig. 2.4).

The fact that stage III and IV ovaries and testes declined in prevalence between April and May and were not found in June and July strongly indicates that fish possessing gonads at these stages, just prior to and early in the spawning period, would progress through to maturity later in that period. It was for this reason that the L_{50}s and A_{50}s for *A. georgiana* at first maturity were determined using the percentage contributions made by gonads at stages III-VIII to the total gonadal complement in the different length and age classes during the spawning period. However, most of the female fish that possessed ovaries at stage III in April and May were less than 230 mm, which suggests that some smaller fish do not reach maturity as early in the spawning season as larger fish.

Oocyte stages and diameter frequencies

The oocytes from ovaries of *A. georgiana* caught in the south-western region of Australia in January and February were all less than 150 µm in diameter (Fig. 2.5) and at an early stage in development, *i.e.* they were chromatin nucleolar or perinucleolar oocytes (Table 2.2). Oocytes at these stages of development, which were present in all subsequent months, were represented by well-defined modes of *ca* 65 µm in the diameter frequency distributions for oocytes in each month (Fig. 2.5). The upper end of the distribution of oocyte diameters increased markedly to 480 µm in March, due to the progression of several oocytes through to the yolk vesicle stage and of some to the yolk granule stage (Table 2.2). The increased prevalence of oocytes with diameters > 400 µm and a rise to 675 µm in their maximum diameter in April and May reflected further maturation of the oocytes (Fig. 2.5). Indeed, the largest oocytes in these two months were undergoing the early stages of hydration (Table 2.2). Since the more advanced hydrating oocytes tend to collapse during sectioning (West 1990), it was not possible to obtain accurate measurements of their diameters in sectioned ovaries. Viable yolk vesicle, yolk granule and hydrated oocytes declined in abundance in June and were not found between July and December (Fig. 2.5). The ovaries examined during the spawning period sometimes contained numerous yolk granule oocytes and post-ovulatory follicles (Table 2.2) and occasionally also hydrated oocytes. Although residual yolk vesicle and yolk granule oocytes were frequently found in the ovaries of *A. georgiana* examined in July, these oocytes were undergoing atresia (Table 2.2).

Table 2.2 Characteristics of the stages of development of ovaries and testes of *Arripis georgiana* and the corresponding histological characteristics of the ovaries.

Stage	Macroscopic appearance	Histological characteristics
I Virgin	Gonads are thread-like, transparent and colourless. Ovarian lobes extend only half the length of the body cavity.	Highly organised lamellae, with stage I (oogonia), stage II (chromatin nucleolar) and stage III (early perinucleolar) oocytes present.
II Maturing virgin/ resting adult	Ovaries small and cylindrical; testes flat and ribbon-like. Ovaries and testes pink to grey and translucent. Eggs not visible in ovaries.	Stage I-III oocytes present. Stage III consists of early and late perinucleolar oocytes. These oocyte stages are found in all subsequent ovarian stages.
III Developing	Ovaries and testes becoming enlarged and contain conspicuous capillaries. Ovaries pinkish; testes still translucent, but with an opaque white band along dorsal midline.	Few to many small stage IV (yolk vesicle) oocytes present.
IV Partially developed	Ovaries relatively large, pinkish white and granular in appearance, with oocytes visible. Testes large and white. Testes and ovaries both occupy about two thirds of body cavity.	Small to large stage IV oocytes present. Ovary moderately to tightly packed.
V Prespawning	Ovaries large, white to yellow. Large oocytes visible and tightly packed. Testes large, lobular and white. Large blood-filled capillaries visible in both ovaries and testes.	Stage IV and early to late stage V (yolk granule) oocytes present.
VI Spawning	Ovaries and testes still large. Hydrated oocytes visible through ovary wall. Pressure results in extrusion of hydrated eggs from ovaries and milt from testes.	Few to many stage IV, stage V and stage VI (hydrated) oocytes present. Post-ovulatory follicles sometimes present.
VII Spent	Ovaries and testes flaccid. Brown tinges at ends of ovary and testis lobes. Some opaque eggs remain in ovary and some white milt remains in testes.	Ovaries appear collapsed, have open spaces and sometimes contain post-ovulatory follicles. Remnant yolk vesicle and yolk granule oocytes undergoing atresia.
VIII Recovering spent	Ovaries and testes empty, flaccid and deep red to brown; capillaries still visible. A few opaque oocytes are still visible.	Lamellae not organised as in early stages of development and contain extensive scar tissue. The few remaining vitellogenic oocytes are in an advanced stage of atresia.

Length and age at maturity

During the spawning periods in 1996 to 1999, the ovarian stages increased progressively with size of fish from exclusively stage II in females that were < 170 mm in length to solely stages V-VIII in those ≥ 280 mm (Fig. 2.6). The L_{50} was 196.9 mm (Fig. 2.6), with a 95% confidence interval of 193.8 to 199.9 mm.

The testes of all males, that were < 160 mm in length during the spawning periods in 1996 to 1999, were at stage II (Fig. 2.6). Testes at stages III and/or greater were first found in the 160-169 mm length

class, in which they represented *ca* 11% of all testes, and were attained by 43% of males in the 170-179 mm length class and by over 80% of males ≥ 190 mm (Fig. 2.6). The length at which 50% (L_{50}) of males reached maturity was 179.0 mm (Fig. 2.6), with a 95% confidence interval of 175.0 to 184.4 mm.

The fact that no female or male *A. georgiana* contained gonads at stages III-VIII at the end of their first year of life, demonstrates that neither sex reached maturity at this age (Fig. 2.7). However, the presence of gonads at stages III-VIII in *ca* 54% of females and *ca* 80% of males at the end of their second year of life demonstrates that substantial numbers of both sexes reached maturity when they were two years old (Fig. 2.7). The vast majority of *A. georgiana* that reached the end of the third year of life became mature. The ages at which 50% of females and males became mature were 1.7 and 1.4 years, respectively, with 95% confidence intervals of 1.6 to 1.7 and 1.35 to 1.5 years, respectively.

Fecundity

The commencement of spawning by an individual female *A. georgiana* is characterised by the presence of a few post-ovulatory follicles in a still enlarged ovary. At this time, the oocytes contain a well-defined size category, which comprises oocytes that are mainly < 150 µm in diameter and are previtellogenic, and another discrete group in which the oocytes are mainly at the yolk granule stage and are usually > 500 µm and thus appreciably larger than an intermediate size group, which rarely exceeded 300 µm (Fig. 2.8). The presence of a 'hiatus' between the largest and second largest groups of oocytes suggests that *A. georgiana* essentially has a determinate fecundity, i.e. the potential fecundity is determined prior to the commencement of the spawning season (Hunter *et al.* 1985, 1992). Yet, it must be recognised that several small vitellogenic oocytes are present in the ovaries of *A. georgiana* during the spawning period. However, since most *A. georgiana* spawn within a month (see Discussion), each individual will presumably spawn over an even shorter period. It is thus proposed that the small vitellogenic oocytes present during the spawning season are unlikely to become mature during that season and that they therefore correspond to those several vitellogenic oocytes, which, in fully spent fish, can be seen to be undergoing atresia. For the above reasons, it is concluded that the number of large vitellogenic oocytes in the prespawning ovaries of fish in mid-May (Fig. 2.8) at the commencement of the short and main period of spawning, will approximate to the number of eggs that would have been produced by that fish during the spawning period and thus provide a reasonable approximate value for the fecundity.

The number of large vitellogenic oocytes of *A. georgiana*, with lengths of 197 to 335 mm and weights of ca 94 to 439 g, ranged from ca 32000 to 207000. The corresponding mean values were 247 mm, 179 g and 84700. The relationships between this estimate of fecundity (F) and the total length (TL), wet weight (W) and age (A) of fish, which are each shown in Fig. 2.9, are expressed by the following equations,

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

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

$$F = 18519\ A + 13640\ (r^2 = 0.71,\ n = 33).$$

Eastern south coast region of Western Australia and South Australia

Gonadosomatic indices and maturity stages

The mean monthly GSIs of all females, that were caught in the eastern south coast region of Western Australia and were ≥ L_{50} at first maturity, remained very low, *i.e.* 0.4-0.5, in all months except March and April of 1998 and, even in those two months, they only rose to *ca* 0.6 (Fig. 2.10). Although the mean monthly GSIs of males were similarly low in all months, *i.e.* < 0.4, they did rise to 1.3 in April 1998 (Fig. 2.10). However, the latter GSI was still far lower than the mean of 2.8 recorded in south-western Australian waters in the same month (*cf* Figs 2.3, 2.10).

Ovaries at stage II predominated in fish from the eastern south coast region of Western Australia in all months and constituted all of those examined between June and February (Fig. 2.11). Although a small number of females with ovaries at stages III, IV or V were found between March and May, no stage VI, VII or VIII ovaries, *i.e.* spawning, spent or recovering spent, were found in any month. The trends just described for ovaries were paralleled by those of testes (Fig. 2.11).

The mean monthly GSIs of females and males, that were caught in South Australia between October 1996 and July 1998 and were ≥ L_{50} at first maturity, remained very low in all months, *i.e.* < 0.4 and < 0.2, respectively (Fig. 2.10). The ovaries and testes of all females and males caught in South Australia were either at stage I or II in all months.

Sex ratios for Western Australia and South Australia

The overall ratios of females to males of *A. georgianus* in catches obtained by netting in south-western Australia and the eastern south coast region of Western Australia were 49.8 : 50.2 and 57.8 : 42.2, respectively, neither of which was significantly different from parity (Table 2.3). However, the corresponding ratios for the catches obtained by angling in these two regions were 68.1 : 31.9 and 75.5 : 24.5 and thus showed a marked predominance of females. Chi-square tests showed that these ratios were significantly different from parity. The ratio of females to males in the samples collected by angling in South Australia was 74.6 : 25.4 and thus, as with the samples caught by anglers in both regions of Western Australia, likewise showed a marked predominance of females. However, in contrast to the situation with samples collected by net in both regions of Western Australia, the ratio of females to males obtained by this method in South Australia was far greater than parity, *i.e.* 74.5 : 25.5 (Table 2.3). Chi-square tests showed that the sex ratios of females to males in the samples collected by both angling and netting in South Australia were significantly different from parity.

Since netting would be likely to sample the fish in an area more randomly than would be the case with angling, which would reflect any tendency for one or the other of the sexes to take bait more readily, the sex ratios for the different age classes of *A. georgianus* were calculated using only data obtained by

Table 2.3 Ratios of female to male *Arripis georgiana* in Western Australia and South Australia between January 1996 and May 1999 and their Chi-square significance levels (*** $P < 0.001$), using data obtained for fish caught by netting in nearshore and offshore waters and angling in waters that were generally greater than 2 m in depth.

Region	*Sampling method*	*n*	*Ratio*
Western Australia			
South-west	Netting	3026	49.8 : 50.2
	Angling	2335	68.1 : 31.9***
Eastern south coast	Netting	135	57.8 : 42.2
	Angling	754	75.5 : 24.5***
South Australia			
All regions	Netting	2257	74.5 : 25.5***
	Angling	725	74.6 : 25.4***

Table 2.4 Ratios of female to male *Arripis georgiana* in sequential age classes in Western Australia and South Australia and their Chi-square significance levels (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$), determined using data obtained for fish caught by netting in nearshore and offshore waters between January 1996 and May 1999. Sample sizes (n) are shown in brackets.

	Age class					
	0+	1+	2+	3+	4+	≥ 5+
Western Australia	50.2 : 49.8 (659)	66.4 : 33.6 (431) ***	52.0 : 48.0 (450)	49.7 : 50.3 (342)	51.7 : 48.3 (180)	50.0 : 50.0 (162)
South Australia	58.5 : 41.5 (164) *	76.4 : 23.6 (1075) ***	72.8 : 27.2 (1047) ***	79.2 : 20.8 (24) **	75.0 : 25.0 (8)	

netting. The ratios of females to males in the samples of *A. georgianus* collected in Western Australia were not significantly different from parity in any of the 0+ to ≥ 5+ cases, apart from the 1+ age class, in which it was 66.4 : 33.6 (Table 2.4). This was not the case for the samples of *A. georgianus* collected in South Australian waters, in which the ratios of females to males were significantly different from parity, with females comprising 58.5% of catches in the 0+ age class and at least 72% of the catches in all other age classes (Table 2.4). The ratio of females to males was not significantly different from parity in the 4+ age class, but in this case the sample was small.

Age and growth

Validation of the ageing technique

The mean monthly marginal increments on whole otoliths possessing one, two, three, four and five or more opaque zones each displayed similar trends between August 1996 and June 1998 (Fig. 2.12). Thus, in both 1996 and 1997, the mean monthly marginal increments declined precipitously from at or near their maxima in September (early spring) to their minima in October to December (mid-spring to

early summer), and then gradually increased in the ensuing months. The above pronounced declines in the marginal increment reflect the fact that a translucent zone (~ marginal increment) starts to form at the edge of this hard structure in spring, thereby delineating the opaque zone on its inner edge. Since the marginal increment declines and then rises progressively only once during the year, irrespective of the number of opaque zones on the otolith, a single opaque zone is formed on each otolith each year. The number of opaque zones on the otoliths of *A. georgiana* can thus be used to help age the individuals of this species.

The number of opaque zones recorded independently by a second reader for the sample of 120 otoliths, in which the number of opaque zones varied, was the same as those recorded by the first author in the case of all but one of those otoliths. Moreover, after re-examining that latter otolith, the second reader agreed that she had failed to detect a zone at the periphery of the otolith.

The number of annuli observed on the scales of each of 120 fish was the same as the number of opaque annuli on the whole otoliths of the corresponding fish in only 9% of those comparisons, with these cases always being restricted to instances when only one or two annuli were present (Table 2.5). In all other cases, the number of annuli observed on scales was up to four fewer than the number of annuli on whole otoliths of the same fish (Table 2.5).

Table 2.5 Percentage number of under- and overestimates of the number of annuli on scales *vs* the number of opaque annuli on whole otoliths.

Number of annuli on otoliths	Differences between the number of annuli on otoliths and scales						
	Under and over estimates using scale annuli (%)						
	-4	-3	-2	-1	0	+1	Sample size
1					71	29	14
2			86	9	5		22
3			91	9			23
4		85	13	2			46
5	79	21					14
6		100					1

Length and age composition and growth curves for Arripis georgiana in south-western Australia

Small *A. georgiana* were first caught in nearshore waters of south-western Australia in July, *i.e.* mid-winter, at which time they ranged in length from 30 to 69 mm (Fig. 2.13). Since spawning occurs in late autumn/early winter, these and the other members of the discrete size group of small fish that were captured in August (late winter) and September (early spring), were the product of the most recent spawning season and thus members of the 0+ age class (Fig. 2.13). The 0+ females increased in size during subsequent months, with the result that, by the following April (mid-autumn), their modal length class had increased to 140-149 mm (Fig. 2.13). By October, when the first annulus was becoming delineated on the otoliths of the 1+ age class, the modal length class of that 1+ cohort had reached 180-189 mm, and by May, *i.e.* at the end of the second year of life, it had reached 210-219 mm (Fig. 2.13). The above pattern of change in the lengths of 0+ and 1+ females during the year was paralleled by those of 0+ and 1+ male fish (Fig. 2.13).

The modal length classes of the 2+ and older age classes of female and male *A. georgiana* in south-western Australia were similar, which emphasises that growth is markedly asymptotic. This similarity in size is illustrated by the fact that, for example, in October, the modal length classes of the 3+, 4+ and 5+ age classes were each 240-249 mm for females and either 230-239 or 240-249 mm for males (Fig. 2.13).

The von Bertalanffy growth curves provided a good fit for the lengths at age of both sexes of *A. georgiana* in south-western Australia, except in the case of a few large females (Fig. 2.14). Those latter large female fish, which were generally six or more years old, were greater than 300 mm in length and thus well above the asymptotic length of 262 mm. The likelihood ratio test showed that the growth curves of females and males in south-western Australia were significantly different ($P < 0.001$). In the von Bertalanffy growth equations, the asymptotic length for female fish, *i.e.* 262 mm, was significantly greater than that of male fish, *i.e.* 239 mm ($P < 0.001$), whereas the reverse was true for the growth coefficients ($P < 0.001$) (Table 2.6). Although the values for t_0 for female and male *A. georgiana* were both close to zero (Table 2.6), which is consistent with the good fit provided by the von Bertalanffy growth curves for the length at age data for the small representatives of both sexes (Fig. 2.14), they were still significantly different at $P < 0.001$.

The maximum lengths and ages recorded for female and male *A. georgiana* in the coastal marine waters of south-western Australia were 355 mm and 10 years and 281 mm and 9 years, respectively. However, most female and male fish in this region were less than 280 and 250 mm in length, respectively, and belonged to the 0+ to 5+ age classes (Figs 2.13, 2.14).

The maximum respective lengths and ages of fish caught in the seasonally closed Wilson Inlet, on the western south coast of Western Australia, were 386 mm and 13 years for females and 267 mm and 6 years for males. The latter data were not included in Figs 2.13 and 2.14, because the *A. georgiana* found in this estuary represent an isolated assemblage, in which the individuals grow at a different rate to those in coastal waters outside this estuary and they also do not reach maturity (Pia Orr pers. comm.).

Table 2.6 von Bertalanffy growth parameters, including upper and lower 95% confidence limits, derived from the length at age data obtained for *Arripis georgiana* in south-western Australia.

		von Bertalanffy parameters			r^2	n
		L_∞	k	t_0		
Females	Estimate	261.8	0.813	-0.041		
	Upper	263.1	0.833	-0.028	0.959	2777
	Lower	260.5	0.794	-0.055		
Males	Estimate	238.7	0.992	0.005		
	Upper	239.9	1.018	0.018	0.968	1985
	Lower	237.6	0.966	-0.007		

Length and age compositions of Arripis georgiana in the eastern south coast region of Western Australia and the South Australian region

The catches of female and male *A. georgiana* in the eastern south coast region of Western Australia were dominated by the 0+ to 2+ age classes. Small 0+ *A. georgiana* were first found in nearshore waters of the eastern south coast region of Western Australia in August, but only in low numbers (Fig. 2.15). The modal length classes of the 0+ fish in each month between August and December ranged from 50-59 mm to 70-79 mm and, in the case of both sexes, subsequently increased to 90-99 mm in February to April and 110-119 mm in May. The modal length classes of the 1+ age class of females and males each increased from 110-119 mm in June to 190-199 mm in May, *i.e.* at the end of the second year of life, while those of the 2+ age class in the monthly samples ranged from 200-209 to 230-239 mm for females and from 180-189 to 220-229 mm for males (Fig. 2.15). The maximum lengths and ages of female and male *A. georgiana* in the eastern south coast region were 300 mm and 7 years, and 267 mm and 6 years, respectively.

As in the eastern south coast region of Western Australia, the vast majority of the *A. georgiana* caught in South Australian waters were less than three years old. The 0+ age class of *A. georgiana* was first caught in South Australian waters in September, but only in very low numbers (Fig. 2.16). The modal length class increased from 70-79 mm in October to 80-89 mm in November to January and then more rapidly to 120-129 mm in May (Fig. 2.16). The modal length classes of 1+ females remained between 110 and 139 mm from June to October, but subsequently increased rapidly to reach 190-199 mm in February. The 2+ age class was well represented between June and December, when, in each of those months, the modal length classes were 210-219 mm, after which it declined markedly in numbers (Fig. 2.16). The monthly length-frequency data for male *A. georgiana* in South Australian waters followed very similar trends to those just described for female fish (Fig. 2.16). The maximum lengths and ages of female and male *A. georgiana* in these waters were 339 mm and 8 years and 244 mm and 4 years, respectively.

Patterns of growth in different regions

The trends exhibited by the mean lengths of the different age classes of *A. georgiana* in sequential monthly samples, based on pooled data for 1996, 1997 and 1998, demonstrate that, during the approximately first 18 months of life, this species grew less rapidly in both the eastern south coast region of Western Australia and South Australia than in south-western Australia (Fig. 2.17). However, growth in the former two regions subsequently increased as that in the latter region started to asymptote markedly, with the result that the mean monthly lengths of the fish in each region eventually became similar as the fish reached about two years of age.

Discussion

Reproduction

Spawning location and timing

The considerable numbers of prespawning, spawning, recently spent and recovering spent *A. georgiana*, that were caught between the Abrolhos Islands (area 2, Fig. 2.1) on the west coast of Australia and Bremer Bay (area 17, Fig. 2.1) on the south coast of Western Australia, demonstrate that this species exhibits substantial spawning activity in coastal waters between 28°43'S, 113°46'E and 34°24'S, 119°24'E. Furthermore, the capture, during the spawning period, of one maturing *A. georgiana* in waters near the southern part of Shark Bay (area 1, Fig. 2.1) indicates that spawning may extend as far north as 26°09'S. However, the absence of gonads beyond stage V in any fish caught during and immediately after the spawning period in areas along the *ca* 600 km coastline east of Esperance (areas 18-23, Fig. 2.1) implies that spawning does not extend eastwards into the eastern south coast region of Western Australia. Furthermore, the absence of gonads beyond stage II in any of the large number of fish caught at any time along the South Australian coast demonstrates that *A. georgiana* does not spawn in those waters. Although some large *A. georgiana* were found along the South Australian coastline, the vast majority of those fish were less than three years old and from length at age data would not usually have reached the L_{50} at first maturity at the end of their second year of life. In contrast, a considerable number of three to five year old *A. georgiana* were found in south-western Australian waters and these normally exceeded the L_{50} at first maturity.

The above data, together with the fact that substantial numbers of 0+ *A. georgiana* are found in nearshore coastal waters in both Western and South Australia and this species constitutes a single stock throughout its distribution (see Chapter 6), support the conclusion that, after spawning has occurred in south-western Australia, some of the resultant larvae and juveniles are carried eastwards by the prevailing currents to South Australia, where they then move into nearshore waters, which then act as nursery areas (footnote 1). Those data also provide overwhelming circumstantial evidence that *A. georgiana* start migrating back to south-western Australia before they become mature. The conclusion that this westwards spawning migration of *A. georgiana* is initiated in summer is consistent with the results of tagging work conducted in the 1950s (see footnote 1). That movement would be assisted by the fact that it occurs at a time when the wind-driven currents have changed to a westerly direction (Lewis 1981; Schahinger 1987). The restriction of spawning activity to coastal waters in

south-western Australia and the use of nearshore habitats in South Australia as nursery areas parallels the situation with the Western Australian salmon *Arripis truttacea* (Malcolm 1960).

The mean monthly GSIs of large female *A. georgiana* in south-western Australia underwent in each year a very pronounced rise between March and May and then a precipitous decline to June. This evidence that *A. georgiana* spawns predominantly between the middle of May and middle of June is consistent with the fact that, in May, the proportion of ovaries of large fish that were at stage V, *i.e.* prespawning, was greater than those at stages VI, VII and VIII collectively, whereas by late June the vast majority of the ovaries of large fish were at stages VII or VIII, *i.e.* spent or recovering spent. The above situation with ovaries in June was paralleled by that of the testes of large male fish in that month. The conclusion that *A. georgiana* spawns over a relatively short period is also supported by the fact that the mean weekly GSIs of large females, based on pooled data for all years, rose sharply and progressively from only *ca* 1.5 in the first week of April, to reach a peak of *ca* 4 in the first to third weeks of May, and then declined precipitously and sequentially to < 1.6 in middle to late June. The above trends are consistent with the fact that, in large females, only 13.1% of the ovaries were spent or recovering spent in the third week of May, whereas 82.7% were at these stages in the fourth week of June. However, the presence in April of a very small number of female fish with ovaries at stage VI, and in which some of the more advanced oocytes were undergoing hydration, suggests that a limited amount of spawning is initiated in this month. Since no females or males contained gonads at stages III to VI in July, *i.e.* all gonads were either immature or spent, spawning did not occur after June. This view is supported by the fact that the remnant vitellogenic oocytes found in ovaries in July were undergoing atresia. The above implications that spawning peaks in late May and early June corresponds with the conclusion of Lenanton (1978), based on an analysis of the gonadal status of *A. georgiana* caught in waters around Rottnest Island, off the lower west coast of Australia (Fig. 2.1).

Relationship between spawning time and water temperature

The remarkable similarity exhibited each year by the trends for the maturation of the gonads in south-western Australia, allied with the brevity of the main spawning period, indicate that sexual maturation and spawning are tightly regulated by environmental cue(s). The fact that samples of the small number of larger and older female and male fish that remained in the eastern south coast region of Western Australia and in South Australia were never found to possess spawning, spent or recovering spent gonads suggests that any such environmental cue(s) are not sufficiently strong to induce full sexual maturation in those regions. It may thus be relevant that, during the period of gonadal recrudescence in south-western Australia, *i.e.* March to May, water temperatures were higher in both the lower west and western south coast waters of Western Australia, where spawning does occur, than in either the eastern south coast region of Western Australia or South Australia, where spawning does not occur. Furthermore, while the gonads of some fish in the eastern south coast region of Western Australia did progress through to stage V, those of the large fish caught in South Australia, where water temperatures were far lower, never developed beyond stage II. Thus, although gonadal maturation and spawning both occur at the time when water temperatures are declining, successful maturation of the gonads may still depend on water temperatures remaining above a certain critical level.

In his review of environmental influences on gonadal activity of fish, Lam (1983) concluded that water temperature was the environmental variable that exerted the most influence on the time of spawning. It thus appears highly relevant that *A. georgiana* spawns in late autumn/early winter, when the water temperature is declining most markedly (Fig. 2.2). Although, in the same waters, the congeneric *A. truttacea* spawns slightly earlier, *i.e.* in the middle of autumn (Malcolm 1960), and *Sillaginodes punctata* slightly later, *i.e.* in winter (Hyndes *et al.* 1998), these two species also spawn when water temperature is declining. In south-western Australia, the mugilids *Mugil cephalus* and *Aldrichetta forsteri* spawn over a very protracted period between early autumn to late winter or early spring (Chubb *et al.* 1981), which thus encompasses the very brief spawning period of *A. georgiana* and during which water temperature is declining. The periods when the above species spawn contrasts with those of other teleosts in south-western Australian estuarine and coastal waters, such as *Nematalosa vlaminghi*, *Apogon rueppellii*, *Cnidoglanis macrocephalus*, *Platycephalus speculator*, *Amniataba caudavittata*, *Sillago burrus*, *S. vittata*, *S. schomburgkii* and *Acanthopagrus butcheri*. These species each exhibit peak spawning activity at some time between the middle of spring and end of summer, when water temperatures are either rising or near their maxima (Chubb and Potter 1984; Chrystal *et al.* 1985; Nel *et al.* 1985; Hyndes *et al.* 1992, 1996; Potter *et al.* 1994; Hyndes and Potter 1997; Sarre and Potter 1999). The above comparisons demonstrate that, as in temperate waters of the northern hemisphere (Lam 1983), any triggers provided by water temperature for fish to spawn in the coastal marine and estuarine waters of south-western Australia vary greatly amongst species. Furthermore, since *A. georgiana* and *A. truttacea* spawn in late autumn/early winter, whereas *Arripis trutta*, which is found in south-eastern Australia, spawns between late spring and late summer (Stanley and Malcolm 1977), the trigger(s) for gonadal recrudescence and spawning can vary markedly even amongst members of the same genus. In the case of the above *Arripis* species, such differences are apparently related to adaptations for life in different environments and, in particular, to those which ensure the optimum dispersal of their larval and juvenile stages.

Although the adults of *A. georgiana* mainly occupy coastal marine waters, some are found in Wilson Inlet on the south coast of Western Australia. Since this estuary becomes closed during summer (Hodgkin and Clark 1988), the large representatives of this species are prevented from migrating out to sea in the months immediately prior to the period when spawning occurs in coastal waters. It is thus relevant that the gonads of none of these fish progressed beyond the prespawning condition, *i.e.* stage V, and histological studies showed that the yolk vesicle and yolk granule oocytes in ovaries of female fish caught in late June, *i.e.* at the end of the period when spawning occurs in marine waters, were undergoing resorption. This parallels the situation with the mugilids *M. cephalus* and *A. forsteri* when these species become landlocked in estuaries (Wallace 1975; Chubb *et al.* 1981). Thus, as with these two species, *A. georgiana*, which likewise uses estuaries as a nursery area (Lenanton 1982; Valesini *et al.* 1997), requires marine conditions for successful spawning.

Spawning frequency and fecundity

Since several of the ovaries of *A. georgiana* examined in late May and early June contained post-ovulatory follicles, together with numerous yolk vesicle and yolk granule oocytes and some hydrated oocytes, there is strong circumstantial evidence that *A. georgiana* is a multiple spawner, *i.e.* its females spawn on more than one occasion in a breeding season (see de Vlaming 1983). This parallels the situation with the closely-related *A. truttacea* and *A. trutta* (Malcolm 1960; Stanley and Malcolm 1977). Since *A. georgiana* has a short breeding season, the bouts of spawning activity by individual females of this species are presumably separated by at most a few days.

The evidence that *A. georgiana* is a multiple spawner emphasises that a reliable estimate of the fecundity of this species cannot be obtained solely by counting the number of hydrated oocytes on a single occasion. The fecundities estimated for *A. georgiana* during the current study represent the number of large vitellogenic oocytes found in ovaries examined just prior to the commencement of the spawning period. Our resultant mean fecundity of *ca* 84700 approaches that of Lenanton (1978), who derived his estimates using the number of oocytes that were > 0.4 mm in diameter during the spawning period.

Sex ratios

Although the sex ratios of all age classes that were caught by netting, apart from that of the 1+ age class, were essentially parity, this did not apply to the fish that were caught by angling and which were predominantly represented by the 2+ and older age classes. The predominance of females in angling catches thus suggests that, amongst the larger fish, the females are more voracious than male fish. The greater number of females than males in the samples of 1+ fish in south-western Australia is probably attributable to the fact that, at this age, the female fish are larger than male fish and are thus more likely to be retained by commercial fishers as these fishers use a mesh which allows smaller fish to escape, and, in addition, commercial fishers tend to select fish greater than 180 mm in length. While the sex ratios in catches obtained by angling in the eastern south coast region of Western Australia and South Australia were similar to those in south-western Australia, the reasons for the predominance of females in commercial catches in South Australia is unknown at this time.

Length and age at maturity and management implications

Our data demonstrate that female and male *A. georgiana* typically reach maturity (L_{50}) at lengths of *ca* 200 and 180 mm, respectively. They also demonstrate that, while *A. georgiana* do not reach maturity at the end of their first year of life, over 50% of females and *ca* 80% of males reach maturity by the end of their second year of life. From the catches of *A. georgiana* provided to us by recreational fishers, it is evident that the recreational sector removes some females and males that are less than their respective L_{50}s at first maturity. Furthermore, the minimum legal length (MLL) of 180 mm for capturing *A. georgiana* by commercial fishers in Western Australia is below the L_{50} at first maturity for the females of this species and there is no size limit for the commercial fishery for *A. georgiana* in South

Australia. However, it should be recognised that, since many *A. georgiana* live for up to six years and some for up to eight years, such fish would presumably spawn during a number of breeding seasons.

Although the bag limit of 40 *A. georgiana* imposed on recreational fishers in Western Australia is rarely achieved (Roennfeldt 1997), the numbers of recreational fishers in this state and elsewhere in southern Australia are increasing rapidly. This point is illustrated by the fact that, between 1987 and 1998, the estimated number of people involved in recreational fishing in Western Australia increased from *ca* 300000 to *ca* 600000 (N. Sumner, Fisheries W.A., pers. comm.). It should also be recognised that commercial fishers on the south coast of Western Australia target in particular, the large *A. georgiana* that are moving westwards in that region immediately prior to and during the commencement of the spawning period. Since, at that time, these fishers place long trap nets, which form a G outwards to approximately 300 m from the shoreline, they capture large numbers of fish that would have been about to spawn. Thus, if the increase in recreational fishers and the collection of prespawning fish by commercial fishers were eventually to lead to a marked decline in the abundance of *A. georgiana*, there would be a case for introducing a MLL for fishers, that would increase the likelihood of fish reaching sexual maturity, and/or placing a restriction on the use of the long G shaped trap nets by commercial fishers. In the case of the possible introduction of a MLL, a value that approximates to the L_{50} at first maturity would appear to be an appropriate initial step. However, since the number of *A. georgiana*, which are greater than the L_{50} at sexual maturity, is relatively low in South Australia, the imposition of such a MLL for *A. georgiana* in that region would have a detrimental influence on the fishery for this species in that state.

Age and growth

Validation of the use of otoliths for ageing Arripis georgiana

The trends exhibited by the marginal increments on whole otoliths of *Arripis georgiana* with different numbers of opaque zones demonstrated that it was valid to use the number of these zones to help age this species. The first annulus typically becomes delineated on otoliths in the spring of the second year of life, which is the same time as Lenanton (1978) found the first annulus to become delineated on scales. However, we found the annuli to be far less clearly defined on scales than on otoliths, which would account, in part, for the marked lack of correspondence between the numbers of annuli on scales and whole otoliths. This implication that the use of the number of opaque annuli on scales is often likely to lead to incorrect estimates of age parallels, to some degree, the results obtained by Eggleston (1975) for the congeneric *Arripis trutta*. In that south-eastern Australian species, the scales were found to be unsuitable for ageing fish more than five years old, whereas otoliths could be used to age fish of all ages. The problems encountered using scales to age both *A. georgiana* and *A. trutta* suggest that, since *Arripis truttacea*, which has a very similar distribution to *A. georgiana* (Lenanton *et al.* 1991), was aged using the number of annuli on scales (Nicholls 1973), the ages recorded for some fish in that study are likely to be invalid.

Dispersal of larval and juvenile Arripis georgiana

The data on length and age compositions of *A. georgiana* demonstrate that substantial numbers of the 0+ and 1+ individuals of this species use nearshore, shallow coastal marine waters along the west and south coasts of Western Australia as nursery areas (see also Lenanton 1982). Furthermore, other studies have shown that certain estuaries are also used by *A. georgiana* as nursery areas (Potter *et al.* 1997; Valesini *et al.* 1997). The above results contrast, to some degree, with the conclusion reached by earlier workers that the main nursery areas of *A. georgiana* are located in South Australia and Victoria (see footnote 1). However, our data do confirm that numerous small Australian herring use nearshore, shallow waters in South Australia as nursery areas. Since *A. georgiana* spawns on the lower west and western south coasts of Western Australia, and all *A. georgiana* belong to a single stock (see Chapter 6), the juveniles of this species that are found in South Australia must presumably have been recruited from the south-western region of Australia. The location of spawning and pattern of dispersal of *A. georgiana* are similar to those exhibited by the West Australian salmon *Arripis truttacea*. The juveniles of the latter species are recruited into nearshore waters of the lower west and south coasts of Western Australia and along the coasts of South Australia, Victoria and Tasmania (Malcolm 1960; Robertson 1982; Kailola *et al.* 1993).

The dispersal of the larvae and juveniles of *A. georgiana* and *A. truttacea* eastwards to nursery areas in South Australia and even Victoria is facilitated by the fact that spawning occurs predominantly in late autumn and early winter when currents are optimal for aiding such transport. Thus, during that and the immediately following period, the eastwards flow of the Leeuwin Current is at its strongest and is supplemented by wind-driven easterly movements of coastal waters (Godfrey and Ridgway 1985; Schahinger 1987; Caputi *et al.* 1996; Pearce *et al.* 1999). Although *A. georgiana* and *A. truttacea* both spawn within the autumn and early winter period, *A. trutta*, which is restricted to south-eastern Australian waters, spawns in late spring to late summer (Stanley and Malcolm 1977). However, as with the first two species, the timing of spawning by *A. trutta* dictates the pattern of dispersal of the larvae and juveniles of this species. Thus, *A. trutta* spawns in south-eastern Australia at a time when the southwards-moving currents on the east coast of Australia and westwards-moving currents in Victoria are strong and thereby result in many larval and juvenile *A. trutta* becoming transported further south to nursery areas in Tasmania and along the southern coast of eastern Australia (Nicholls 1973; Stanley and Malcolm 1977; Kailola *et al.* 1993). Thus, as with *A. georgiana* and *A. truttacea* in south-western Australia, *A. trutta* spawns at a time when the currents are most likely to aid the dispersal of its larvae and juveniles into the widely-distributed nearshore coastal waters that are utilised as a nursery area by this species.

The vast distance between south-western Australia and the regions where the juveniles of *A. georgiana* were caught in South Australia would account for the fact that substantial numbers of this species were recruited earlier into the former than latter region, *i.e.* August *vs* October. Furthermore, those early 0+ fish, which were recruited into nearshore waters in south-western Australia, would soon have been able to capitalise on the high productivity of those habitats. In contrast, those that are recruited into South

Australian waters would have spent the initial months of life, *i.e.* June to October, being transported eastwards by a combination of the Leeuwin current and wind-driven easterly movements of coastal waters along the south coast (see above). The resultant differences in the type of environment occupied during the first few months of life, and consequently the amount of food that would have been available, could thus partly account for the fact that, in late spring and summer, the juveniles were larger in south-western Australia than in South Australia.

It is proposed that the larvae and juveniles produced by *A. georgiana* that spawn nearest to the coast will be most likely to enter nearby, nearshore habitats, and that this will be particularly the case along the lower west coast of Australia north of Cape Naturaliste (33°32'S, 115°00'E; see Fig. 2.1), where the north-westerly winds, that prevail in winter (Masselink 1996), produce currents that would tend to drive those eggs and larvae shorewards. In contrast, those larvae and juveniles, which are produced a little further offshore and particularly along the south coast, would be more likely to come under the influence of the eastward-moving currents that prevail at that time and thus be carried towards and into South Australian waters.

Spawning migration of Arripis georgiana

The data on age composition demonstrate that a considerable number of *A. georgiana* that are three years or older in age are present in south-western Australian waters, whereas relatively few such fish are found in South Australian waters. Furthermore, the 2+ fish in South Australian waters declined markedly in numbers in mid to late summer, presumably reflecting a pronounced tendency for such fish to embark on their migration towards their spawning grounds in south-western Australia in early to mid-summer. The conclusion that such a migration occurs at this time of year is consistent with the results of tagging experiments (see footnote 1). Such a westerly migration may initially be stimulated by the upwellings of cool water that occur on the coast of South Australia during summer and then be assisted by the shift to a wind-generated westerly movement that occurs in those coastal waters in November and which extends until March (Lewis 1981; Schahinger 1987).

The very strong circumstantial evidence that *A. georgiana* migrate westwards from South Australia to south-western Australia during the summer of their third year of life would also be consistent with the fact that these 2+ fish often exceed 200 mm and are thus longer than the L_{50}s of 197 and 179 mm for the respective lengths of female and male *A. georgiana* at first maturity. However, in contrast, the lengths of most of the 1+ females in these waters at the same time of the year are less than those in south-western Australia, where even there only about half will become mature during the following late autumn/early winter, *i.e.* at the end of their second year of life. The growth undergone in South Australian waters by *A. georgiana* during the second half of the second year of life was particularly rapid, reflecting the use of food resources for somatic growth rather than gonadal development.

A pronounced westward migration of *A. georgiana* as they approach maturity for the first time would account not only for the paucity of this species that are greater than 2.5 years old in South Australian waters, but also for the considerable number of fish that are above this age in south-western Australian waters. The age structure of *A. georgiana* in the eastern south coast region of Western Australia is similar to that in South Australia and the individuals in the former region likewise do not become sexually mature. It is thus assumed that the larger and older *A. georgiana* in the eastern south coast region of Western Australia will contribute to the westwards summer spawning migration of this species.

The migratory movements undergone by *A. georgiana* broadly parallel those of the congeneric *Arripis truttacea* (Malcolm 1960). Furthermore, maturing *A. trutta* also undergo a prespawning migration from their nursery areas in Victoria and Tasmania to coastal waters of southern New South Wales where spawning occurs (Nicholls 1973; Stanley and Malcolm 1977). However, in terms of size, *A. truttacea* and *A. trutta* attain far greater maximum total lengths, *i.e.* 961 and 890 mm, respectively, than the maximum of 411 mm recorded for *A. georgiana* (Hutchins and Swainston 1986). The greater maximum size of *A. trutta* than *A. georgiana* is consistent with the fact that the former species can live for over 20 years (Eggleston 1975; Stevens and Kalish 1998), whereas none of the large number of *A. georgiana* aged during the present study were over 13 years old.

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Appendix 2.1 Sampling localities, site names and approximate latitudes and longitudes and methods used for collecting adult and juvenile *Arripis georgiana* in the lower west coast region of Western Australia. Area numbers listed in this table refer to area numbers shown on Fig. 2.1.

Locality	Site name	Area number	Approximate latitude and longitude	Method
Lower west coast region				
Shark Bay	Steep Point	1	26°09'S, 113°09'E	R
Geraldton	Abrolhos Islands	2	28°43'S, 113°46'E	R
Dongara	Dongara marina	3	29°14'S, 114°56'E	R
Jurien	Jurien Bay	4	30°18'S, 115°02'E	R
Cervantes	Cervantes	4	30°30'S, 115°04'E	R, SO
	Thirsty Point	4	30°30'S, 115°04'E	SO
Lancelin	Lancelin	5	31°01'S, 115°21'E	R
Yanchep	Yanchep	6	31°33'S, 115°37'E	R
Perth	Pinnaroo Point	6	31°48'S, 115°44'E	R, SR
	Ocean Reef	6	31°49'S, 115°43'E	R
	Waterman	6	31°50'S, 115°44'E	R
	North Beach	6	31°51'S, 115°44'E	R
	City Beach	6	31°57'S, 115°44'E	R
	Cottesloe	7	31°59'S, 115°44'E	R
Rottnest Island	Rottnest Island	7	32°00'S, 115°30'E	R
Carnac Island	Carnac Island	7	32°07'S, 115°38'E	R
	Straggler's Rocks	7	32°07'S, 115°38'E	R
Kwinana	Woodmans Point	7	32°08'S, 115°44'E	R
Rockingham	Cockburn Sound	7	32°11'S, 115°44'E	R
	Success Bank	7	32°11'S, 115°44'E	R
	Garden Island causeway	7	32°16'S, 115°41'E	R
	Shoalwater Bay	7	32°17'S, 115°41'E	R
	Penguin Island	7	32°18'S, 115°40'E	SO
	Warnbro Beach	7	32°20'S, 115°44'E	R, SR, SO
	Long Point	7	32°22'S, 115°42'E	SO
	Comet Bay	7	32°31'S, 115°42'E	SO
Mandurah	Dawesville Channel	8	32°37'S, 115°38'E	R
Yalgorup	Preston Beach	8	32°53'S, 115°39'E	R
Bunbury	Leschenault Estuary	9	33°17'S, 115°49'E	SO
	Koombana Bay	9	33°17'S, 115°47'E	SR
Busselton	Geographe Bay	10	33°39'S, 115°21'E	H, R
Dunsborough	Toby's Inlet	10	33°38'S, 115°11'E	H, R, SO, SR
	Quindalup	10	33°37'S, 115°07'E	H, SR
	Dunsborough Town Beach	10	33°37'S, 115°07'E	H, SR
	Eagle Bay	10	33°33'S, 115°04'E	R
	Rocky Point	10	33°33'S, 115°04'E	R
	Bunkers Bay	10	33°32'S, 115°02'E	R
Yallingup	Yallingup Beach	11	33°38'S, 115°02'E	R
	Smith's Beach	11	33°40'S, 115°01'E	R
	Canal Rocks	11	33°40'S, 115°00'E	R
	Injidup	11	33°42'S, 114°59'E	R
Margaret River	Bob's Hollow	12	34°04'S, 115°00'E	R
	Conto's Springs	12	34°05'S, 115°00'E	R
	Boranup Beach	12	34°09'S, 115°01'E	R
Augusta	Hamelin Bay	12	34°13'S, 115°02'E	R, SR
	Foul Bay	12	34°22'S, 115°01'E	R
	Deadfinish Anchorage	13	34°22'S, 115°10'E	R, SR

N.B. Sampling method: H = haul net, R = rod and line, SO = seine net (opportunistic), SR = seine net (recruitment survey).

Appendix 2.2 Sampling localities, site names and approximate latitudes and longitudes and methods used for collecting adult and juvenile *Arripis georgiana* in the western south and eastern south coast region of Western Australia. Area numbers listed in this table refer to area numbers shown on Fig. 2.1.

Locality	Site name	Area number	Approximate latitude and longitude	Method
Western south coast region				
Walpole	Circus Beach	14	35°02'S, 116°43'E	R
	Shelly Beach	14	35°02'S, 116°44'E	T
	Blue Holes	14	35°02'S, 116°49'E	R
	Peaceful Bay	14	35°03'S, 116°56'E	R, T
	Irwin Inlet	14	35°00'S, 116°58'E	R
	Quarram Rocks	14	35°02'S, 117°01'E	R
	Quarram Beach	14	35°02'S, 117°02'E	R
	Boat Harbour	14	35°02'S, 117°04'E	R, T
Denmark	Wilson Inlet	15	34°50'S, 117°25'E	H
	Lowlands Beach	15	35°05'S, 117°31'E	R
	Bornholm Beach	15	35°05'S, 117°34'E	R
	West Cape Howe	15	35°08'S, 117°36'E	R
Torbay	Horton Beach	15	35°04'S, 117°39'E	R, SR, T
Albany	Princess Royal Harbour	16	35°03'S, 117°53'E	H, R
	Deep Water Point	16	35°02'S, 117°54'E	R
	Middleton Beach	16	35°01'S, 117°55'E	R
	Emu Beach	16	35°00'S, 117°57'E	SR
	Oyster Harbour	16	34°59'S, 117°58'E	T
	Gull Rock	16	35°01'S, 118°00'E	R
	King George Sound	16	35°02'S, 117°58'E	R
Two Peoples Bay	Two Peoples Bay	16	34°58'S, 118°11'E	R, SR
	Bettys Beach	16	34°56'S, 118°13'E	R, T
Cheyne Beach	Cheyne Beach	16	34°53'S, 118°24'E	R, T
	Bluff Creek	16	34°50'S, 118°24'E	R
Bremer Bay	Cape Riche	17	34°37'S, 118°47'E	T
	Reef Beach	17	34°29'S, 119°12'E	R
	Stream Beach	17	34°29'S, 119°16'E	R
	Dillon Bay	17	34°27'S, 119°18'E	T
	Bremer Bay	17	34°24'S, 119°24'E	T
	House Beach	17	34°21'S, 119°31'E	T
	Trigelow Beach	17	34°14'S, 119°31'E	R, T
	Drage Beach	17	34°22'S, 119°32'E	T
Eastern south coast region				
Esperance	Eleven Mile Beach	18	33°52'S, 121°44'E	R
	Ten mile lagoon	18	33°53'S, 121°45'E	R
	Salmon Beach	18	33°53'S, 121°51'E	R
	Esperance	18	33°52'S, 121°54'E	R, SR
	Wylie Bay	18	33°50'S, 121°59'E	R
Cape Le Grand	Dunn Rocks	19	33°56'S, 122°21'E	R
Wharton	Victoria Harbour	19	33°56'S, 122°30'E	R
	Duke of Orleans Bay	19	33°55'S, 122°35'E	R, SR
Alexander River	Alexander Beach	19	33°53'S, 122°45'E	R
Cape Arid	Tagon Bay	20	33°53'S, 122°59'E	R
	Thomas River	20	33°52'S, 123°01'E	R
	Poison Creek	20	33°54'S, 123°21'E	R, SR
Israelite Bay	Israelite Bay	21	33°37'S, 123°53'E	R, SO
Cocklebiddy	Eyre Bird Observatory	22	32°15'S, 126°24'E	SO
	Noonera Beach	22	32°15'S, 126°24'E	R, SO
Mundrabilla	Red Rocks Point	23	32°13'S, 127°33'E	SO

N.B. Sampling method: H = haul net, R = rod and line, SO = seine net (opportunistic), SR = seine net (recruitment survey), T = G-trap net.

Appendix 2.3 Sampling localities, site names and approximate latitudes and longitudes and methods used for collecting adult and juvenile *Arripis georgiana* in the western, central and eastern regions of South Australia. Area numbers listed in this table refer to area numbers shown on Fig. 2.1.

Locality	Site name	Area number	Approximate latitude and longitude	Method
Western Region				
Ceduna	Point Bell	24	32°12'S, 133°08'E	R
	Purdie Islands	24	32°16'S, 133°04'E	R
	James Beach	24	32°11'S, 133°27'E	SR
	Davenport Creek	24	32°09'S, 133°29'E	SR
	Evans Island	24	32°22'S, 133°29'E	R
	St. Francis Isles	24	32°31'S, 133°18'E	R
	Franklin Islands	24	32°27'S, 133°40'E	R
Streaky Bay	Streaky Bay	25	32°35'S, 134°10'E	R
	Venus Bay	26	33°14'S, 134°42'E	H, R
Elliston	Waldegrave Island	26	33°36'S, 134°48'E	R
	Elliston	26	33°39'S, 134°53'E	SO
	Flinders Island	27	33°42'S, 134°32'E	R
	Pearson Island	27	33°57'S, 134°18'E	R
Central region				
Eyre Peninsula	Coles Point	28	34°22'S, 135°21'E	R
	Farm Beach	28	34°28'S, 135°23'E	SO
	Coffin Bay	28	34°28'S, 135°20'E	R
	Thistle Island	28	35°00'S, 136°08'E	R
	Port Lincoln	28	34°44'S, 135°52'E	R
	Tumby Bay	29	34°21'S, 136°08'E	SO
	Lipson Cove	30	34°14'S, 136°17'E	SR
	Dutton Bay	30	34°03'S, 136°25'E	R
	Arno Bay	30	33°55'S, 136°35'E	SO
Whyalla	Cowleds Landing	31	33°22'S, 137°24'E	SO
	Whyalla	31	33°02'S, 137°36'E	R
Port Pirie	Port Germein	31	33°01'S, 138°00'E	R
	Port Pirie	31	33°09'S, 138°01'E	R
	Port Davis	31	33°15'S, 137°48'E	R
Port Broughton	Fisherman Bay	31	33°34'S, 137°56'E	R, SR
	Port Broughton	31	33°36'S, 137°56'E	R
Yorke Peninsula	Point Turton	32	34°56'S, 137°21'E	R
	The Pines	32	34°54'S, 137°11'E	R
	Corny Point	32	34°54'S, 137°01'E	R
Eastern region				
Yorke Peninsula	Wedge Island	33	35°10'S, 136°24'E	R
	Port Moorowie	34	35°12'S, 137°37'E	SR
	Edithburgh	35	35°07'S, 137°44'E	R
	Coobowie	35	35°03'S, 137°43'E	SO
	Giles Point	35	35°03'S, 137°46'E	R
	Wool Bay	35	34°59'S, 137°45'E	SR
	Port Vincent	35	34°47'S, 137°51'E	R
Port Wakefield	Port Wakefield	35	34°11'S, 138°09'E	R
	Point Parham	35	34°26'S, 138°15'E	H
Adelaide	Port Adelaide	35	34°48'S, 138°28'E	R
	Angus Inlet	35	34°46'S, 138°30'E	SO
Barker Inlet	Section Bank	35	34°49'S, 138°33'E	SO
	North Arm	35	34°49'S, 138°33'E	SO
	Quarantine Station	35	34°49'S, 138°33'E	SO
	Kings Beach	35	34°49'S, 138°33'E	SO
Fleurieu Peninsula	Rapid Bay	36	35°32'S, 138°11'E	R

N.B. Sampling method: H = haul net, R = rod and line, SO = seine net (opportunistic), SR = seine net (recruitment survey).

CHAPTER 3. HATCHING PERIOD AND GROWTH OF JUVENILE AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*) DETERMINED FROM OTOLITH MICROSTRUCTURE ANALYSIS

W.F. Dimmlich, D. Fleer and I. Keay

Objective 1. Determine the age structure, growth and reproductive biology of Australian herring and the source of recruitment to the Western Australian fishery.

This objective was addressed, in conjunction with ageing and reproductive studies on adult Australian herring (described in Chapter 2), by examining various aspects of the early life history of the Australian herring through analysis of otolith microincrements. Otoliths were sourced from fish collected through the recruitment index netting programme and assessed for suitability in ageing work. The otoliths were found to be relatively difficult to work with. However, fish collected during the early months of each years sampling provided satisfactory estimates of age in days. These age estimates were used to identify periods of hatching activity for the years 1996-1998, which was found to occur over approximately 12 weeks from April to June, peaking in the first half of May. Growth rates from hatching to time of capture were able to be estimated, indicating growth rates over the first 6 months of life of approximately 0.32 mmd^{-1} for Western Australian fish and 0.18 mmd^{-1} for South Australian fish.

Introduction

Survival and subsequent recruitment of young fish is dependent on the combined influences of various biological and physical factors, such as starvation, predation, temperature and larval transport. Marine fishes are generally known for their high mortality during the early life stages and this is one main factor that affects population size (Nishimura and Yamada 1988). Larval size and growth are of particular significance to the recruitment process because size can be linked to resistance to starvation and predation (Miller *et al.* 1988), while small changes in spawning period, growth rates and the duration of advection phase can form the basis for significant interannual fluctuations in recruitment (Houde 1987). Distributions of hatch-dates, estimated from ages of juveniles at the time of capture, can be used to identify periods of successful spawning, which can then be related to environmental conditions (Methot 1983; Checkley *et al.* 1988; Nyman and Conover 1988).

However, before investigations into recruitment fluctuations and possible environmental linkages can proceed, basic information on timing and duration of early life-history events needs to be obtained. This chapter provides estimates of age and growth rates of mid- to late juvenile stages of Australian herring and the timing and duration of spawning period for the three years during which sampling was undertaken. These estimates are made based on otolith ageing techniques which are commonly employed as a practical tool in fish age and growth studies (Pannella 1980; Brothers *et al.* 1976; Campana and Neilson 1985; Rice 1987). Three pairs of otoliths are found in fish, the sagittal, lapillus and asteriscus (Pannella 1980) and one of these, the sagitta was used in this ageing study.

Use of otoliths in ageing of juvenile fish and subsequent back-calculation of hatching dates operates under the assumption that increments are laid down at the rate of one per day although this may be susceptible to modification by other cyclic environmental variables (Campana and Neilson 1985). The daily periodicity of increment formation in otoliths of Australian herring is also investigated in this study.

Materials and Methods

Sampling

Specimens of Australian herring were captured during monthly sampling over the period July-January in South Australia (SA) and June-December in Western Australia (WA) for the years 1996-1998. Sampling stations which contributed fish used in otolith analysis were located at a number of fixed sites along both the WA and SA coastlines (Figure 3.1). A total of 59 sites were sampled but only those which contributed fish which were aged by otolith increment analysis are included in this section. Comprehensive details of all sites sampled can be found in chapter 2.

Fish were caught during daylight hours using a 67m long beach-seine net (2m drop; 34mm mesh wings; 12mm mesh at cod-end), which was either waded out in shallow water or set from a small aluminium boat. Each site was sampled 3 times. The position of each of the three replicate seine hauls was fixed for each site and repeated for each month sampled.

Total length (TL in mm) and weight (g) were measured for each fish captured and otoliths extracted (lapilli and sagittae). A selection of sagittal otoliths collected in South Australia were also weighed. An attempt was made to identify the sex of Australian herring during the initial stages of the study but proved unreliable for at the early age being captured and was subsequently discontinued.

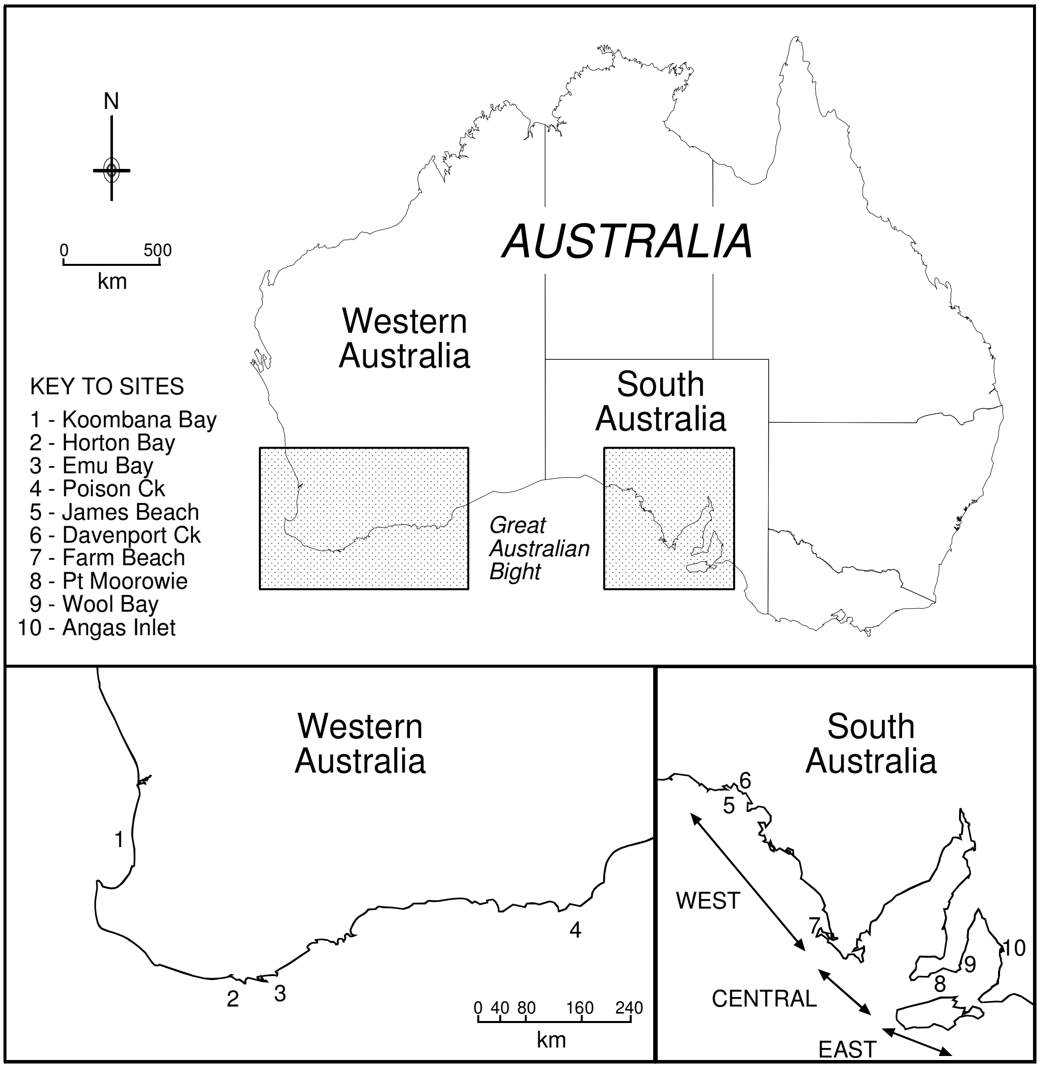

Figure 3.1 Location of sites from which otoliths were sourced for ageing.

Otolith preparation and analysis

Alternative hardparts

Initially the use of lapilli to age Australian herring was investigated as an alternative to sagittae. Although good ring structure was observed several factors mitigated against their use. Primarily, the small size of these otoliths obtained from specimens of a relatively high minimum age (approx. 120+ days) resulted in a highly compact/dense ring structure, making accurate counts difficult and time-consuming. Previous attempts to age Australian herring by lapilli increment analysis have resulted in counts which greatly underestimate corresponding sagittal counts (Fahlbusch 1995). Additionally, their small size made these structures difficult to locate and extract and, combined with the large numbers of fish requiring processing, also proved prohibitively labour-intensive.

Scales were also examined as an alternative method for determining the age of juvenile Australian herring as they appeared to display a relatively unambiguous concentric ring structure. Although counts of increments in scales were able to be made with greater precision than sagittae, it was felt they lacked the accuracy required to identify the spawning period of Australian herring as counts of these rings were found to significantly underestimate the age of fish and consequently were not given further consideration for the purposes of the current study.

Preparation

Examination of whole-mounts of sagittal otoliths produced little in the way of observable increments. Therefore, it was necessary to thin-section otoliths in order to reveal daily growth increments. Several sections, including transverse and sagittal sections, were trialed before the section along the sagittal plane was established as the most consistent method for ageing juvenile herring.

Whole sagittae were embedded concave surface facing up in a small amount of translucent thermoplastic cement (Crystal Bond®) on a glass microscopy slide. The sagittae were then ground level using wet P1200 grade carborundum paper before being polished using a fine-grade lapping film. The cement was reheated and the sagittae turned over and re-embedded in the cement with the convex surface facing up. This surface was then also progressively ground and periodically examined under compound microscope until the nucleus (or primordium) and surrounding growth increments became visible. The sagittae were then polished again before a final protective layer of transparent cement was applied obviating the need for a cover-slip.

Age determination

Otoliths from fish captured only during the first several months of sampling were used for ageing purposes as errors in interpretation of growth increments increase significantly with age of the fish. Generally, this resulted in fish captured in September and October of each year sampled in SA forming the basis for the ageing work carried out in this study. Even then, October-caught fish were markedly more difficult to age accurately than September-caught fish. It is assumed that fish caught in the 60-80mm size range during these early months of recruitment to the inshore areas would be equally vulnerable to capture by beach-seine as younger fish may pass through the net-wing mesh and fast-swimming older fish may be able to evade capture entirely.

Fish were caught sooner in WA waters, but these early-season fish were not included in hatch-date analysis as it is uncertain whether all these fish were indeed Australian herring. A significant proportion of fish caught during early-season sampling may be juvenile Australian salmon (*Arripis truttacea*) which are also present in the locations sampled and closely resemble Australian herring.

Australian herring otoliths display a complex multi-prismatic structure which has been observed in other fish species (Pannella 1980; Karakiri and Westernhagen 1989; Morales-Nin and Aldebert 1997). They also display a distinct boundary of discontinuous growth at age 25-35 days (Figure 3.2) similar to that described by Morales-Nin and Aldebert (1997). Several secondary nuclei (Figure 3.2), also described as 'accessory primordia' or 'peripheral nuclei' (Campana 1984) are commonly present at this discontinuity.

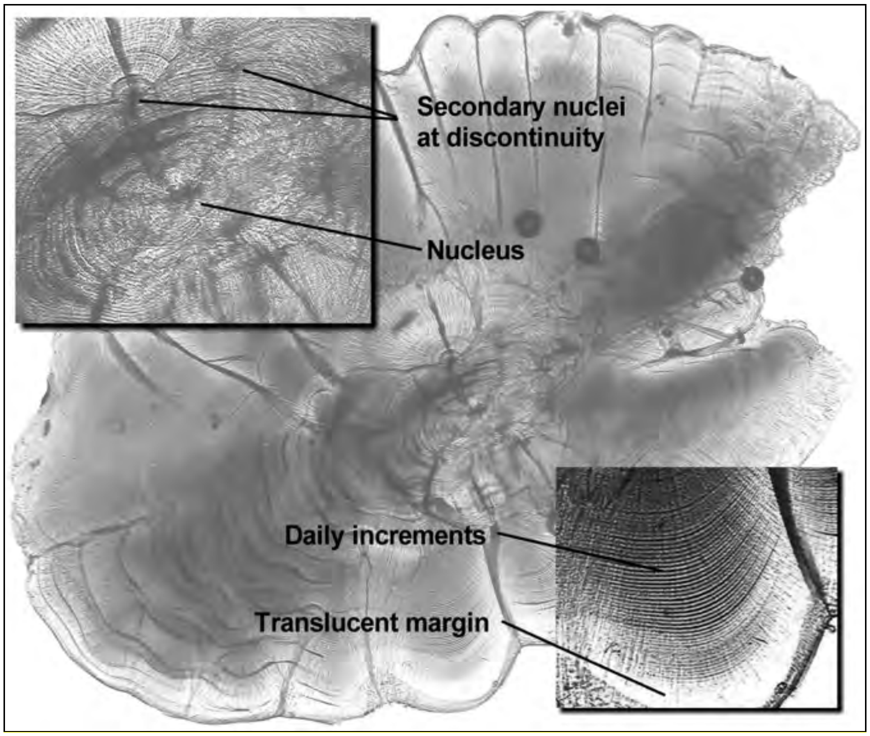

Figure 3.2 Herring otolith sectioned along the sagittal plane (approx. 150 days).

Rings were generally counted following the path of clearest increment formation from the central nucleus outwards to the otolith margin. When the increment pattern failed along a particular counting axis, the last distinct increment was followed laterally and counting continued along the next clear increment sequence. Also, care was taken when counting the compressed central increments, which may approach the resolution limit of light microscopy resulting in systematic underestimates of ages (Campana and Moksness 1991). Counting was generally carried out at 300x magnification under compound microscope using transmitted light. Counting at higher magnifications was possible and occasionally necessary, however doing so may potentially result in misleading higher counts due to the improved resolution of sub-daily increments (Campana and Neilson 1985; Sweatman and Kohler 1991). Three replicate counts of each otolith were made and the mean of these replicates used to age each animal. These replicates usually included both 'aggressive' counts during which possible sub-daily increments were considered daily and 'conservative' counts during which these questionable increments were not included in the count. All ageing was carried out by the author as subjective decisions on the part of the reader in determining whether rings were daily or subdaily were often required and other studies indicate reader experience may be a significant factor in reducing inaccuracies in ageing (Campana and Moksness 1991).

Validation

Laboratory marking experiments with oxytetracycline hydrochloride ($C_{22}H_{24}N_2O_8 \cdot HCl$) were conducted at the West Beach laboratories in an attempt to validate the daily periodicity of otolith ring formation. A number of fish were immersed in a tetracycline solution (5.0g tetracycline in 20 litres seawater) for approximately 12 hours prior to transferral to a holding tank (Schmitt 1984; Dimmlich and Hoedt 1998). The fish were maintained for several weeks during which time approximately half were removed after a fortnight and the rest removed after approximately 1 month. All fish were measured and otoliths extracted and prepared for microscopic examination under ultraviolet light.

As an indirect validation method (Geffen 1987; Morales-Nin and Aldebert 1997; Gjosaeter *et al.* 1984), the back-calculated hatch-dates were compared with the independently identified spawning period determined by gonadosomatic index (GSI) data (Chapter 2, Figure 2.3) assisting in evaluating the strength of the assumption of daily ring production. This test increases in power with shorter spawning periods (Gjosaeter *et al.* 1984) and Australian herring appear to have a relatively short spawning period (Chapter 2, Figures 2.3-2.5; Lenanton 1978) minimising the effect of selective mortality of hatching cohorts. Any major discrepancies arising between calculated hatch-dates and expected hatching dates might indicate periods of cessation of ring deposition, or deviations from daily ring deposition thus invalidating assumptions of daily periodicity of increment formation.

Data analysis

A spawning date was assigned each juvenile Australian herring aged by using the estimated age of the fish in days to back-calculate from the date of capture. For the purposes of some growth analyses, older fish from the 1996 year class, which were unable to be directly aged due to increased complexity of otolith microstructure were assigned ages calculated using the estimated date of peak spawning activity in their respective season as their hatch-date (15/5/96). For SA these fish were grouped into three regions (Figure 3.1). Fish from two WA sites (Koombana Bay and Poison Creek) were also assigned ages based on estimated hatch-dates in order to investigate regional variation in growth rates.

Hatch-date frequency distributions were generated for the 1996, 1997 and 1998 year-classes based on otolith increment counts. The hatch-date frequencies were aggregated into 15 day or approximately bi-monthly cohorts. Due to the age and complex structure of the otoliths which result in low counting precision attempting to achieve higher data resolution than 2 weeks is probably unrealistic. Studies requiring daily resolution may be beyond the capabilities of otolith microstructure studies of many species (Campana and Moksness 1991) and in order to achieve higher temporal definition of Australian herring spawning period, sampling of larval fish no more than 1-2 months post-spawning would be necessary.

Results

Age and growth

Ages of 164 juvenile Australian herring, collected over the range of sampled sites, ranged from 76 to 196 days (Table 3.1). The maximum estimated age of fish captured during sampling was 908 days (~2.5 years) for 1996 year-class fish. Otoliths were generally able to be aged up to about 160 days before marginal increments became difficult to resolve. At this age the otolith margin becomes translucent and increments are no longer visible.

Table 3.1 Summary of age and length ranges of fish aged through otolith increment counts.

Yearclass	No. aged	Age (d)	TL (mm)
1996	40	76-161	31-81
1997	47	116-196	61-80
1998	77	88-180	48-86

Ageing precision up to this age was generally moderate. This was determined using the coefficient of variation (CV), which is defined by Chang (1982) as the standard deviation divided by the mean. This figure represents an assessment of the precision of counts and is not necessarily correlated with their accuracy, which is assessed separately. Figure 3.3 indicates that the CV of counts expressed as a percentage remained fairly constant below 20% over the size range aged. Any variations indicated in count precision are almost certainly artefacts of the 'aggressive/conservative' approach to individual otolith counts resulting in a range of imprecise ages around an overall accurate estimate of the fish's actual age. Not shown are ages obtained from older fish, as the transition period from readable to unreadable is quite abrupt at the fifth or six month of life and, although attempts were made, these fish were not aged.

Estimated age and length data from WA and SA sites were combined into respective datasets and growth for these two regions was described with standard power curves over the range of lengths which were subjected to direct ageing by otolith increment counts (Figure 3.4).

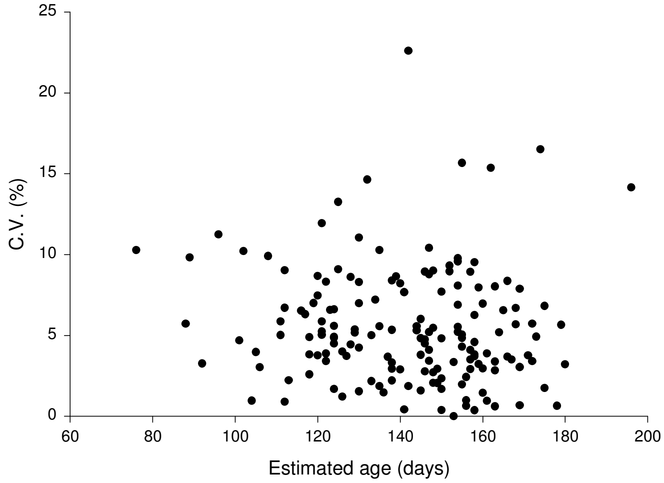

Figure 3.3 Assessment of precision of age estimation using coefficient of variation (CV) expressed as a percentage.

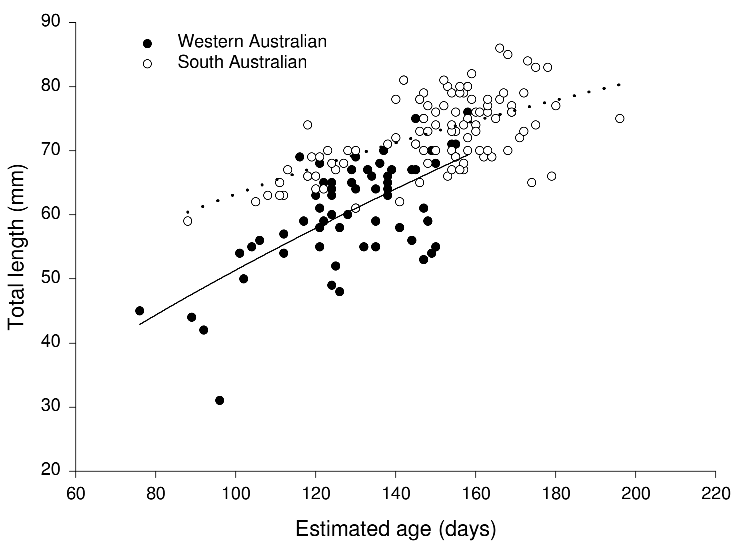

Figure 3.4. Age at length for all fish directly aged through otolith increment counts.

Estimates over the size-range of fish for which otoliths were examined indicated overall mean growth rates from age zero (TL 0 mm) for WA and SA Australian herring of 0.47mm d^{-1} (min: 0.32; max: 0.59) and 0.49mm d^{-1} (min: 0.36; max: 0.67), respectively. However, a linear regression model relating TL (mm) against estimated age (days) yielded measured growth rates for WA and SA Australian herring of 0.32 ± 0.048mm d^{-1} (95% CI; $r^2 = 0.42$) and 0.18 ± 0.024mm d^{-1} (95% CI; $r^2 = 0.35$), respectively (Figure 3.4).

Growth curves obtained from assigned-age fish indicated that higher growth rates were expressed by westernmost WA fish, while fish obtained from the eastern WA coast expressed growth rates more similar to SA fish (Figure 3.5). A large proportion of the aged WA otoliths were sourced from the easternmost Poison Creek site and these are likely to have reduced overall growth rates for WA. These growth curves were derived by regressing TL (mm) against estimated age (days) (Table 1.2).

Table 3.2 Summary of coefficients for standard power curve describing growth of Australian herring (obs = ages obtained directly from otolith analysis; est = ages obtained from hatch-date).

Site/Region	a	b	r^2	N
SA (obs.)	11.95	0.36	0.38	102
WA (obs.)	1.91	0.75	0.44	62
SA West (est.)	3.74	0.58	0.96	1158
SA Central (est.)	3.81	0.59	0.93	157
SA East (est.)	4.21	0.54	0.85	642
WA Koombana (est.)	1.28	0.81	0.87	358
WA Poison Ck (est.)	3.61	0.58	0.79	646

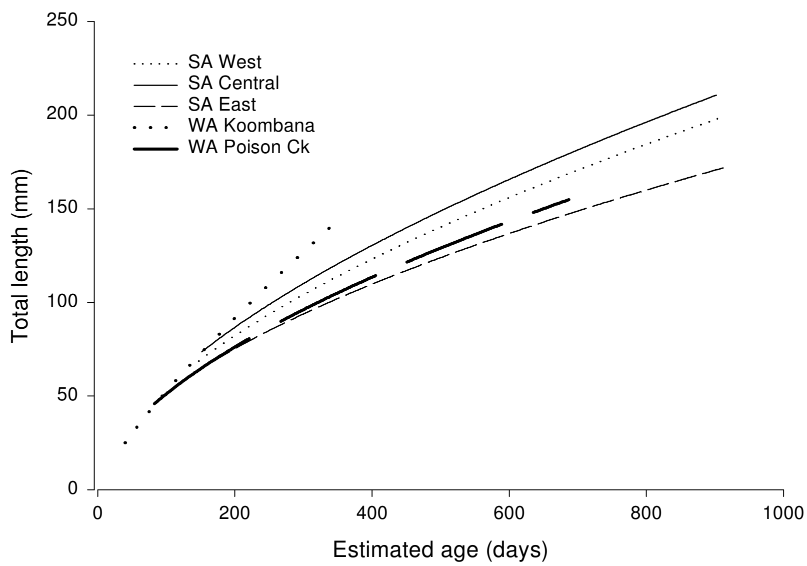

Figure 3.5 Growth curves for SA regions and selected WA sites using age data derived from estimated date of peak hatching activity in 1996.

Spawning period

Back-calculated hatch-dates for 1996, 1997 and 1998 year class juveniles were calculated for fish that survived until the time of sampling (Figure 3.6). Hatching activity peaked in the first half of May in both 1997 and 1998. Spawning activity was significant also in the first half of May 1996 but, rather than exhibiting the rapid decline displayed in subsequent years, increased further during the second half of May to a peak of similar magnitude to 1997/1998 prior to a precipitous decline in early June to levels commensurate with following years. In all three years sampled, hatching commenced at the end of March and concluded by the end of June.

Validation

The tetracycline marking experiment proved unsuccessful. This was due to the age of the fish used in this study. When the marked sagittae were sectioned and examined it was found that it was not possible to satisfactorily resolve the marginal otolith increments in order to determine the number which had been deposited post-immersion. Examination of otoliths obtained from younger fish captured at Western Australian sites indicated a possible size range of 50-65mm which may prove better suited for such a study. Otoliths obtained from fish within this size range exhibit good marginal increments.

However, back-calculated hatch-dates (Figure 3.7) corresponded with peaks in GSI in all years (see chapter 2) indicating the likelihood that increments are deposited on a daily basis. All back-calculated birthdates fell within known annual parturition periods. Lenanton (1978) concluded that spawning took place over a short period of several weeks during the months April-June. Hatch-dates estimated in this study also correspond with hatch-dates of post-larval Australian herring found by Fahlbusch (1995), who nominated a period of spawning activity between April and early June in 1994.

Daily increment formation has been validated in the closely related species, New Zealand kahawai (Stevens and Kalish 1998), which is also known as Australian salmon in Australian waters and it is reasonable to extend the validation on this species to include Australian herring.

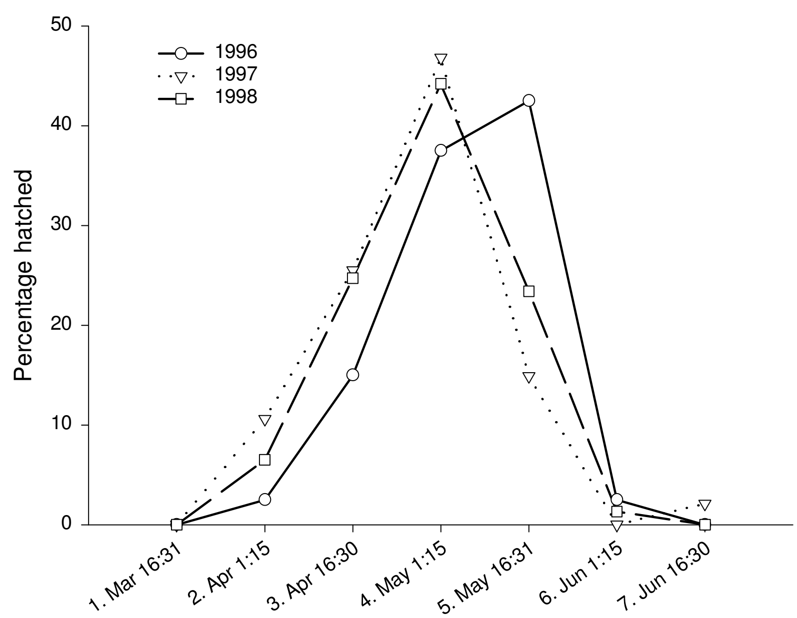

Figure 3.7 Back-calculated hatchdate distributions for the years 1996-1998.

Discussion

Age and growth

As is generally the case in many pelagic fish species, the primary source of age estimation inaccuracy in Australian herring over the age range discussed in this section appears to lie with the first-formed increments, whether due to compressed and visually unresolvable increments or to uncertainty surrounding age at first increment deposition. Variability in age and length estimates can potentially have a large impact on reliability of growth rate estimates, especially when calculated over short time intervals. For example, a difference of 0.3mm per day between two growth rate estimates may be substantial when reliability of growth rate estimates is high, or inconsequential when reliability is low (Rice 1987). However it is believed that age estimates obtained for Australian herring in this study are reliable over the size range of fish aged and that individual variability in growth indicated is in fact significant and not an artefact of poor accuracy in age or length estimates.

The complex multi-prismatic internal structure of Australian herring otoliths effectively confounds interpretations of growth and events over the first 6 months of life. The most noticeable feature is the ubiquitous presence of a major discontinuity at the 25-30 day region (similar to that observed in two flounder species by Jenkins 1987), at which several secondary nuclei formed. It is likely that this feature may be related to a transition event in the life-cycle of larval herring (Campana and Neilson 1985; Pannella 1980; Brothers and McFarland 1981) though, with little information available for these early stages in the Australian herring life-cycle, cannot be confidently attributable to any specific event. With no direct observations on timing of larva-postlarva transition, yolk-sac absorption, age at first feeding *etc.* any relationships between otolith microstructure and early-life events remain somewhat obscure.

High individual variability displayed in the age/length relationships might be related to either unsatisfactory age-reading due to the complex structure of otoliths or indeed reflect highly variable individual growth rates, which in turn may be due to inherent variability in the various transport mechanisms, temperatures, salinities, food availability *etc.* (Wright and Bailey 1996; Karakiri and Westernhagen 1989; Campana 1996) over the 2000+ kilometres travelled by each surviving fish sampled in SA. Studies have identified temperature change and salinity change as a major factor contributing to changes in patterns of otolith increment formation (Karakiri and Westernhagen 1989). Whether the effects of such influences are represented within Australian herring otoliths as larvae move from warm low-salinity Leeuwin current waters to cooler, higher salinity SA waters is unknown, though it is possible they may contribute to otolith complexity.

Pannella (1980) noted that the magnitude and features of growth disturbances reflected in otoliths could be directly related to the magnitude of the stress and to the time span during which the stress is experienced. This may be particularly relevant for Australian herring for which duration of the advection phase may be critical in determining individual growth over the first year of life (Woodbury and Ralston 1991). It is possible that discrete cohorts of larvae may be caught in large scale oceanic eddies or delayed by more localised wind-driven effects, which would prolong the period of feeding on planktonic copepods and consequently delay the post-settlement transition to preying on smaller fish species in nursery areas. This effect may in some part explain the higher growth rates exhibited by fish from Koombana Bay, WA, which experience a far shorter advection phase than SA fish or Poison Creek (WA) fish. The effect of differing periods of advection phase on growth may also be reflected in the low growth rates of fish sampled from the eastern region of SA.

It is also possible that geographical differences in growth may be caused by other influences in early life history, e.g. earlier/later spawned fish growing quicker/slower (Nishimura and Yamada 1988) due to environmental changes over the spawning period (temperature, food availability, *etc.*). This effect is not believed to be significant for Australian herring as spawning appears to be localised, of short duration and for the first several months all larvae are exposed to similar environmental conditions during the advection phase before fish settle into differing nursery areas. This effect may however be useful in explaining differences in recruitment success to nursery areas between Australian herring and Australian salmon. Both species exhibit very similar early life history with the notable exception of timing of the spawning period.

It is worth noting that although growth may be greatly affected over the advection phase of the life-cycle it is generally believed that periods of starvation do not appear to affect the periodicity of otolith increment formation (Sweatman and Kohler 1991; Jenkins 1987). Studies indicate that starvation periods of 5-8 days may be required to interrupt daily ring deposition (McGurk 1984) and it is unlikely that early juvenile Australian herring would remain deprived of food while covering a distance of approximately 150km over that period, i.e. they are not confined to an area of poor food availability for any period of time. Although mortalities due to starvation may be experienced to some unknown degree by Australian herring larvae over the protracted advection phase, investigations of starvation effects on clupeoid larvae indicate that any larvae which obtain enough food to survive apparently obtain enough to grow rapidly (Methot and Kramer 1979) albeit with high variability in the case of Australian herring.

Spawning Period

Estimated hatch-dates fell well within the range of observed dates (Lenanton 1978; Fahlbusch 1995). Previous work in Western Australia (Lenanton 1978) indicated that spawning took place over a relatively short period (several weeks) with all females caught over the period 9th April to 28th May 1973 being in immediate prespawning condition. Lenanton (1978) noted that the proportions of females in prespawning condition declined rapidly after this period, a trend which was mirrored for all three years of the current study with minor variations. One significant variation however was an apparent fluctuation of several weeks in the duration of the spawning period in 1996 which coincides with a season of markedly higher recruitment of juvenile Australian herring to the eastern nursery areas (Chapter 4).

Although data resolution of GSI data is coarser than that used in analysis of hatch-dates through direct ageing, overall both techniques concur in identifying a relatively brief period of spawning activity which takes place predominantly during May. GSI data obtained in the current study (Chapter 2) indicated a peak in late May in all years, which was reflected only in the 1996 hatch-date results. However it must be borne in mind that hatch-date distributions are calculated from ageing of survivors and do not necessarily correlate with peak spawning as indicated by GSI investigation.

Variable larval survival rates over the reproductive season may result in back-calculated hatch-date frequencies differing from the actual pattern of egg production (Zastrow *et al.* 1991). This effect over the spawning period may be ameliorated in the case of Australian herring due to the relative short duration of the spawning peak. It is possible that Australian herring larvae hatched early in the spawning season may enjoy greater survival rates than those hatched later in the season and hence enjoy greater representation in ageing studies (Jenkins 1987). To correct for the problem of misleading over-representation of surviving juveniles in hatch-date calculations, estimates of the numbers born by date should be adjusted for differences in mortality (Woodbury and Ralston 1991), i.e. to have been available for sampling, older juveniles must have survived for a longer period of time than younger ones. However, estimates of early larval and juvenile mortality rates are unavailable and hence the hatch-date distributions presented here represent the fish that survived to the time of sampling.

It is also possible that factors not directly linked to larval mortality rates may influence the timing of recruitment of fish to nursery areas where they are then available for sampling. During the spawning and post-spawning period the eastward flowing Leeuwin current, which is believed to provide the main transport mechanism toward nursery areas, progressively loses strength and consequently later spawned fish may be disadvantaged by virtue of a failing current, settling at a later date into nursery areas at an age beyond that which could be aged through otolith increment analysis.

Conclusions

Although this investigation has succeeded in providing general data on hatching-period and growth in late-juvenile stages of the Australian herring life-cycle, the shore-based approach to sampling necessarily places limits on what can be achieved. In effect this study can only examine in detail approximately 60 days, or 1/50th of the average life span of the Australian herring. Data obtained through other components of the overall herring study, including ageing of adult fish, provides information on growth beyond that covered in this section but information on age and growth during what is perhaps the critical formative period for any particular year-class is lacking.

In order to satisfactorily resolve issues arising from timing and influence of transitional events during egg, larval and post-larval stages on the development of otolith microstructure it is recommended that future work concentrates on early life history of this species prior to settlement in nursery areas. It is also recommended that should it be necessary to attempt to correspond particular otolith structures with ‘events’ (eg. storms) then counts should be made backwards from the otolith margin as the date of formation of the outermost increment would presumably be known (date of capture) with higher certainty than the date of first increment formation.

Information is required on the timing of events such as age at first feeding which may correspond with initial increment formation and hence clarify number of days which need to be added to otolith increment counts as a general ageing correction. It is unknown whether this corresponds with complete yolk-sac absorption. These and other dates are species-specific (Brothers *et al.* 1976; Woodbury and Ralston 1991) and cannot confidently be derived from known dates of other larval fish species, with perhaps the exception of Australian salmon for which, unfortunately, these data also are lacking.

Particular emphasis should be placed upon implementing a program of offshore planktonic sampling to determine spawning area of Australian herring and obtain early- and late-larval samples in order to examine early growth increment formation and to obtain estimates of larval and juvenile mortality rates to enable adjusting for mortality effects on perceived hatch-dates derived from otolith analysis.

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CHAPTER 4. DEVELOPMENT OF AN EXPLORATORY MODEL OF LARVAL AND JUVENILE AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*) TRANSPORT FROM WESTERN AUSTRALIAN SPAWNING GROUNDS TO COASTAL NURSERY HABITATS

W.F. Dimmlich, S.G. Ayvazian, R. Allison and D. Fleer

Objective 3. Develop a more useful, ongoing index of recruitment of immediately post-settled juvenile Australian that settle in shoreline nursery areas between Geographe Bay in Western Australia and the Coorong Estuary in South Australia.

The objective was achieved by establishing a consistent regime of beach seining carried out over the months June to January. Netting for juvenile Australian herring in inshore nursery habitats along the Western Australian and South Australian coastlines continued for 3 years and the sampling results were used to generate recruitment indices. These indices were then able to be used in conjunction with an independently derived transport model incorporating aspects of current strength, wind patterns, and fish swimming velocities to explain and predict the degree of recruitment success to various regions of the southern Australian coastline. The combined results of the transport model and recruitment indices indicated that inter-annual recruitment mechanisms over the period studied were variable in strength, contributing to fluctuations in recruitment success of juvenile Australian herring, particularly to regions east of the Great Australian Bight. In general, during years of relatively stronger transport, recruitment indices for eastern regions were higher than those estimated for western regions, and in years of weaker transport, indices in western regions were higher than eastern. The indices appear to reflect the degree to which numbers of larval Australian herring are able to be successfully transported across the Great Australian Bight region, which offers few suitable habitats for juvenile fish to settle.

Introduction

Most marine fish and invertebrate species spawn a large number of small offspring that are transported away from spawning areas by an intricate combination of physical and biological processes (McFarland *et al.* 1985; Hare and Cowen 1996; Shenker *et al.* 1993; Dedah 1993). Survival of these early life history stages is to a certain extent dependent on the outcome of their planktonic transport, as well as on their feeding success and ability to avoid predation (Meng 1993; Miller *et al.* 1988). The influence of planktonic transport processes on juvenile recruitment, however, will be magnified in species whose juvenile nursery habitats are spatially distinct from spawning locations, thereby making the continuation of the life-cycle dependent on the outcome of larval transport (Bailey 1981; Hare and Cowen 1993; Hare and Cowen 1996). For a species such as Australian herring, larval transport processes may be critical to both the magnitude and timing of recruitment to inshore South Australian nursery habitats. Recruitment is one of the principal processes that govern population sizes and community structure in marine ecosystems (Bailey 1981; Norcross and Wyanski 1993; Shenker *et al.*

1993; Thorrold *et al.* 1994) and understanding the biotic and abiotic factors affecting recruitment is essential in order to explain and predict population fluctuations and subsequent shifts in community structure.

Although the exact temporal and spatial pattern of Australian herring spawning remains uncertain, the general patterns of spawning and recruitment to nursery areas have been documented in other sections of this report. In brief, a single spawning event occurs annually off the south-western corner of Western Australia from April to June, peaking over a two-week period in May. Fish spawned during this period recruit thereafter to Western Australian coastal areas and ultimately to South Australian nursery areas from September to November. The route and processes acting on these larvae during the highly dynamic advection phase are not understood with any confidence, although it is hypothesised that larval transport can be broken down into three components which may account for a significant percentage of the overall transport mechanism: Leeuwin Current-associated larval transport; wind-driven flow; active crossing of the shelf by young Australian herring to the inshore habitats.

In this section we present indices of recruitment generated from the 3 year survey of newly recruited juvenile Australian herring and attempt to investigate whether significant interannual variations in recruitment strength are due to a combination of short term variability in wind-driven currents and interannual fluctuations in relative strength of the Leeuwin Current. We also incorporate the potential contribution of active swimming by larvae and juveniles to the overall transport mechanism. To aid in these investigations an exploratory model of the overall eastward transport process is developed to assist in qualitatively assessing the possible mechanisms necessary for the recruitment of juvenile Australian herring to nursery habitats.

Materials and Methods

Sampling

Establishing an index of recruitment strength was necessary to compare the interannual fluctuations in recruitment success to inshore nursery habitats. Sampling was carried out using beach seines, as previously described in Chapter 3, at numerous sites largely encompassing the geographic range of Australian herring from Western Australia to the Victorian border (Figure 4.1). Although a large number of sites were sampled initially, a representative subset of sites which were sampled consistently over the 3 year period were considered useable for generation of recruitment indices (highlighted, Figure 4.1). Sites which were omitted were either generally unproductive for Australian herring or were unable to be sampled monthly over the three year sampling period for reasons ranging from inclement weather and unsuitable tidal patterns to access difficulties.

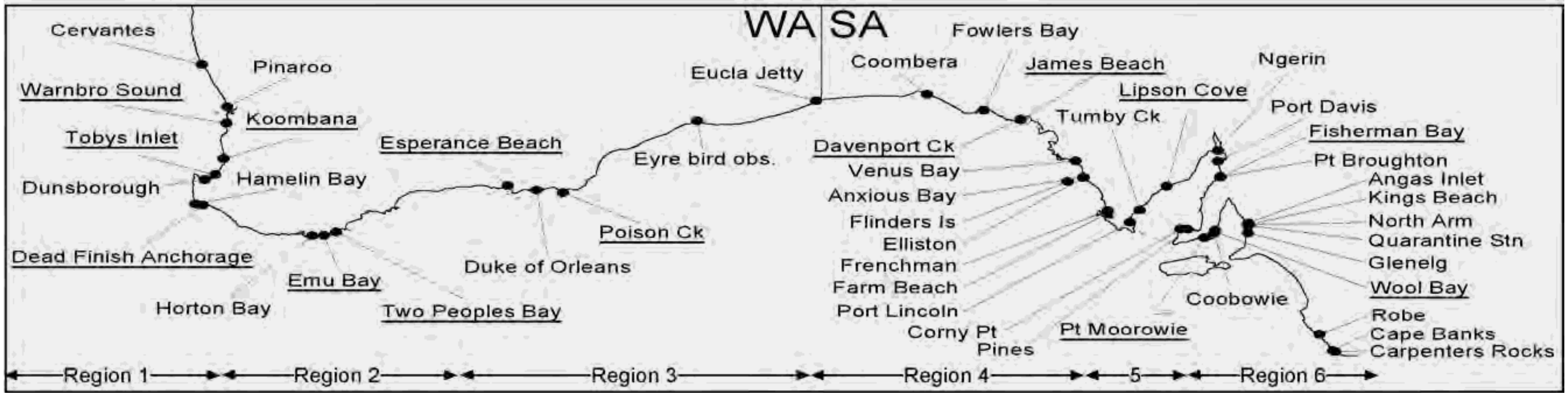

Figure 4.1 All sites sampled including sites used to generate recruitment indices (highlighted).

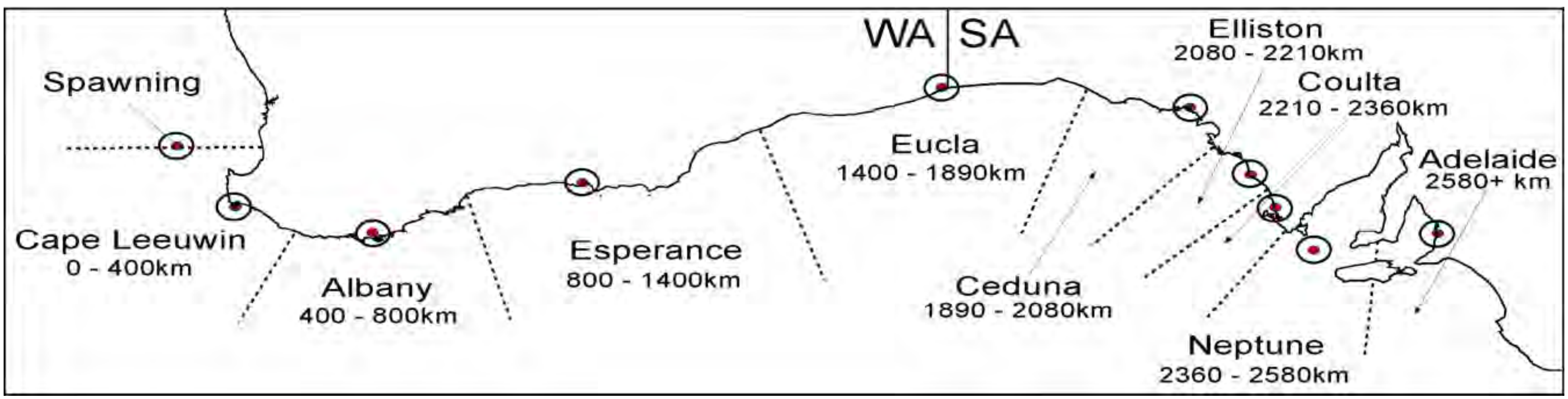

Figure 4.2 Location of weather stations from which wind speed and direction data were sourced. Dashed lines delineate ‘wind blocks’ used in transport model.

Transport Model Development

Wind-generated current

Wind-aided recruitment of larval and juvenile fish has often been demonstrated (Bailey 1981; Simpson 1987; Fechhelm and Fissel 1988; Fechhelm and Griffiths 1990; Katz and Spaulding 1994) and it is believed may provide a significant component of the eastward transport mechanism for Australian herring.

Wind data for the months May to October for the years 1996 to 1998 were obtained from the Australian Bureau of Meteorology[4]. Data for these periods were sourced from nine weather stations dispersed along the southern Australian coastline. The relative locations of these stations were used to divide the hypothetical path (assumed to roughly follow the shelf-edge) taken by larval Australian herring into a series of sections (Figure 4.2) using an estimated overall dispersal velocity of 0.2 ms^{-1} (mean velocity required to traverse the distance from spawning ground to Angas Inlet nursery [Figure 4.1] within observed time frames). For example, to cover the 400km range of the first section post-spawning would take from 15th of May to 7th June, hence wind data from the Cape Leeuwin meteorological station were used for this period. For the next section wind data from the Albany station were used and so on, until the journey concludes at the Angas Inlet nursery area, where data from the Adelaide Airport meteorological station were used. The daily mean wind speed and direction was calculated for each day of travel.

The transport of larvae due to wind-generated surface currents (Figure 4.3) was described by:

$$W_i = -(\sin\phi \frac{\pi}{180} v) \cdot c \qquad (4.1)$$

where W_i = wind generated component (ms^{-1}) of transport mechanism at time i (days), v = wind speed (kmh), ϕ = wind direction (degrees) and c is a coefficient (0.03 in this model) that describes the wind-induced transport as some percentage of the absolute wind speed (Katz *et al.* 1994; Fechhelm *et al.* 1994). Wind direction data were transformed from a circular to a linear variable using the inverse sine of the wind direction angle (Clark *et al.* 1996). Westerly winds receive a higher positive weighting and easterly winds receive a corresponding negative weighting, producing an inhibiting effect on the eastward transport process. Specifically, winds blowing directly from the west received a score of +1.0; winds from the east , -1.0 and those with northerly or southerly components, scored between +0.9 and -0.9. Geostrophic effect on the direction of the current generated is not incorporated into the present model although future application of this exploratory model may benefit from such refinements.

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[4] URL: http://www.bom.gov.au/

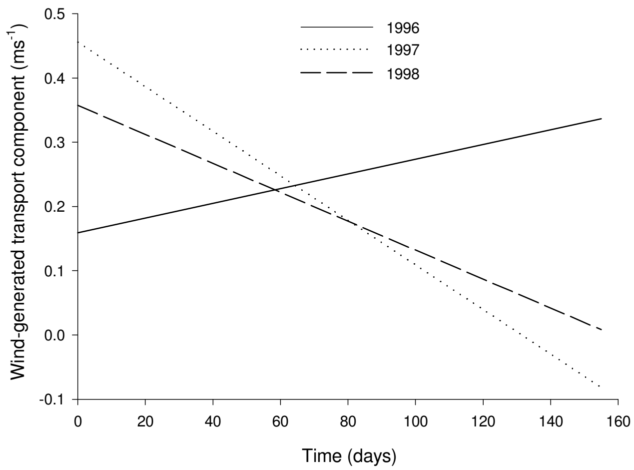

Figure 4.3 Estimates of wind-induced current for inclusion in transport model.

Investigations of transport trajectories due solely to wind influences were also investigated. Daily mean wind direction was used to assign either a north, south, east or west vector to the transport and the magnitude of the vector was provided by the absolute (positive) value of equation 4.1. A correction to the wind direction data was made in this case to account for the effect of the Coriolis force which, depending on wind velocity, produces a current flow between 0 and 25^{o} (mean 15^{o}) to the left of the wind in the southern hemisphere (Katz *et al.* 1994).

Leeuwin Current

The Leeuwin current is believed to provide a significant contribution toward the initial transport of egg and larval Australian herring from the spawning region. A simplified Weibull model of the current was developed based on reported current velocities at specific distances from the spawning area and is described:

$$L_i = [0.50 - (0.45e^{-338.64 D_{i-1}^{1.03}})] \cdot SOI_{\text{mod}} \qquad (4.2)$$

Where L_i = Leeuwin current component (ms^{-1}) of transport mechanism at time i (days), $D_{i\text{-}1}$ = total distance traversed to time i-1, and SOI_{mod} = Southern Oscillation Index modifier for that year. The base curve (unmodified by SOI_{mod}) conservatively reflects contemporary estimates of current velocity, ranging from 0.5 ms^{-1} whilst rounding Cape Leeuwin to a low of approximately 0.1 ms^{-1} toward the eastern-most extent of the study area (Cresswell 1991; Pearce 1991; Fletcher *et al.* 1994). The value for SOI_{mod} was derived using the mean SOI value for each year (5.16, -11.03 and –1.15 for 1996, 1997 and 1998 respectively) expressed as a percentage of the maximum mean SOI over the years studied (ie. 5.16 in 1996) which is then added to a *base* value of 0.50. This results in percentages of 1.0 (100%) for 1996, 0.0 (0%) for 1997 and 0.61 (61%) for 1998 in turn providing values for SOI_{mod} of 1.50 (*base* +

1.00), 0.5 (*base* + 0.00) and 1.11 (*base* + 0.61) for 1996, 1997 and 1998 respectively, producing a separate estimate of current strength for each year investigated (Figure 4.4). Original Southern Oscillation Index data were obtained from the Queensland Department of Primary Industries[5].

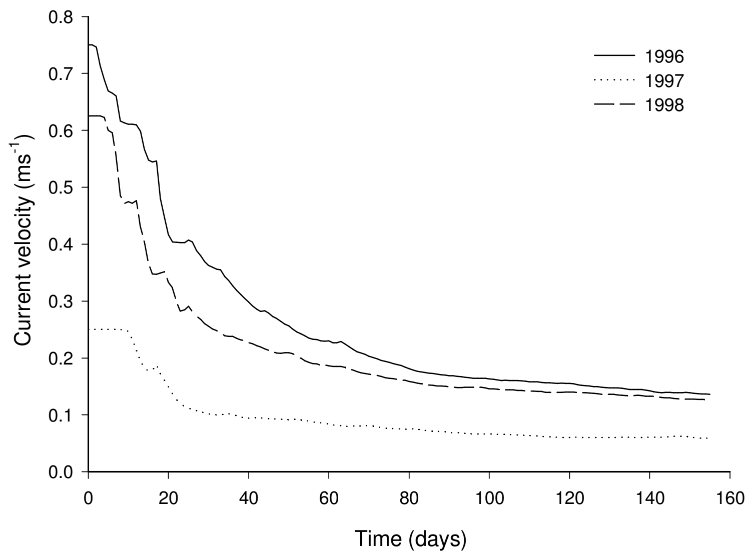

Figure 4.4 Estimates of current velocity produced for inclusion in transport model.

Swimming speed

Although passive drift must necessarily account for much of the transport, Australian herring themselves become increasingly capable swimmers over the duration of the advection period. No data are available describing the sustainable swimming speed of Australian herring, however numerous studies have been conducted on other fish species (Houde 1969; Beamish 1978; Bernatchez and Dodson 1985) and it is generally accepted that there is minimal interspecific variation in the sustainable swimming speeds of most pelagic larval and juvenile fish species. A conservative estimate of Australian herring swimming speed of 2 body lengths per second was used in the present model, being approximately half of the asymptote of 3-4 body lengths per second described for other pelagic species at a similar size range (Houde 1969; Dabrowski *et al.* 1988; Meng 1993). This conservative estimate also allows for time spent in undirected swimming while juveniles actively pursue planktonic prey species (Munk and Kiørboe 1985; Dabrowski *et al.* 1988).

$$F_i = \frac{2 \cdot (2.59 i^{0.66})}{1000} \qquad (4.3)$$

where F_i = active swimming component (ms-*1*) of the transport process at time i (days). Body length (BL) in mm at time i was estimated using the growth equation developed in Section 3 (BL = $2.59i^{0.66}$).

[5] URL: http://www.dnr.qld.gov.au/longpdk/longpdk.htm

Estimates produced for inclusion to the model are very conservative, with predicted swimming speeds falling well within reported limits for similar sized fish (Beamish 1978). However, even these conservative projections predict that at the distal end of the migration path the contribution of fish swimming component equals and eventually exceeds the current component of the eastward dispersal vector. The duration of time fish are able to maintain these velocities has not been extensively reported, though several endurance studies indicate speeds of 1-2 BL sec^{-1} may be maintained for periods of 1-3 weeks (Beamish 1978).

Recruitment indices

The numbers of 0+ Australian herring captured each month from the primary sampling sites in both WA and SA (Figure 4.1) were compiled and natural log (x + 1) transformed to normalise the data. The juvenile recuitment index was calculated from an analysis of variance with the factors region, month and year. The least square mean values of the natural log (x + 1) transformed numbers of Australian herring provided the index of recuitment, which was standardized for the other fators (Caputi and Brown 1986). This procedure was carried out for two sets of data. The index was calculated using 0+ fish sampled until the month of peak abundance and over the entire period.

The validity of this index as a measure of year class strength was established during previous investigations of recruitment to a single South Australian nursery habitat over a period of 15 years by Jones, Dimmlich and Partington (unpublished data) who report that this type of index serves to reflect changes in the relative abundance of year classes of Australian herring. The indices generated here are not in any way to be considered as absolute measures of abundance, but should prove useful for comparing recruitment success between years. Recruitment indices for each region were compared with the results of the transport model to examine whether there exists any correlation between variations in environmental parameters (expressed as predicted distance travelled) and the fluctuations in juvenile recruitment to nursery areas in Western Australia and South Australia.

Results

The estimation of magnitudes and durations of three primary oceanographic and biological processes believed to account for much of the larval and juvenile Australian herring advection permit the construction of a simple transport model (eq. 4.4) which can be independently assessed against the recruitment indices estimated by direct observation of juvenile recruitment to inshore nursery areas and vice versa.

$$D_i = D_{i-1} + [(\frac{W_i + L_i + F_i}{3}) \cdot 86.4] \qquad (4.4)$$

where D_i = distance travelled in a single day in kilometres ([60*60*24]/1000 = 86.4), W_i = wind generated component of transport mechanism at time *i* (eq. 4.1), L_i = Leeuwin current component of transport mechanism at time i (eq. 4.2) and F_i = active swimming component of the transport process at time i (eq. 4.3). The model, operating in this case within the constraints of a 155 day period extending from a standardised initial date of 15th May (refer Chapter 3), approximates the distance travelled by larval and juvenile Australian herring from the spawning ground in Western Australia to the Angas Inlet sampling site located within the Barker Inlet region of South Australia for the years 1996-1998 (Figure 4.5). These results suggest that under the influence of large-scale oceanographic and meteorological processes operating for each of those years, juvenile Australian herring may experience significant variations in the distance traversed over the time period under review.

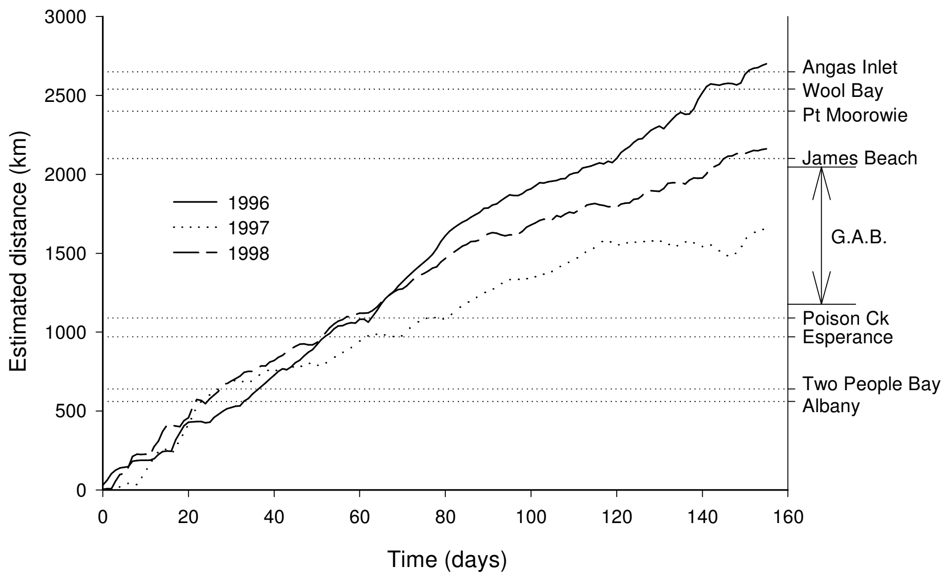

Figure 4.5 Results of model run for the years 1996-1998.

In broad terms, the results of the model runs for each of the three years predict relatively poor recruitment to South Australian nursery areas in 1997, with an unquantifiable, though potentially significant, proportion of 0+ fish failing to negotiate the geographic barrier of the Great Australian Bight (GAB) within the prescribed time period of 155 days. The situation would appear to improve somewhat in the following year, with Australian herring in 1998 experiencing improved recruitment to the eastern side of the GAB. Most successful in terms of predicted recruitment to eastern nursery areas, the 1996 year class would appear to have been readily transported in greater numbers to the eastern nursery areas.

Figure 4.6 illustrates the estimated time in days required by larvae and juveniles to reach the approximate midpoints of each region. Specifically, the time predicted to reach the 200km, 600km, 1200km, 1800km, 2300km and 2500km way-points for each year is used to compare the predictive capabilities of the transport model with the observed recruitment of 0+ Australian herring to the respective regions, as measured by the recruitment indices.

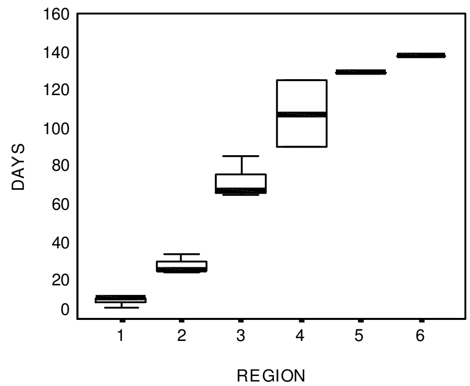

Figure 4.6 Estimated time in days to reach each region (averaged over 3 years). Dark line = mean number of days.

Recruitment indices calculated using 0^+ fish caught up to the month of peak abundance (Table 4.1) and indices calculated using all fish caught over the entire sampling period (Table 4.2) were not found to be significantly different (paired samples t-test, t=2.968, $.005 < p < .01$). The most notable discrepancy between the two techniques occurred within region 3 during 1996 and it would be impossible to conclude with any degree of certainty which index is most representative of fish abundance in that region at that time. However, sampling continued throughout the year at two sites within regions 1 and 3 and it is considered that for purposes of inter-site comparisons, the recruitment indices calculated to peak abundance should be used.

With only minor inconsistencies, both series of recruitment indices for the 6 regions (Figure 4.7, Figure 4.8) displayed contrasting trends between locations situated on either side of the Great Australian Bight. In South Australia a year of strong recruitment, as measured by 1996 indices, was followed by a year of relatively weak recruitment and then, with the exception of region 6, a general increase in recruitment in 1998. These trends were not evident in Western Australia where recruitment strength in all regions apparently increased in 1997 rather then decreased. With the exception of region 3, indications of a further slight increase in recruitment were evident in 1998. To examine more closely possible linkages between recruitment indices and predicted transport distance, each region is analysed individually (Figure 4.9) on the general assumption that higher recruitment indices represent periods of stronger transport and consequently lower predicted travel times to regional mid-points. Unless otherwise noted the recruitment indices discussed in the following paragraphs represent a general trend indicated by both methods of index estimation. Also, where the estimated transport duration is predicted to exceed the 155 day time-frame of the model run, the maximum value of 155 days is assigned to that data point.

Region 1 is located close to the spawning grounds which may confound possible relationships between pre-recruit index and model transport prediction as there is comparatively little distance and time in which trends may be established and identified by the transport model. However low indices in 1996 do appear to result in longer transport times to the 200km way-point. A slightly higher index the following year does not correspond with a decline in transport time, though a sharp decline in predicted transport duration is indicated in 1998, commensurate with a further increase in the pre-recruit index for that year.

The number of days to arrive at the 600km way-point within region 2 was highest in 1996 which corresponds with low pre-recruit index. An increase in the index is mirrored (i.e. negative relationship) in 1997 with a decrease in predicted travel time but a further minor increase in index for 1998 results in only a 1 day differential (increase) in travel time.

Somewhat paradoxically, the highest recruitment index for region 3 occurred during the 1997 season which the model flags as the weakest year in terms of transport strength. This region also produced conflicting recruitment indices with the index calculated to the month of peak abundance duplicating the pattern of transport duration to the 1200km point and diverging from the index calculated using the entire season's data.

Trends displayed by both indices and transport times in region 4 appear to best summarise the underlying assumptions of this analysis. For each year sampled and modelled the number of days to reach the 1800km waypoint in this region appears to be strongly negatively correlated with the respective pre-recruit index, although with a time series of only 3 years a meaningful statistical measure of the strength of this apparent relationship is not feasible.

A similar relationship may be observed to exist for region 5, though the time limit of 155 days is exceeded in both 1997 and 1998 seasons. Low recruitment indices for these years agree with the model in identifying a possible failure of the transport process to the 2300km point of this region.

Again, a similar pattern is demonstrated in the final region, with fish failing to be transported in significant numbers (though what constitutes 'significance' in this case remains unknown) to the 2500km end-point within region 6. At this point it should be borne in mind that the model does not predict that no fish at all will be transported to the distal regions of South Australia in years of poor recruitment due to hypothesised variations in transport strength, but simply attempts to quantify in terms of approximate number of days required to travel a certain distance by a single representative fish spawned on May 15th for the years 1996-1998.

Table 4.1 Recruitment indices (+ SE) by sampling region calculated to peak abundance.

Year	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
1996	0.6348	0.9398	2.1973	2.4590	2.3023	1.4348
	(0.31)	(0.43)	(0.45)	(0.58)	(0.81)	(0.49)
1997	1.2739	1.8826	3.6698	1.0602	0.8641	1.0260
	(0.32)	(0.43)	(0.47)	(0.43)	(0.41)	(0.41)
1998	1.4921	2.2673	2.1671	2.6105	1.2143	0.8598
	(0.28)	(0.44)	(0.45)	(0.39)	(0.41)	(0.39)

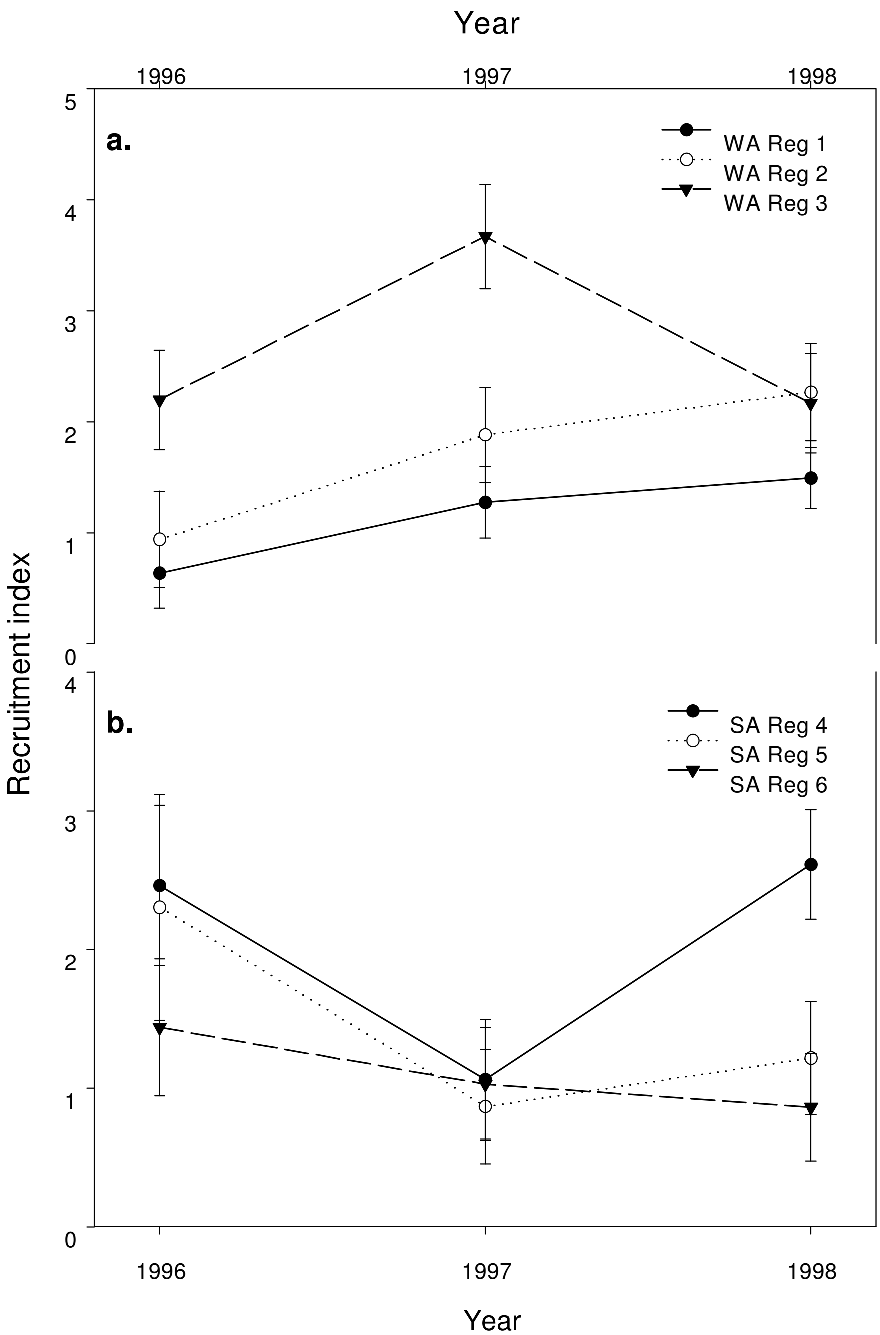

Figure 4.7 Recruitment indices calculated to peak abundance by sampling region (a. WA; b. SA).

Table 4.2 Recruitment indices (+ SE) by sampling region calculated using all data.

Year	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
1996	0.2552	0.2484	2.8987	2.1805	2.1789	1.7445
	(0.26)	(0.36)	(0.36)	(0.41)	(0.60)	(0.50)
1997	0.8567	1.1272	2.5718	0.7186	0.5602	0.5611
	(0.24)	(0.34)	(0.33)	(0.40)	(0.41)	(0.38)
1998	1.3683	1.3182	2.1484	2.3306	1.1139	0.6554
	(0.27)	(0.36)	(0.41)	(0.40)	(0.41)	(0.41)

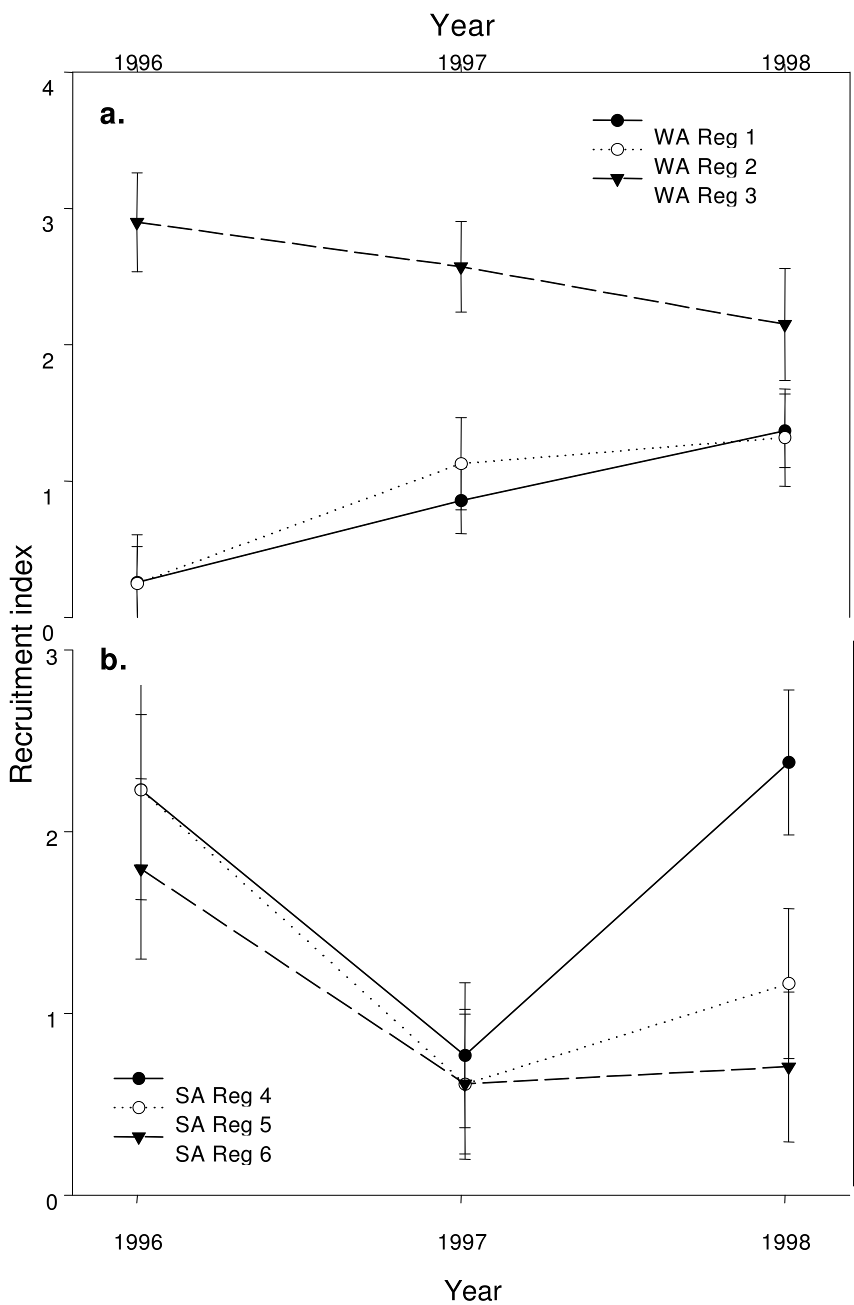

Figure 4.8 Recruitment indices calculated using all data by sampling region (a. WA; b. SA).

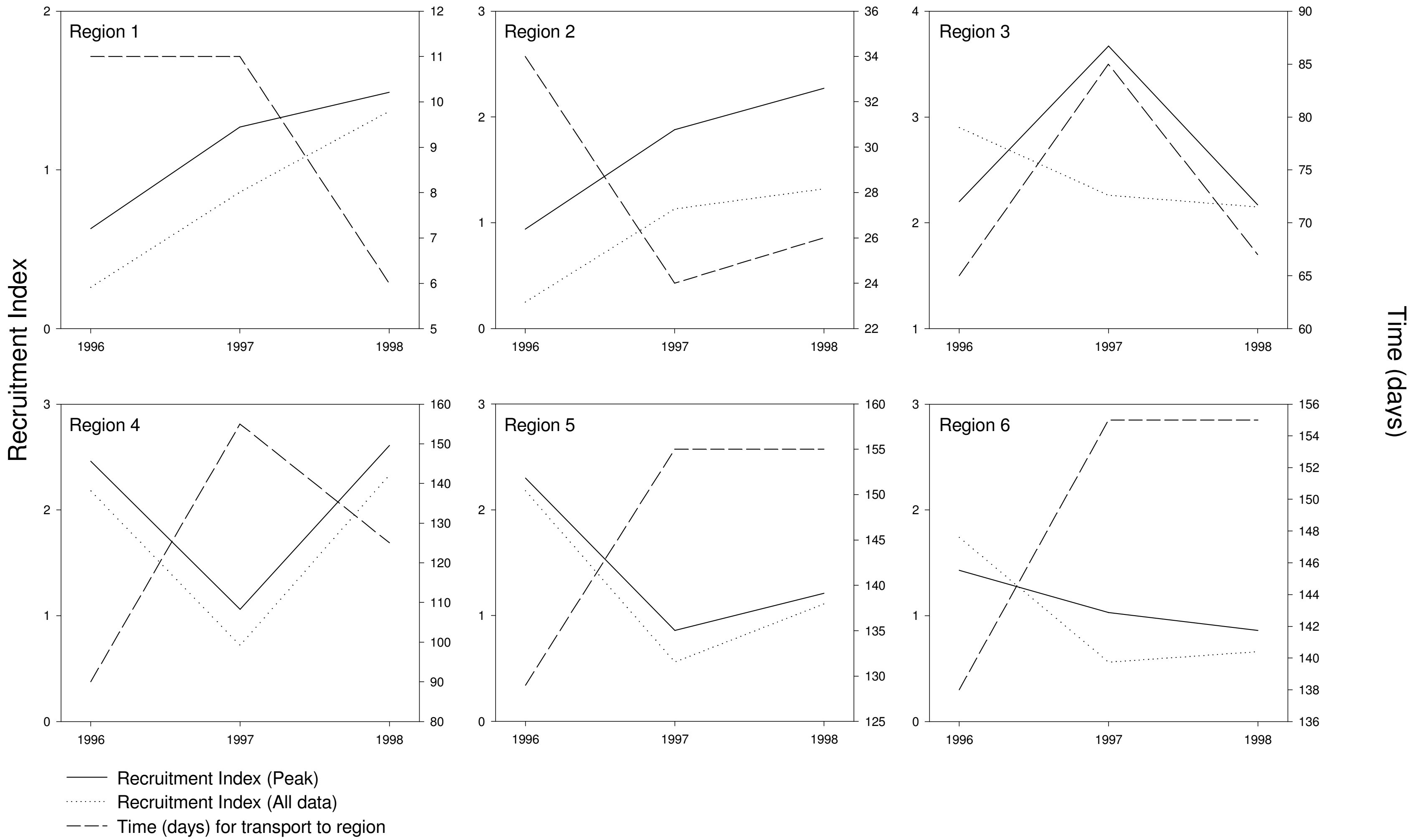

Figure 4.9 Plots of pre-recruit index and predicted travel time to region mid-point (days) by region.

In order to elucidate further the influence of wind speed and direction on the eastward transport of larvae and juveniles a simple 4-way (N,S,E,W) trajectory plot was generated (Figure 4.10). This facilitates an examination of the varying wind regimes acting on each year's transport process. Even with the contributions of oceanic current and active swimming by Australian herring removed, the 1996 wind currents followed a trajectory with a higher easterly component than those reproduced for 1997 and 1998. Although 1997 experienced the lowest observed recruitment to SA, winds in that year displayed a relatively high easterly component. This apparent advantage may have been offset, however, by an extended period during the final stages of the transport period of winds counter to the eastward direction. Winds in 1998 also experienced a period of high directional instability at about 2/3 distance. Interestingly, a north-east or cross-shelf vector was established under the influence of a south-west wind in all years during the eastern 1/3 of the transport process, which may assist in driving the fish toward South Australian nursery areas. These wind processes may have even greater implications for recruitment to nursery areas east of Angas Inlet, to the extreme range of Australian herring distribution.

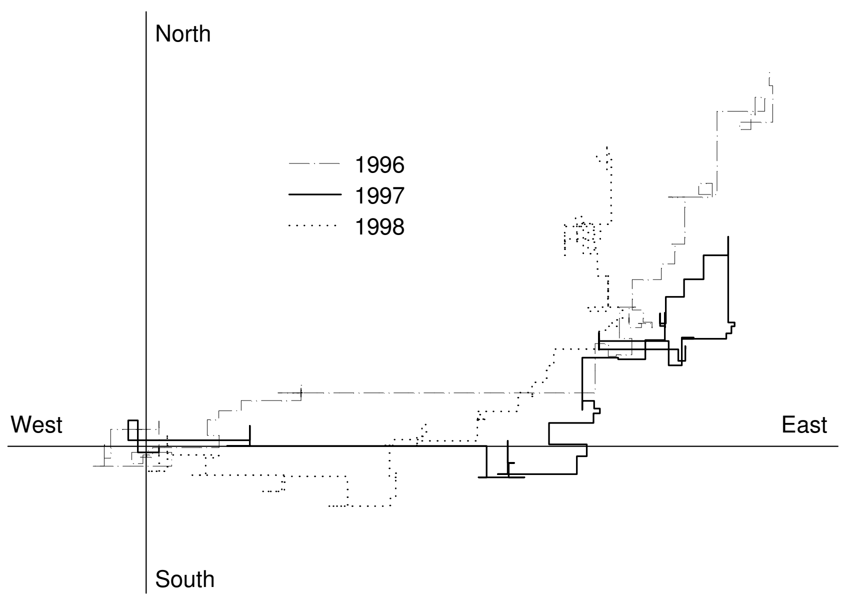

Figure 4.10 Trajectory plot of wind-generated currents for the years 1996-1998 (units of distance arbitrary, but relative to each other).

Discussion

The transport of Australian herring larvae from Western Australian spawning grounds to South Australian nursery areas is complex and involves a variety of mechanisms and water masses. The implications of the model explored in this study are that Australian herring are well-adapted to a particular transport regime which they appear to take advantage of through a relatively brief, single spawning period and thus, deviations from this regime could prove to be a major factor in determining the relative strength of recruitment to nursery areas along the southern Australian coast.

To summarise the combined outcomes of both the recruitment indices and the transport model over the years 1996-1998, the apparent underlying factor determining the degree of recruitment success experienced by a particular year-class is dependent on whether sufficient eastward movement can be generated by a union of oceanic and wind-induced currents to enable post-larval Australian herring to cross the geographical divide presented by the Great Australian Bight. It would appear that a failure of suitable winds or current or both may result in Australian herring failing to successfully negotiate the Bight in numbers, resulting in disproportionately higher recruitment to WA nursery areas, particularly the eastern-most areas encompassed by region 3 in this study. This would explain why, in years of low recruitment indices generated for SA sites (assumed to identify a reduction in strength of transport processes), WA sites are misleadingly represented by higher indices, indicating strong transport when in fact the contrary is quite likely to be true.

It is not known whether the strong recruitment which evidently took place in eastern WA and SA during 1996 represents a common or infrequent event caused by an unusual conjunction of several environmental effects culminating in variations in recruitment strength similar to those which have been described for other species (Van der Veer *et al.* 1990; Polacheck *et al.* 1992). However, in temperate waters, the role of wind-driven currents or Ekman transport is becoming increasingly clear (Bailey 1981; Checkley *et al.* 1988; Simpson 1987; Johannessen and Tveite 1989) as a fundamental factor in affecting recruitment. Consequently, recruitment patterns will inevitably be subject to the unpredictable and highly variable meteorological patterns common to the region over which they operate. Larval and juvenile recruitment of fish species such as Australian herring, which demonstrate restricted or relatively brief spawning periods, are far more vulnerable to episodic environmental events then those with a more protracted spawning period (Shenker *et al.* 1993). These effects on Australian herring recruitment are likely to be attenuated due to the duration of the advection process to the South Australian coastline.

Timing as well as duration of the Australian herring spawning period may also manifest itself as a critical factor in determining successful juvenile recruitment to SA nurseries. The Leeuwin current is believed to be strongest from April to August (Cresswell 1991) and Australian herring spawning appears to take place over a short period of time during this period. Normally, current strength across the Great Australian Bight declines rapidly during the early winter months, reducing the net eastward current velocity. Leeuwin current strength has also been linked to fluctuations in the Southern Oscillation Index, with an overall reduction in current strength during El Nino years (Lenanton *et al.* 1991) and it is likely that a relatively late spawning, occurring during an El Nino year may predispose a year-class to poor recruitment to South Australia. Any coincident period of instability in the prevailing wind-patterns would then be likely to assure a general failure to recruit to the eastern range of Australian herring distribution.

Because Australian herring are not recruited into the commercial fishery until they are several years old, WA catches would not be expected to reflect fluctuations in the magnitude of juvenile transport until approximately 3 years after initial dispersal from Western Australian spawning grounds. At the time of writing, high numbers of Australian herring were observed on WA south coast beaches which appears to confirm the influx of large numbers of fish from the strong 1996 year class. However, a lack of market demand resulted in low south coast trap net commercial catches. If this apparent linkage between strong recruitment to SA nursery areas and subsequent increases in commercial catch several years later does exist, failure in the transport process may result in significant mortalities of larval and juvenile fish in years of poor recruitment to SA areas.

Recruitment indices generated by this study do indicate that juvenile recruitment to WA is higher in years of weaker transport processes, but fluctuating historical commercial catch data would suggest this does not fully compensate for fish lost. It is possible that year-class abundance is linked to juvenile recruitment success to South Australian nursery areas.

This model does not include considerations of interannual spawning biomass variation as little information is available, focusing instead on the processes of transport as the primary factors influencing recruitment. However, should biomass estimates become available it may be useful to include them in the model, though they may not fluctuate significantly enough to influence recruitment (Bailey 1981). Similarly, no consideration of the interannual effects of variable larval stage growth and mortality on recruitment was attempted, partly because these factors lie outside the scope of this study, but also due to lack of information on the early life-history of the Australian herring. Fluctuations in larval survival rates have been correlated with juvenile-stage recruitment indices in other fish species (Miller *et al.* 1988; Rutherford *et al.* 1997) and it may also be useful to consider these effects in future investigation of recruitment variability in Australian herring.

Some consideration of biological contributions to the transport mechanism were included in the current model. Australian herring larvae may be capable of using a number of mechanisms, including directed swimming, to move from oceanic waters to juvenile habitats. Definitive conclusions are not possible but it is reasonable to assume that the pelagic juvenile stages are able to have a strong influence on their own fate in the pelagic environment (Thorrold *et al.* 1994). It would be useful, within the context of modelling the transport process, to know if Australian herring are able to act in a similar manner to many fish species (Shenker *et al.* 1993; McFarland *et al.* 1985) and occupy various strata of the water column to take advantage of more rapid horizontal transport. Because currents may vary substantially with depth, especially if they are produced by winds, fish larvae may modify drift by controlling their vertical position in the water column, acting to modify their transport and adding a biological component to the velocity vectors (Power 1984).

The final component of Australian herring transport from spawning grounds to nursery areas is movement across the shelf itself. Two potential mechanisms exist: wind-driven flow and active horizontal swimming. Directed swimming by juvenile pelagic fish has rarely been invoked as a horizontal transport mechanism with some exceptions (Hare and Cowen 1996), but in the case of

Australian herring a degree of self-determination must be essential if fish are to cross the shelf into nursery areas. By the time they are in SA waters Australian herring are capable of contributing a significant component of the overall transport vector. However, the mechanism by which they orient their swimming behaviour at this stage remains unknown. It is possible that they orient themselves in relation to the west-east current, wave direction (Cook 1984) or even navigate geomagnetically (Power 1984).

Studies of other species have identified a reduction in swimming capacity at lower temperatures (Beamish 1978; Bernatchez and Dodson 1985; Dabrowski *et al.* 1988) and higher turbulence (Chesney 1989) and further exploration of active swimming by Australian herring as a component of the transport process may benefit from assessment of sea-surface temperatures and surface turbulence using readily available remotely-sensed data over the latter stages of the advection period.

Conclusions

This study represents a preliminary investigation of a coupled biological-physical model of larval transport. Future research should focus on investigating each component of the transport process separately, e.g. laboratory studies of swimming ability and perhaps orientation mechanisms, ichthyoplankton surveys along the suspected transport route with concomitant collection of current flow data. Some investigations incorporating shore angles into the model may also be warranted. A similar investigation into Australian salmon recruitment may prove a useful comparison in fully understanding the transport processes influencing successful recruitment of juvenile arripid species to SA nursery habitats.

The overall conclusions from our field evidence and dispersal model pose important implications for the regional population dynamics and management of Australian herring. Specifically, if the results of this exploratory study can be confirmed and extended to explain fluctuations in recruitment to the Port River-Barker Inlet estuary as measured over a 15 year time-series by Jones, Dimmlich and Partington (unpublished data) then the simple 3-component model described here may be utilised as a low-cost, minimal-effort tool in determining the probable recruitment strength of a particular year class to various regions of the southern Australian coastline without the need for extensive sampling of juveniles in the field. These predictions may provide the fishing industry and fishery managers with knowledge of fluctuations before these fluctuations impact the fishery. Predicted recruitment strength should become manifest as an increase in commercial and recreational fishery catch some 2 years later in SA and 3 years later in WA (Dimmlich and Jones 1997). With further refinements to the basic model developed here, recruitment strength projections could be used as an independent baseline measure against which to measure other impacts on Australian herring stocks such as declines in spawning biomass.

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CHAPTER 5. AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*) CATCHES IN WESTERN AUSTRALIA AND SOUTH AUSTRALIA: THE INFLUENCE OF TIME OF DAY AND SEINE NET LENGTH

S. G. Ayvazian, H. Cheng, G. Nowara, W. Dimmlich and D. Fleer

Objective 3: Develop a more useful, ongoing index of recruitment of immediately post-settled juvenile Australian herring that settle into shoreline nursery areas between Geographe Bay in Western Australia and the Coorong Estuary in South Australia.

Diel cycles can influence the species composition and abundance of fish assemblages in temperate nearshore and estuarine habitats. These variations can be problematic if they have not been recognised and the information is to be used for fisheries assessment research. In order to design a rigorous sampling plan for the development of an index of recruitment we evaluated the influence of diel variation and two seine net lengths on the abundance of 0^+ and 1^+ Australian herring in Western Australia and South Australia. The results for the day - night variation were not consistent between sites in each state. At Koombana Bay, Western Australia, the 0^+ Australian herring were significantly more abundant during the day compared to the night. Only six 1^+ fish were caught during the entire sampling period and the catch data were not analysed further. At James Beach, South Australia, the 0^+ fish did not show day - night differences in abundance, however, the 1^+ - 3^+ fish moved inshore at night and showed significantly higher abundance than during the day. These results suggest that the day-night pattern of habitat use for juvenile Australian herring may be site specific. A comparison of the catches of Australian herring collected from a 61 m and 120 m seine net showed no significant difference in the catches of Australian herring in either WA or SA. Future sampling regimes to maximise the likelihood of catching juvenile Australian herring must take diel variation into account. This information can then be used with confidence to develop an index of juvenile recruitment.

Introduction

Diel cycles can influence the species composition and abundance of fish assemblages in temperate nearshore and estuarine habitats (Helfman 1993). These variations can be problematic if they have not been recognised and the information is to be used to estimate population size for fisheries assessment research (Konstantinov 1964). Changes in the day-night species composition may result from temporal partitioning of the available habitat in response to prey availability, avoidance of predators and maintaining favourable environmental regimes (Gibson *et al.* 1996). Additionally, many species may exhibit gear avoidance during the daylight period (Hoese *et al.* 1968; McCleave and Fried 1975).

While investigations of the composition and abundance of day-night assemblages of shallow water temperate fishes remain sparse (see Rooker and Dennis 1991; Helfman 1993) several generalisations can be made based on the existing literature. Comparison of the total number of individuals, the total biomass and the number of species present in seine net and/or trawl samples has been compared between day and night samples. Predominantly, night collections contain significantly greater values than the corresponding day collections for at least one of the three measures of abundance e.g. total number of individuals, total biomass and total number of species (Hoese *et al.* 1968; Horn 1980; Allen and De Martini 1983; Ross *et al.* 1987; Roundtree and Able 1993; Gibson *et al.* 1996; Young *et al.* 1997). However, McCleave and Fried (1975) showed a lower number of fish and an equal number of species at night compared to day collections from a cove in Maine; and Grant and Brown (1998b) showed greater numbers of 0^+ cod during the day when they are shoaling and a decline following dispersal from the shallows at night in Newfoundland.

In an attempt to better describe observed diel differences these results have been used to support the lack of a distinctive 'day-night' assemblage amongst temperate marine fish assemblages (Helfman 1993), species specific diel activity patterns (McCleave and Fried 1975), prey availability (Grant and Brown 1998a), and visually mediated gear avoidance (McCleave and Fried 1975; Romer 1990). Confounding these considerations are fluctuations in assemblages between seasons (Nash 1986; Nash *et al.* 1994), light levels (Nash 1986; Nash *et al.* 1994), and tidal influences (Gibson *et al.* 1996). Additionally, the choice of sampling gear may influence estimates of abundance and patterns of distribution (Leber and Greening 1986; Dewey *et al.* 1989). The contrasting results from the above studies, and the complexity of the interactions, demonstrate the need to understand the diel activity pattern for the species under investigation to ensure an appropriate sampling design and an accurate assessment of abundance.

This research reports the results of a day-night sampling experiment and a seine net comparison trial designed to quantify the variation in juvenile Australian herring distribution and abundance on a Western Australian and a South Australian beach. Australian herring is an abundant, pelagic fish distributed between Shark Bay, Western Australian and Port Phillip Bay, Victoria. They are among the top 5 'bread and butter' recreational species in Western Australia and South Australia, and they support a commercial fishery in each state (Chapter 1). Preliminary investigations of the spatial and temporal patterns of abundance of 0^+ Australian herring at 25 locations between Perth, W.A. and Adelaide, S.A. indicated that Koombana Bay, Western Australia and James Beach, South Australia were locations where newly settled Australian herring were abundant during the late winter and spring.

In order to investigate the diel effects on recruitment variability of juvenile Australian herring, day and night seine net collections were taken at Koombana Bay, W.A. and James Beach, S.A. to examine (1) whether the relative abundance of Australian herring differs between day and night samples; (2) how abundance and distribution are affected by sampling location along the beach; (3) the depletion rate of catching Australian herring by continuous sampling and (4) to compare the variation in abundance between fixed and random sampling sites. Additionally, a 61 m and a 120 m seine net were used each season between October 1996 and December 1997 to examine differences in the abundance of 0^+ Australian herring.

Material and Methods

Diurnal-Nocturnal Sampling

Site description

Koombana Bay is a north-westerly facing sandy embayment near the mouth of the Leschenault Estuary (33^0 17' S, 115^0 47' E) located in Bunbury, Western Australia (Chapter 4, Figure 4.1). During the summer and autumn months the north-western exposure protects the beach from prevailing south-west winds leaving the embayment calm. Sampling was undertaken at the southern end of Koombana Bay with the beginning of the sampling area delineated by the presence of a 75 m rock groyne.

James Beach is a westerly facing sandy beach located near Ceduna on the west coast of South Australia (32^0 11' S, 133^0 27' E) (Chapter 4, Figure 4.1). The eastern portion of the beach is exposed to low to moderate surge while the western portion is sheltered from surge and swell by an offshore tapeweed (*Posidonia australis*) meadow and limestone reef complex. Sampling was undertaken on the sheltered western end of the beach, onshore of the limestone reef complex.

Sampling methods

Examination of day-night differences in the abundance and distribution of Australian herring was undertaken using a 61 m long beach seine net with 29.1 m wings (22 mm mesh), a 2.4 m bunt (8 mm mesh) and which sampled to a depth of 2 meters. The seine net was deployed from a small dinghy and, when set in this fashion, swept an area of 592.2 m^2. All Australian herring were removed from the seine nets and returned to the laboratory.

Sampling protocol

The experimental protocol was designed in order to examine spatial and temporal differences in abundance of Australian herring between fixed and randomly chosen sites, day and night, and sequential days. Preliminary analysis of two and a half years of monthly diurnal sampling data for Australian herring at 25 nearshore sampling sites between Perth and Adelaide indicated that the abundance of Australian herring was consistently higher at Koombana Bay, WA and James Beach, SA than at other sampling sites, particularly during the full moon phase (Ayvazian, unpublished data). Consequently, the day-night experiment was undertaken at these sites. When possible sampling dates were chosen to coincide with the full moon increasing the likelihood of high catches. In order to maximise catches of 0^+ Australian herring, the sampling was conducted in the late spring to coincide with the peaks in juvenile settlement in the nearshore habitat.

The sampling period was six consecutive days starting on the first day of November and December 1998 at Koombana Bay, and the 15th day of October and the first day of November 1998 at James Beach. The October sampling in SA occurred during a new moon phase, while the November and December sampling coincided with the full moon. On days 1, 2, 4, and 6, four-day and four-night seine net hauls were completed. On day 3, only four-day samples were collected and day 5 was a 'no sampling' day. Both beaches were divided into two blocks, and in each block, one fixed site (F1 and F2) and three random sites (R1, 2, 3 and R4, 5, 6, for blocks 1 and 2 respectively,) were established. During the day, F1 was sampled first followed by one of the three randomly selected sites in block 1, then F2 was sampled and one of the three randomly selected sites in block 2. During the night, one of the three randomly selected sites in block 1 was sampled first followed by F1, and then one of the three randomly selected sites in block 2 and finally F2. The day seine hauls were taken between 8:00 and 11:00 and the night seine hauls were taken between 20:00 and 23:00 (Table 5.1). This experimental design allowed for a carry over effect analysis to examine whether repeated sampling had an effect on subsequent catches.

Table 5.1 Experimental sampling design for day-night sampling of Australian herring.

Time (hr)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
8:00 – 8:45	shot1 (F1)	shot1 (F1)	shot1 (F1)	shot1 (F1)		shot1 (F1)
8:45 - 9:30	shot 2 (R1,2,3)	shot 2 (R1,2,3)	shot 2 (R1,2,3)	shot 2 (R1,2,3)		shot 2 (R1,2,3)
9:30 - 10:15	shot 3 (F2)	shot 3 (F2)	shot 3 (F2)	shot 3 (F2)		shot 3 (F2)
10:15 - 11:00	shot 4 (R4,5,6)	shot 4 (R4,5,6)	shot 4 (R4,5,6)	shot 4 (R4,5,6)		shot 4 (R4,5,6)
20:00 - 20:45	shot 5 (R1,2,3)	shot 5 (R1,2,3)		shot 5 (R1,2,3)		shot 5 (R1,2,3)
20:45 - 21:30	shot 6 (F1)	shot 6 (F1)		shot 6 (F1)		shot 6 (F1)
21:30 - 22:15	shot 7 (R4,5,6)	shot 7 (R4,5,6)		shot 7 (R4,5,6)		shot 7 (R4,5,6)
22:15 - 23:00	shot 8 (F2)	shot 8 (F2)		shot 8 (F2)		shot 8 (F2)

Data analysis

Australian herring were counted, and each fish measured (total length to the nearest mm) and weighed (to the nearest 0.01 g). The abundance of Australian herring from each seine net haul was expressed as the number per haul.

The influence of the independent factors; month, sampling day, day versus night, block, site within block, and carry over effect between seine net hauls on the abundance and distribution of Australian herring was assessed using analysis of variance testing (SAS 1988). These data have been log (x+1) transformed prior to analysis in order to account for the skewness of catch rate data.

Seine net comparisons

Catches of Australian herring were compared between the 61 m (details of net construction above) which swept an area of 592.2 m^2 and a 120 m long beach seine net (comprising 30 m wings of 30 mm stretch mesh and a 60 m bunt of 10 mm mesh) which sampled an area of 2,292 m^2. The abundance of Australian herring caught with each net was compared from the following sampling locations: Koombana Bay and Toby's Inlet in Western Australia during October and December 1996, and July, October and December 1997; and at Barker Inlet, Coobowie, Pt. Moorowie and Wool Bay in South

Australia during October 1996, and January and February 1997. At each of these locations, three replicate hauls were undertaken with both the small and large seine nets in a randomly assigned manner.

Data analysis

Australian herring were counted, and each fish was measured (total length to the nearest mm) and weighed (to the nearest 0.01 g). The abundance of Australian herring from each seine net haul was expressed as a density (number of fish per 1000 m^2) and log (x+1) transformed prior to analysis of variance testing in order to satisfy assumptions of normality. One way analysis of variance was performed for each location and each season to compare the abundance of Australian herring captured with the two seine nets.

Results

Diurnal-Nocturnal Sampling

In Koombana Bay, newly settled 0^+ (young of the year) Australian herring were significantly more abundant during the day than at night (P=0.0001) with an average (± 1 SE) of 20.00 (± 5.18) and 1.22 (± 0.34) fish caught during the day and night, respectively (Table 5.2). In contrast, no significant relationship was observed for month of capture (P=0.527) or between the five sampling days in each of the months (P=0.793) (Table 5.2).

Table 5.2 Summary statistics from the day versus night sampling program at Koombana Bay, Western Australia. * denotes statistical significance P < 0.05

			0^+ Australian herring		
			Mean	± 1 SE	P
Factor	Variable	N			
Month	November	36	13.19	4.96	0.527
	December	36	10.11	3.68	
Diel	Day	40	20.00	5.18	0.000*
	Night	32	1.22	0.34	
Day	1	16	16.06	8.44	0.793
	2	16	3.25	1.41	
	3	8	21.50	10.85	
	4	16	11.31	8.04	
	6	16	11.06	5.16	
Block	1	36	19.25	5.69	0.046*
	2	36	4.06	1.62	
Site	1	18	32.67	10.18	0.020*
	2	5	5.00	3.87	
	3	6	12.33	7.82	
	4	7	0.86	0.40	
	5	18	5.89	3.05	
	6	4	1.50	1.50	
	7	9	3.11	1.98	
	8	5	1.20	0.80	

ANOVA showed that block 1 had a significantly greater abundance of the young of the year Australian herring than block 2 (P=0.046), with an average (± 1 SE) of 19.25 (± 5.69) fish in block 1 compared to 4.06 (± 1.62) fish in block 2 (Table 5.2). There was a significant difference in the abundance of 0^+ Australian herring between sites nested within block (P=0.020) with F1 having the highest average abundance of fish (32.67 ± 10.18) followed by R2 (12.33 ± 7.82) (Table 5.2). There was no statistically significant carry over effect, measured as the influence of the catches from the first seine haul on the sequential catches from the three seine hauls from the day and night sets, respectively within each block (P=0.089). Similarly, there was no statistically significant carry over effect between catches from fixed sites between each day and night pair (P=0.211).

The abundance of newly settled young of the year Australian herring caught at James Beach during October and November showed no statistically significant relationship with any of the independent factors; month (P=0.726), day versus night sampling (P=0.107), sampling day (P=0.061), block 1 versus block 2 (P=0.778), and site within block (P=0.324) (Table 5.3). The carry over effect showed no statistically significant relationship between the catches of the first seine haul to the sequential three hauls (P=0.761) or from catches from the fixed sites between each day and night pair (P=0.693).

Table 5.3 Summary statistics from the day versus night sampling program at James Beach, South Australia. * denotes statistical significance P < 0.05.

			0^+ Australian herring			1^+- 3^+ Australian herring		
			Mean	± 1 SE	P	Mean	± 1 SE	P
Factor	Variable	N						
Month	October	36	1.22	0.69	0.726	8.78	2.85	0.233
	November	36	0.97	0.60		7.72	3.47	
Diel	Day	40	1.73	0.79	0.107	0.33	0.14	0.000 *
	Night	32	0.31	0.14		18.16	4.46	
Day	1	16	0.56	0.44	0.061	16.87	7.64	0.217
	2	16	3.44	1.86		7.38	20.67	
	3	8	0	0		0.25	0.25	
	4	16	0.06	0.06		9.13	5.30	
	6	16	0.88	0.49		3.63	1.90	
Block	1	19	0.58	0.38	0.778	8.05	4.50	0.647
	2	53	1.28	0.60		8.32	2.59	
Site	1	1	0		0.324	0		0.252
	2	18	0.61	0.40		8.50	4.74	
	4	35	1.89	0.90		8.57	3.35	
	5	10	0.20	0.20		11.50	7.09	
	6	8	0	0		3.25	2.18	

Similarly, the abundance of 1^+ Australian herring caught at James Beach, SA during October and November showed no statistically significant relationship between months (P=0.233), sampling day (P=0.217), block 1 versus block 2 (P=0.647), site within block (P=0.252) (Table 5.3) and carry over effect between the catches of the first seine haul to the sequential three hauls (P=0.143) or from catches from the fixed sites between each day and night pair (P=0.843). However, there was a statistically significant relationship between the day and night samples (P=0.000), with a greater average abundance of Australian herring in the night samples than the day samples (night = 18.16 ± 4.46: day =0.33 ± 0.14) (Table 5.3).

Seine net comparisons

Comparison of 0^+ and 1^+ Australian herring catches from a 61 m and 120 m seine net at Koombana Bay, and Toby's Inlet on Geographe Bay, revealed no statistically significant relationship between the density of Australian herring and the length of the two seine nets for the months sampled at either Koombana Bay (P=0.239) or Toby's Inlet (P=0.454).

In South Australia, there were sufficient data for analysis at Point Moorowie only. The density of Australian herring showed no statistically significant relationship with either seine net (P=0.80).

Discussion

Australian herring are a commonly occurring finfish in the nearshore waters along the southern Australian coastline. In both Western Australia and South Australia they are a highly sought after recreational species and form part of a mixed coastal and estuarine commercial fishery. Newly settled 0^+ Australian herring are first captured in July in Western Australian waters, with peak abundances reported between October and December, while a two to three month lag period applies to the time of first capture and peak abundances of Australian herring in South Australian waters. While this study focused on the collection of newly settled Australian herring from nearshore areas, they have also been caught in deeper waters, sometimes in association with other fish species. In order to develop an index of juvenile recruitment for this species to be used as an indicator of future commercial catches it was necessary to consider day-night variation in abundance and design a sampling regime which accounts for these differences in abundance. Complications involved with estimating fish abundance for stock assessment research based on only day or night trawls has been discussed for diurnal vertical migratory demersal fish (Konstantinov 1964).

The pattern of activity of 0^+ Australian herring at Koombana Bay may have developed in response to prey availability, predatory avoidance and/or favourable environmental conditions at this site. Koombana Bay is a sheltered sandy beach with little wave action. The first sampling site (F1) was approximately 10 m from a rocky groyne where the 0^+ Australian herring shoal, perhaps to avoid predation by larger fish and birds. The concentration of fish at this site accounted for a significant proportion of the observed variation in day - night abundances. In contrast, James Beach is a more exposed sandy beach site lacking any structures around which the young of the year fish might congregate and their distribution may be uniform throughout the nearshore during the day. The catches of 0^+ Australian herring from James Beach were low, making it difficult to draw conclusions about patterns of distribution. Catches of 0^+ Atlantic cod were always higher during the day than the evening, when the young of the year were in shoals foraging on zooplankton (Grant and Brown 1998a,b).

During the present study, the 1^+ - 3^+ Australian herring also showed contrasting patterns of habitat usage between the Western Australian and South Australian sites. While numbers of 1^+ - 3^+ fish were limited at Koombana Bay, these age classes were abundant at James Beach, particularly at night. Grant and Brown (1998b) indicated the shoreward migration of foraging 1-3 year old cod at night for feeding caused the dispersal of the shoals of 0^+ cod. Nash *et al.* (1994) has demonstrated a greater nighttime abundance of five species of juvenile flatfish at Port Erin (Isle of Man) during certain months of the year. These older age classes of Australian herring may be using the nearshore as a refuge from daytime predation and as a feeding area. The November sampling period coincided with the full moon, however there were overcast skies for all but one evening. The greatest catches of Australian herring occurred during the overcast night, with fish seen scattering during the moonlit night. October collection which occurred during the new moon were consistent over the night time samples.

The low abundances of 1^+ - 3^+ year old Australian herring in Western Australia and the 0^+ year class in South Australia, during this study, make it difficult to elucidate diel patterns of habitat usage at Koombana Bay and James Beach. It may be necessary to repeat this experiment during other months or at other sampling sites in order to construct an accurate representation of the abundance and distribution of the juvenile life history stages of this species.

Diel fluctuations in temperate fish assemblages, measured by the number of species caught during the day and night, and the number and biomass of individuals per species has been reported for tidal cove (McCleave and Fried 1975), estuarine (Horn 1980; Young *et al.* 1997; Gray *et al.* 1998), inlet (Hoese *et al.* 1968), surf zone (Ross *et al.* 1987; Romer 1990), and nearshore beach habitats (Allen and DeMartini 1983; Nash *et al.* 1994). McCleave and Fried (1975) reported equal numbers of species and fewer individuals caught at night in a tidal cove in Maine, USA; which was a result of feeding preferences. Day-night collections of fish assemblages from a surf zone beach in South Africa showed the same species composition; however the number of individuals per species indicated, generally, a more abundant daytime assemblage (Romer 1990).

However, the most common pattern suggests a greater species diversity, individuals per species and/or biomass per species, caught during night sampling (Gibson *et al.* 1996, Horn 1980, Hoese *et al.* 1968). Additionally, while this diel variation exists few studies have shown a unique day and night assemblage (Gibson *et al.* 1996; Helfman 1993). Day-night differences may be the result of several factors including; life history stage, decreased net avoidance at night, increased prey availability, feeding behaviour, and diminished risk of predation from piscine and avian predators. In addition, a marked change in daylight hours between seasons at high latitudes has been shown to alter the structure of the shallow water fish assemblage (Nash 1986).

Variation in the abundance and distribution of fishes on a Scottish sandy beach was examined over tidal and diel cycles during two months (Gibson *et al.* 1996). While the greatest changes in the species composition were related to the tidal cycle, there were subtle changes in the composition over the diel cycle with slightly more species collected at night. Some species were more abundant in the nearshore at night, making an onshore migration at dusk and returning offshore at dawn. This pattern was shown most clearly by four gadoid species and one species of flatfish. While Gibson *et al.* (1996) found it difficult to draw any firm conclusions, they suggest that this movement pattern may be in response to prey availability, predation pressure and physio-chemical conditions. Young *et al.* (1997) demonstrated greater abundance of finfish collected at night in the Moore River Estuary. The nighttime ichthyofauna were represented by small species or juveniles of larger species which may move into the shallows to avoid predation by avian piscivores during the day. A similar diel pattern was shown in a marsh creek assemblage with high abundances of the small atherinid species, dominating the nighttime catch. However, Ross *et al.* (1987) showed that the density or standing crop of fishes from a Gulf of Mexico surf zone did not vary significantly between day and night collections; but the average weight of individual fish was significantly greater at night suggesting that larger fish move into the nearshore shallows at night.

Generally, authors agree that day - night variation results from the interaction of a suite of factors. Sampling programs designed to estimate the abundances of a species, particularly in fisheries assessment research, must investigate day and night abundances, in order to establish a sampling regime which will provide the most accurate estimates of population abundance. Clearly, the results of this study support this contention as it is important to understand the day - night variation in abundances of 0^+ Australian herring in WA and SA waters before designing a sampling regime to estimate an index of juvenile recruitment.

The seine net comparison indicated the catches of Australian herring were not significantly different between the small and large net at the two Western Australian and one South Australian shallow nearshore sampling sites. The 120 m seine net covers approximately four times the area as the 61 m seine net. The absence of any statistically significant increase in abundance with the larger net may be due to the young of the year's patchy distribution and schooling behaviour. Therefore the larger seine net did not improve the likelihood of catching juvenile Australian herring. The importance of evaluating fishing gear to maximise catches has been emphasised particularly in the case of comparing species abundance and composition between habitat types (Leber and Greening 1986; Dewey *et al.* 1989) and in developing assessments of recruitment processes (Jackson and Noble 1995).

In summary, the results of the present study suggest that the pattern of day - night variation in abundance was not consistent between study sites and the response of the 0^+ Australian herring may depend on the unique biological and physical attributes of each site. Therefore, it may be necessary to examine diel variation at key sampling sites to assess the behaviour of the juvenile year classes, prior to planning a sampling regime to develop an index of recruitment. Understanding the diel variation in abundance will assist with generating a more accurate measure of abundance. There was no difference in the density of juvenile Australian herring captured from either seine net; therefore the 61 m net will remain the standard sampling gear for future programs. Data were also collected on the other species caught during the day - night collections and in the two seine nets. These will be analysed in the near future to evaluate diel variation in the complete assemblage structure from each site.

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CHAPTER 6. STOCK IDENTIFICATION OF AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*) USING THREE TECHNIQUES

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Objective 4. Determine the movement patterns of Australian herring and their vulnerability to capture by Western Australian commercial and recreational fishers.
This section of the project was designed to examine the source of recruitment to the Western Australian fishery and to examine movement patterns of Australian herring. The objectives were achieved by using three stock identification techniques; tagging the fish with an external tag, conducting allozyme electrophoresis and stable isotope analysis of otolith carbonate. The results from each method supported the premise that Australian herring form one stock across their geographic range. Australian herring move from the south east to the south west of Australia during the autumn, coinciding with the spawning period. While some individuals on the south coast of Western Australia remained local, other individuals migrated to the west, then northward up the west coast of Western Australia. The proportion which migrates from the south coast to the west coast is limited. The level of mixing between South Australia and the south and west coasts of Western Australia is sufficient to support the single stock hypothesis for this species.

Introduction

Identification and discrimination of a fish ‘stock’ is a fundamental issue in fisheries biology, particularly for population modellers trying to develop realistic mathematical models of the dynamics of the stock, and for fisheries managers who need to understand the geographical limits of the stock they manage. Several definitions of a stock have been proposed which more or less explicitly involve the role of fisheries management. This is exemplified by the following two commonly cited definitions of a stock. Ihssen et al. (1981) relies solely on a genetic and ecological basis in his definition of a stock as “an intraspecific group of randomly mating individuals with temporal or spatial integrity”; while Larkin (1972) considers the importance of fisheries management in his definition, “a population of organisms which, sharing a common gene pool, is sufficiently discrete to warrant consideration as a self-perpetuating system which can be managed”.

What is the application of these definitions to fish stocks, particularly to the species under question, Australian herring (*Arripis georgiana*)? Stock assessment analysis is constructed at the most primary level on the assumption of a unit stock (Gulland 1983). Violations to the assumption of a single stock include the fact that the fishery is composed of many stocks, the fishery only exploits a small portion of a large stock or that the fishery expands to exploit new stocks (Gulland 1983). Stock assessment analysis, constructed under faulty assumptions, will not produce worthwhile advice on which fisheries managers can act. Both recreational and commercial fisheries managers of the Australian herring resource, in Western Australia and South Australia, need information on the size of the stock which is practicable to manage. Understanding any unique ecological and genetic constraints which may account for population subdivision is an essential component in the analysis of stock structure.

Resolving the question of the unit stock relies on various techniques which aim to describe the temporal and spatial discreteness of a stock of fish. Seven broad categories of research techniques have been presented by Ihssen *et al.* (1981); population parameters, marking, physiological and behavioural attributes, morphometric and meristic attributes, calcareous attributes, cytogenic attributes and biochemical attributes. Data from each category provides information on a particular life history aspect therefore it is important to use the technique most applicable to the question being addressed.

Australian herring are an abundant pelagic fish occurring along the west and south coasts of Australia. They are found in coastal and estuarine habitats and form the basis of a popular shore and boat based recreational fishery in both Western Australia and South Australia. There is a haul net and gill net commercial fishery for Australian herring in both states; additionally there is a trap net fishery operating seasonally on the south coast of Western Australia. On the basis of the biological and fisheries information presented in this report it is clear that Australian herring are distributed from the lower west coast of Western Australia through to Victoria. A summer westward migration followed by an autumn spawning in Western Australian waters is believed to bring together fish from all parts of the geographic distribution. The timing of this migration coincides with the WA south coast trap net fishery, which takes the bulk of the annual WA commercial catch. Larvae and juveniles are dispersed eastward along the coast and settle during the winter and spring in coastal waters between WA and Victoria. However, several issues remain unresolved. It is not clear what proportion of the 'stock' migrates from the south coast to the lower west coast of Western Australia for spawning and whether there are unique genetic and/or ecological units along the broad distribution of this species. The hypothesis to be tested is that there is only one unit stock in both a biological and management sense.

Three techniques have been used to examine the single stock hypothesis for Australian herring; tagging, allozyme electrophoresis and stable isotope analysis of otolith carbonate. Each of these techniques has an established role in stock delineation for fisheries research (Ihssen *et al.* 1981; Nelson *et al*. 1989). Australian herring were tagged as they moved along the south coast of WA during the spawning migration to examine movement patterns along the south and west coasts of WA. Tagging data have been used to measure movement and infer the level of connection between populations and to estimate the size of a stock (Allen 1989; Begg *et al,* 1997; Young *et al.* 1999). The genetic structure of the Australian herring stock(s) was examined using allozyme electrophoresis. Samples were collected throughout the species distribution and included both open coastal and estuarine locations. Allozyme electrophoresis has been an important and powerful biochemical technique to discriminate between fish stocks (see Ryman and Utter 1987; Avise 1994). Stable isotope analysis of Australian herring otolith carbonate was examined to detect whether differences exist between sites due to water temperature and other environmental factors. Analysis of the attributes of these calcified structures has been used successfully in recent studies to identify separate stocks of pilchards (Edmonds and Fletcher 1997), pink snapper and tailor (Edmonds *et al.* 1999).

Methods

Tagging

During March-April 1997, Australian herring were tagged at House Beach and Peaceful Bay, Western Australia (Figure 1.1, Chapter 1). They were tagged first at House Beach, which is the most easterly beach within the south coast commercial trap net fishery. Tagging began 5 days before the beginning of the Australian herring commercial fishing season in order that the tagged Australian herring might be caught and returned during the commercial fishing season by commercial fishers as well as by recreational anglers who congregate along south coast beaches during Easter and the April school holiday period to fish for Australian herring and western Australian salmon. Australian herring commercial fishermen assisted Fisheries Research for several days using trap nets to collect fish for this tagging experiment. At dusk, the approximately 900 metre long nets were set from shore, commencing perpendicular to the shore and anchored into a G shape opened to the direction of movement of the migrating Australian herring. In the morning, the nets were closed and the trapped Australian herring transferred to small holding pens. These fish were retrieved from the floating net pens, measured (total length, nearest mm) and tagged with an anchor T bar spaghetti tag (5 cm long, Hallprint Inc., Australia) by Fisheries WA staff trained in fish tagging. Tagging began at about 8:00 hours and was completed by 17:00 hours each day. The fish were released in small groups of 100-200. The tags had a unique identification number and Fisheries WA Research Division phone number. Posters with detailed information regarding this research and notification of a reward for all returned fish were placed at Fisheries WA District Offices and tackle shops along the south coast. An article was placed in local newspapers to inform commercial fishers and recreational anglers about the research program. Interviews were conducted with local ABC regional radio and regional television to inform the public about the Australian herring research project and specifically the tagging program.

During the second year of the tagging program in March 1998, Australian herring were tagged at House Beach according to the methods described above. Inclement weather prevented the commercial fishers from setting their nets at Peaceful Bay; therefore there was no tagging conducted at this location. In an effort to examine the movements of the west coast fish, Australian herring were tagged at three locations in Geographe Bay: Meelup, Quindalup and Dunsborough Beaches. At these locations the fish were caught by a commercial fisher using a 210 metre haul net with ¾ and 1 inch mesh. Fish were again placed into floating net pens where they were retrieved, measured and tagged. The tagged Australian herring were released in small schools. As with the 1997 tagging season, in order to make the public aware of this research program and the need to return tagged fish to Fisheries WA, posters were placed at the Fisheries District Offices and key fishing locations and the local newspapers and the regional ABC radio were contacted with information about this project.

Allozyme Electrophoresis

Australian herring were collected using a variety of fishing gear types from recreational and commercial fishers in WA and SA and from fishery independent sampling conducted by Fisheries Research Division, Fisheries WA and the Aquatic Sciences Section of the South Australian Research and Development Institute.

After capture by either commercial or recreational fishers, whole individual fish were frozen and stored at -20^{o}C. Liver tissue was removed for the allozyme study. The same fish were further processed for age, growth, reproduction studies (Chapter 2) and otolith microchemistry analyses (this chapter) and stored at –70 ^{o}C.

The extraction of enzymes involved homogenising a small portion of the liver in an equal volume of grinding buffer (0.02% bromophenol blue; 0.1% mercaptoethanol; 0.24 M sucrose; 0.2 M Tris-HCl, pH 8). Electrophoresis was conducted on horizontal starch gels (StarchArt) with allozymes visualised through histochemical stains. Recipes for the buffers and histochemical stains used follow Richardson *et al*. (1986).

As no previous electrophoretic work had been conducted on Australian herring, it was necessary to screen for polymorphic loci. Screening involved individuals from the most geographically distinct areas, as well as estuarine populations. If genetic differences exist they should be most apparent from fish caught from distinct and disjunct areas. A total of 23 enzymes were screened for polymorphisms on several buffers.

The recorded genotypes for each specimen from all 16 populations examined were analyzed for a number of genetic measures through BIOSYS ver. 1.7 (Swofford and Selander 1981).

Due to variation in sample sizes, mean heterozygosity was estimated by an unbiased method. The proportion of the overall genetic variation that is attributable to variation between samples (or subsets of some samples) was estimated using Wright's F_{st}. Weir and Cockerham's (1984) weighted means method was used for F_{st} analysis, as it permitted comparisons between populations of different sample sizes. Nei's unbiased genetic distance (Nei 1978) was used to describe the degree of isolation between populations. Nei's unbiased genetic distance allows comparisons between populations without being biased by different sample sizes. Therefore, the matrix of genetic distance was calculated between sites as well as at a regional level.

Otolith Microchemistry

Australian herring were collected using a variety of fishing gear types from recreational and commercial fishers in WA and SA and from fishery independent sampling conducted by Fisheries Research Division, Fisheries WA and the Aquatic Sciences Section of the South Australian Research and Development Institute.

Sagittal otoliths were removed from the fish, rinsed with distilled water and stored in paper envelopes. One otolith from each pair, selected at random, was washed in purity (Milli-Q) water with ultrasonication, dried (40 ^{o}C) and powdered. The resultant powder was deproteinated by treatment with hydrogen peroxide and analysed for ^{18}O:^{16}O and ^{13}C:^{12}C ratios by standard mass spectrometric techniques after the carbonate was decomposed to CO_2 with 100% phosphoric acid (CSIRO Division of Water Resources, Perth). Values are reported in standard δ notation relative to PDB-1 standard (Epstein *et al.* 1953).

The relationship between $\delta\ ^{18}O$ values and sea surface temperatures (SST) was explored to ascertain whether the isotopic signature of Australian herring otoliths would correlate with the temperature of each location; indicating the separateness of the sampled populations.

Statistical analysis of both the $\delta\ ^{18}O$ and $\delta\ ^{13}C$ values and the factors, location, sampling date and otolith weight were examined using analysis of covariance (ANCOVA). The two factors in the analysis were location and sampling date, and were treated as fixed and orthogonal factors in the analysis. Whereas, otolith weight was used as a covariate in the analysis due to its variation with the age. Type III sums of squares were used to test the hypothesis of differences in the population means.

Results

Tagging

The vast majority (90%) of the tagged fish were sexually mature based on their length. Tagged Australian herring were returned to Fisheries Research from the commercial and recreational fishing sectors, the Fisheries Research Division, as well as fish processors and rock lobster fishers who found tagged fish in their bait boxes. The details from one recapture came from a Queensland Aquarium (who found the tagged Australian herring in a box of dolphin food) another came from the Melbourne Zoo (who found the tagged herring in a box of seal food) and one tagged Australian herring was found in the stomach of a western Australian salmon. The level of non-reporting of tagged Australian herring was unknown. On two occasions a resident of a south coast WA town was walking along the beach and found Australian herring tags in the sand.

During the 1997 tagging season, 4,860 Australian herring were tagged at House Beach and 4,900 fish were tagged at Peaceful Bay. The overall recapture rate of Australian herring was 2.20% (N=214). The vast majority of these fish (98%) were recaptured during 1997. In 1998, there were four recaptures from the 1997 tagging. Three tags were returned from bait boxes and one was from an unknown location. There were 147 Australian herring recaptures from the House Beach release which included 133 recaptures from the south coast, six recaptures from fish which had moved to the west coast and two recaptures from fish which had moved further to the east along the south coast and were recaptured in Esperance. There were also five recaptures from bait boxes and one unknown return. There were 63 Australian herring recaptured from the Peaceful Bay tagging. The majority of returns, 53 tags, were from the south coast, with six recaptures from the west coast and four from bait boxes. Overall, 5.6% of recaptures from the 1997 tagging came from the west coast and 87% of the recaptures came from the south coast (Figure 6.1).

The average time at liberty for the tagged Australian herring released at House Beach in 1997 and recaptured from the west coast was 36 days, from the south coast was 26 days and from Esperance was 94 days. Fish tagged at Peaceful Bay were at liberty an average of 94 days before being recaptured from the west coast and 30 days before recovery from the south coast.

During the 1998 tagging experiment, 4,980 fish were tagged at House Beach and 4,000 fish were tagged at three sites in Geographe Bay. There was a lower overall recapture rate (1.15%) for Australian herring tagged on the west and south coasts in 1998. As with the previous year, the vast majority of the Australian herring tagged at House Beach were recaptured from the south coast (N=74, 1.14%), while two fish were recovered from the west coast, one from Esperance and one unknown return. Two of the returns during 1999 were from fish in bait boxes. All 40 recaptures (1.0%) of Australian herring originally tagged in Geographe Bay were from the greater Geographe Bay region, with 39 recoveries in 1998 and one from 1999 (Figure 6.2).

The average time at liberty for Australian herring tagged at House Beach and recaptured along the south coast was 17 days, and twice as long, 35 days for fish recovered on the west coast, while the one fish recovered from Esperance was at liberty for 90 days. There was moderate variation for time at liberty with recaptures from fish originally tagged on the west coast from 25 days. The one west coast tagged Australian herring recaptured in 1999 was at liberty for 326 days.

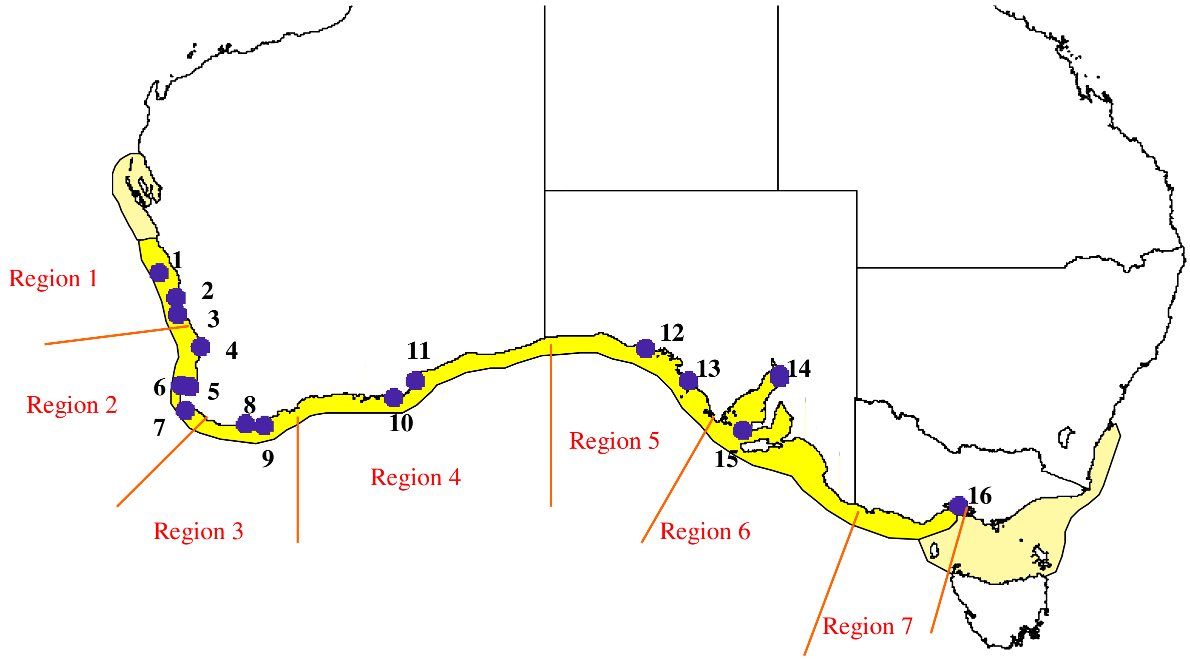
Allozyme Electrophoresis

A total sample of 686 Australian herring was collected between April 1997 and February 1998 from 16 sites spanning 4,400km (Figure 6.3). Populations were sampled from throughout the species distribution and incorporated sites that were potentially isolated, such as sites to the north of the proposed spawning ground, as well as sites from embayments and estuaries.

There were 23 enzyme systems surveyed for polymorphic loci. Four of the 23 surveyed enzyme systems could not be resolved for possible variation and they were omitted from further examination. Of the remaining 19 surveyed enzymes, six (32%) enzymes demonstrated signs of polymorphism, with no criterion as to the frequency of the most common allele. For the six loci that showed signs of variation, Ak_1 and G6pd were unable to be scored consistently and reliably. As the extent of their variation could not be examined, they were omitted from the examination of the percentage polymorphism at the <0.99 and <0.95 criteria. Therefore, Australian herring exhibits a 6% ($^1/_{17}$) frequency of polymorphic loci by the 0.99 criterion (Pgi p = 0.97) and 0% at the 0.95 criterion. It should, however, be noted that this is an under estimation of the potential proportion of polymorphic loci in Australian herring as the extent of variation could not be examined in Ak_1 and G6pd.

Another measure of variation levels within a system is overall heterozygosity. A low overall level of variation within the populations and enzyme systems examined was found with a mean heterozygosity (H) of 0.02.

Variation between different cohorts could only be examined at two sites in Western Australia, Geographe Bay and Poison Creek. These sites provided adequate sized samples of the 1997 young of the year age class and the 1996 1+ age class. At both sites, variation attributable to between cohort variation was small when compared to that within each cohort. This was demonstrated by low pairwise F_{st} values for the cohorts at each site (Geographe Bay F_{st}. = 0.0016 and Poison Creek F_{st}. = 0.0028). The lack of genetic differentiation between the cohorts was also reflected by Nei's unbiased genetic distance which was zero between both cohorts at each site.



Site	Site Name	Collected	N	0+ / 1+	Region Name
1	Abrolhos	September '97	5		1 – Midwest Coast
2	Jurien	August '97	10		
3	Cervantes	November '97	14		
4	Perth	June '97	21		2 – West Coast Fishery
5	Geographe Bay	October '97	94	24 / 28	
		December '97	47		
6	Rocky Point	February '98	31		
7	Augusta	April 97	18		
8	Wilson Inlet	May '97	46		3 – South Coast Fishery
9	Albany	April '97	59		(3a – Wilson Inlet Fishery)
10	Esperance	September '97	37		4 – South East Coast Fishery
11	Poison Creek	September '97	105	56 / 49	
12	Point Bell	May '97	39		5 – South Australian West Coast
13	Venus Bay	April '97	58		
14	Port Pirie	April '97	28		6 – Spencer Gulf
15	Wedge Island	April '97	17		
16	Port Phillip Bay	July '97	55		7 –Victorian Fishery

Figure 6.3 Distribution of Australian herring and the sample sites used for electrophoretic examination of stock structure.

The sampling design did not allow temporal and geographic variation to be separated clearly. To minimise the effects of geographic variation on examination of temporal variation, and vice versa, the temporal examination was confined to a single region (Region 2- south coast of WA). For the examination of geographic variation samples were limited to all those collected within the month of April. Both Region 2 and April were nominated as they provided the greatest temporal and geographical range of sample sites, respectively.

Temporal variation examined from five sites within Region 2 incorporated samples from pre, mid and post migratory fish. This was to elucidate any differences in the genetic structure of 'resident' or migratory fish. An F_{st} value of 0.0255 and negligible genetic distance between these samples (Nei's unbiased distance; D = 0 or 0.01) indicates a lack of temporal variation between sites within the region.

An examination of geographic variation was performed on five sites collected within April ranging from Port Pirie, SA in the east to Augusta, WA in the west; a distance of approximately 2,500 km. There was little overall genetic variation explained through differences in geography (F_{st} = 0.0016). Nei's genetic distance (Nei's D = 0) also demonstrated no genetic differences between sites.

Regional variation assessed differences throughout the entire geographic range of the Australian herring. While the geographic analysis discussed above revealed little genetic subdivision, it did not include some of the regions that may provide suitable habitats (i.e. estuaries) for genetic subdivision to occur.

The seven regions defined within the Australian herring's distribution (Figure 6.3) reflect major geographical and fishery boundaries. Within each region however, there exists temporal and cohort variation; however the negligible levels of variation for these factors suggests they can be discounted when examining regional variation.

The proportion of the total variation explained by inter-regional differences was very low (F_{st} = 0.0007). With a genetic distance (Nei's D) between all regions being zero, this confirms little genetic separation of the eight regions.

Otolith Microchemistry

A total of 599 Australian herring otoliths from 13 sites between Port Adelaide in the east to Dongara on the west coast of WA were analysed for their $\delta^{18}O$ and $\delta^{13}C$ composition (Table 6.1). Australian herring ranged in size from 152 mm (1+) to 358 mm (mature adult). The minimum and maximum values for the $\delta^{18}O$ isotope was 0.38 to 2.29; and for the $\delta^{13}C$ isotopes was -0.89 to -5.69 (Table 6.1, Figure 6.4 and 6.5). The SST values (^{o}C) ranged from 16.8 at Port Adelaide to 21.1 at Midwest (Table 6.1).

The distribution of the $\delta^{18}O$ values for the locations sampled in this study are shown in Figure 6.4. From the comparison of these histograms it is evident that of the locations Perth has the broadest range of values, except for Spencer Gulf (Port Pirie and Port Germein) and Wilson Inlet.

Table 6.1 Summary of sampling program and results for $\delta^{13}C$ and $\delta^{18}O$ analyses of Australian herring otolith carbonate. SST = annual mean surface temperatures (average of the 12 monthly means for the years 1997 to 1998 (Reynolds and Smith, 1994)).

Location	Position	Date	N	Fish length (LFC, mm) mean (range)	Otolith weight (mg) mean (range)	$\delta^{13}C$ mean (range)	$\delta^{18}O$ mean (range)	SST (^oC)
Port Adelaide, SA	34^o 51'00"S, 138^o 30'00"E	1997	45	199(179-222)	28.2(34.3-24.3)	-3.58(-4.70 to -1.59)	1.28(1.02 to 2.20)	16.80
Spencer Gulf, SA	33^o 11'00"S, 138^o 00'00"E	1997	53	204(170-237)	28.6(19.2-35.5)	-3.33(-4.95 to -1.66)	1.60(1.02 to 2.29)	17.13
Point Bell, SA	32^o 10'00"S, 133^o 09'00"E	1997	53	240(198-339)	37.2(26.2-91.7)	-4.28(-3.47 to -2.59	1.32(1.08 to 2.14)	17.75
Esperance, WA	33^o 51'30"S, 121^o 55'08"E	1997	20	228(213-253)	32.8(26.0-36.9)	-4.24(-5.22 to -2.58)	1.24(0.38 to 1.51)	17.44
Albany, WA	35^o 01'07"S, 117^o 52' 56"E	1997-8	178	224(155-292)	38.2(19.3-56.8)	-3.86(-5.76 to -1.75)	1.30(0.76 to 2.26)	17.50
Wilson Inlet, WA	34^o 59'23"S, 117^o 24' 58"E	1997	40	259(224-358)	39.2(18.3-66.3)	-3.67(-5.03 to -2.26)	1.12(1.12 to 1.53)	17.50
Augusta, WA	34^o 18'49"S, 115^o 09'28"E	1997	30	228(184-255)	38.5(27.6-49.6)	-4.10(-5.19 to -2.94)	1.20(0.81 to 1.84)	18.70
Bunbury, WA	33^o 20'29"S, 115^o 38'26"E	1997	20	227(210-270)	33.8(29.5-44.9)	-3.66(-4.90 to -2.36)	1.24(0.49 to 1.66)	19.50
Perth, WA	31^o 51'30"S, 115^o 44'57"E	1997	93	232(197-267)	34.7(24.5-52.3)	-3.51(-5.54 to –1.72)	1.28(0.68 to 2.25)	20.37
Midwest, WA	30^o 29'44"S, 115^o 03'59"E	1998	27	238(242-280)	35.3(24.6-50.9)	-3.77(-5.69 to -2.12)	1.18(0.92 to 1.57)	21.08

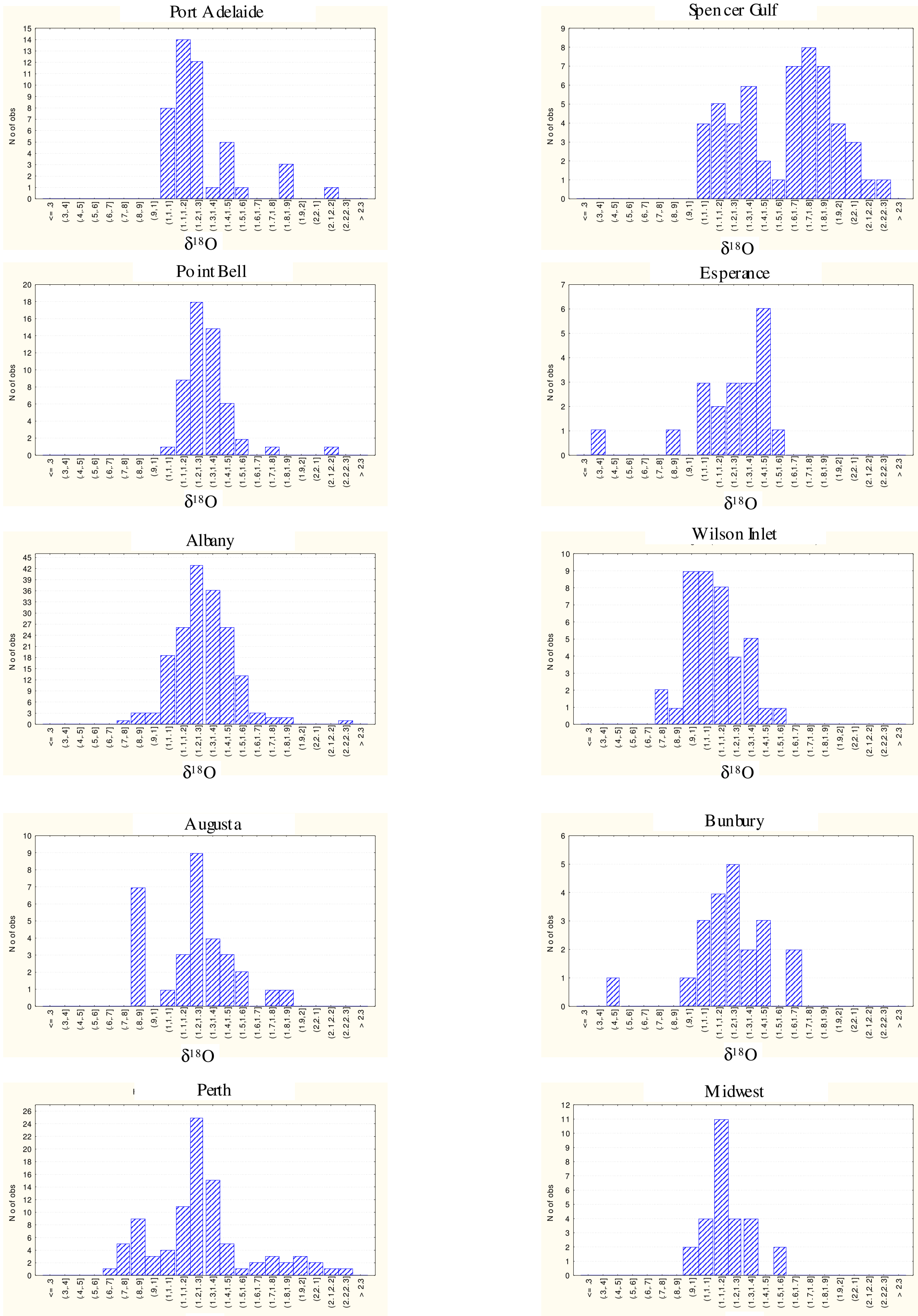


Figure 6.4 Histograms of $\delta^{18}O$ values for Australian herring otolith carbonate for each location.

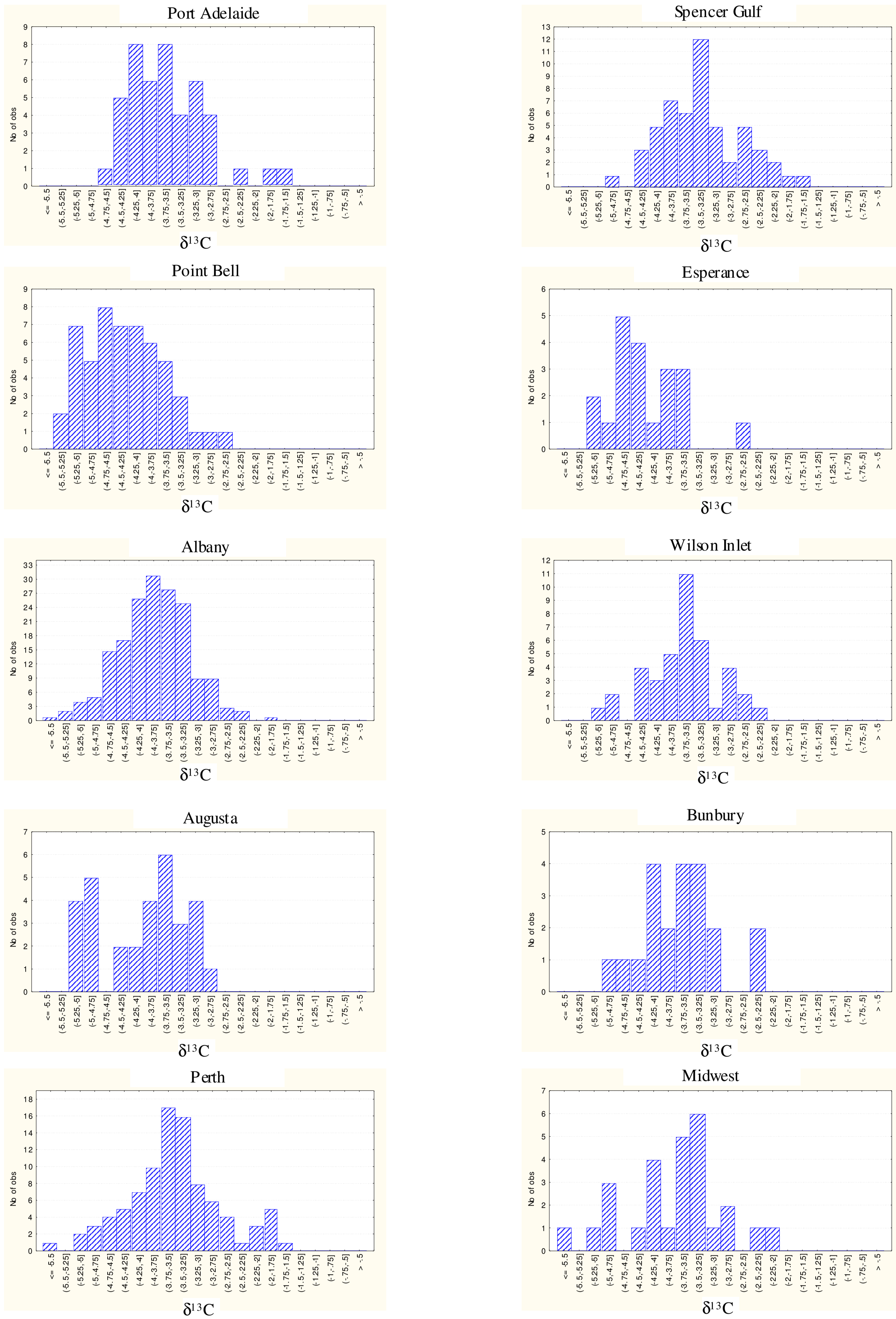


Figure 6.5 Histograms of $\delta^{13}C$ values for Australian herring otolith carbonate for each location.

Similarly, the distribution of the $\delta^{13}C$ values for the locations sampled in this study are shown in Figure 6.5. However, no clear trend was observable for $\delta^{13}C$ values with most locations having a broad range of values.

Spencer Gulf and Wilson Inlet are both areas where the hydrologies of these bodies of water have been influenced by either evaporation or freshwater. A preliminary analysis of the $\delta^{18}O$ and $\delta^{13}C$ values of Australian herring otolith carbonate from these sampling sites indicated that the unique hydrologies of these basins were confounding the results. Spencer Gulf in South Australia is an area with elevated salinity due to high of evaporation and low rainfall (Nunes and Lennon, 1986; Nunes *et al.,* 1990). The evaporation process can also cause an enrichment of the heavier isotopes in these waters. The $\delta^{18}O$ values of otolith carbonate for Australian herring caught in this area of higher salinity have an expanded range and are enriched when compared to other areas. Further examination of the $\delta^{18}O$ distribution of otolith carbonate for fish caught in this region, shows a bimodal distribution of $\delta^{18}O$ values (Figure 6.4). The mode represented by the lower values of $\delta^{18}O$ are similar to values of oceanic stocks near this area, such as Port Adelaide, while the mode with the higher $\delta^{18}O$ values are likely to represent stocks that have spent significant time in the higher salinity and $\delta^{18}O$ enriched waters of Spencer Gulf. The carbon isotopes of Australian herring otolith caught in Spencer Gulf also show an enrichment, which is likely to be a result of the higher salinity waters of this environment. The increasing salinity dramatically reduces the solubility of CO_2 and results in the assimilation pathway of CO_2 by algae to be largely *diffusion-limited* (Schidlowski *et al., 1984, 1994).* Consequently, the carbon isotopes of the food web in these environments may be enriched and result in an enrichment of the carbon isotopes of the otolith carbonate of the Australian herring caught in these environments. Similarly, Australian herring sampled from Wilson Inlet have been influenced from freshwater resulting in the depletion of their otolith carbonate $\delta^{18}O$ values. Further examination of the distribution of $\delta^{18}O$ values for fish caught in this region show a broad distribution, suggesting that there has been mixing of the Wilson Inlet stocks with oceanic stocks (Figure 6.4).

ANCOVA of the $\delta^{18}O$ values and the factors location, date and otolith weight showed that the factors location and location x date interaction were not statistically significant. Location and location x date interaction accounted for only a small proportion of the variability in the $\delta^{18}O$ values, explaining 1.6 % and 0% of the sum of squares, respectively (Table 6.2, Figure 6.6). Date and otolith weight were statistically significant factors, however explaining only 1.1 % and 6.9 % of the sum of squares, respectively (Table 6.2, Figure 6.6). The results of the ANCOVA for the $\delta^{18}O$ values compare well to the graphical representation in Figure 6.6, which clearly shows little difference between locations and $\delta^{18}O$ values.

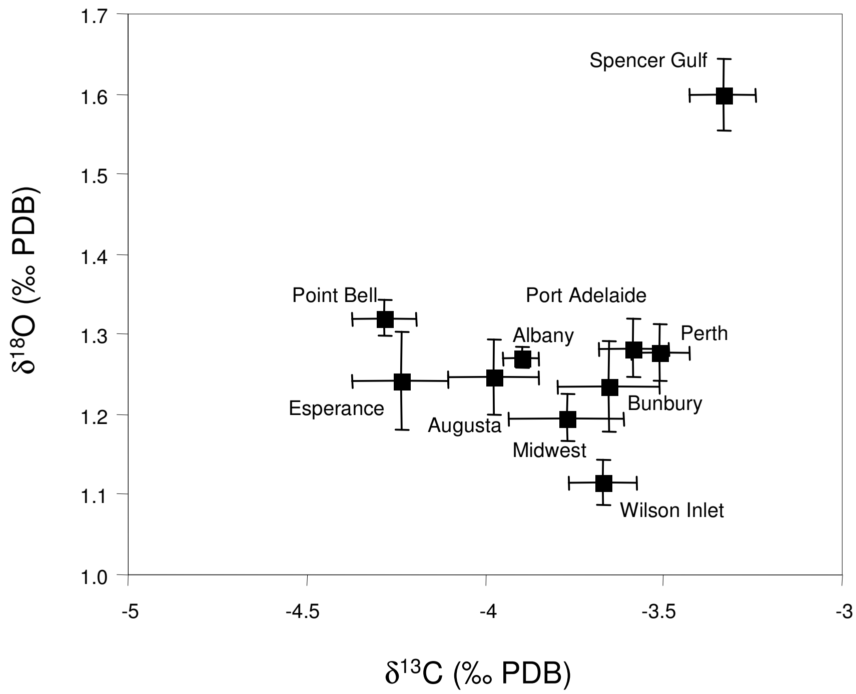


Figure 6.6 Mean δ^{18}O values (± standard error) versus mean δ^{13}C values (± standard error) for Australian herring otolith carbonate.

Table 6.2 ANCOVA of the δ^{18}O values for the sagittal otolith carbonate of Australian herring (excluding samples from Spencer Gulf and Wilson Inlet). * indicates statistical significance.

Source	DF	SS	MS	F	p
Location	7	0.3929	0.0561	1.1540	0.3281
Date	1	0.2725	0.2725	5.6037	0.0183*
Location x Date	0	0.0000	0.0000		
Otolith Weight	1	1.7413	1.7413	35.8041	<0.0001*
Residual (Error)	456	22.1770	0.0486		
Total	465	25.3074	0.0544		

In contrast, ANCOVA of the δ^{13}C values and the factors location, date and otolith weight showed that the factors date and location x date interaction were not statistically significant (Table 6.3). Date and location x date explained 0.6 % and 0 % of the sum of squares, respectively. However, the factors location and otolith weight were significant, accounting for 16.4 % and 8.6 % of the sum of squares, respectively (Table 6.3, Figure 6.6).

Table 6.3 ANCOVA of the $\delta^{13}C$ values for the sagittal otolith carbonate of Australian herring (excluding samples from Spencer Gulf and Wilson Inlet). * indicates statistical significance.

Source	DF	SS	MS	F	p
Location	7	41.0491	5.8642	13.3266	<0.0001*
Date	1	1.3793	1.3793	3.1346	0.0773
Location x Date	0	0.0000	0.0000		
Otolith Weight	1	21.6302	21.6302	49.1556	<0.0001*
Residual (Error)	456	200.6556	0.4400		
Total	465	250.9088	0.5396		

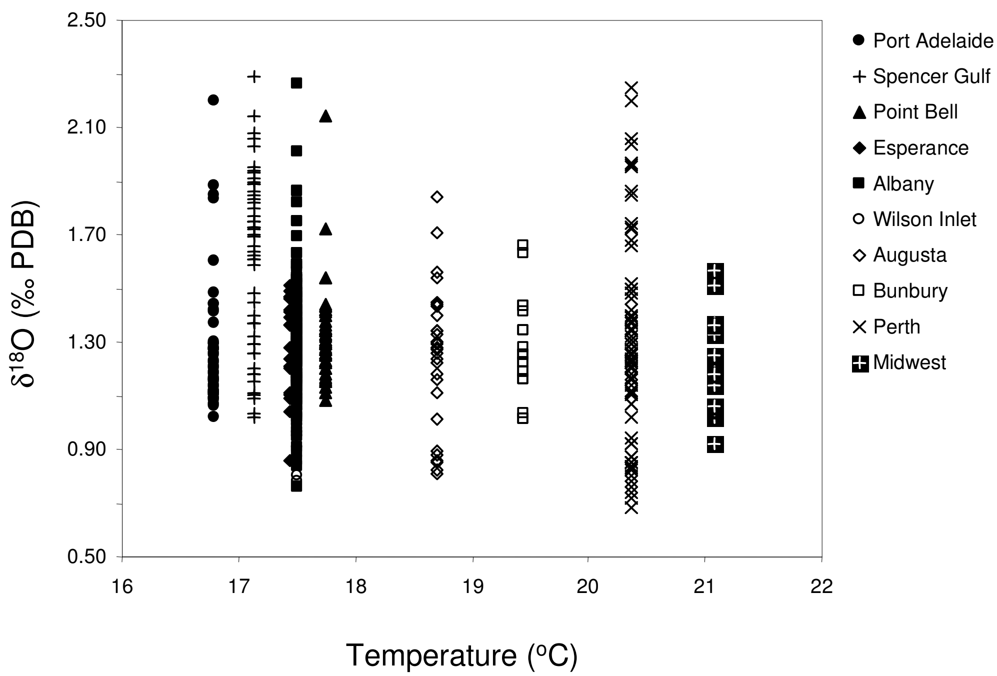


Figure 6.7 $\delta^{18}O$ values for Australian herring otolith carbonate versus mean sea surface temperature from 1996 to 1998 (derived from average monthly sea surface temperature from 1996 to 1998; see Reynolds and Smith 1994) for each location.

The relationship between $\delta^{18}O$ values and SST was explored with the expectation that if Australian herring are separate stocks the isotopic signature of their carbonate otoliths would correlate with temperature. The relationship between $\delta^{18}O$ values and SST for Australian herring in this study was not statistically significant ($\delta^{18}O = 1.5 - 0.014\ (T^{o}C)$, $r^2 = 0.0065$, excluding samples from Spencer Gulf and Wilson Inlet) (Figure 6.9). The mean $\delta^{18}O$ values for Australian herring otolith carbonate and calculated $\delta^{18}O$ values (based on the relationship of $\delta^{18}O$ with SST from Edmonds and Fletcher 1997; Edmonds *et al.* 1999) were plotted for the locations sampled in this study (Figure 6.10). This figure clearly shows that the mean $\delta^{18}O$ values of the Australian herring otolith carbonate does not vary with the SST of the waters where the fish were caught. Furthermore, the mean $\delta^{18}O$ values of the Australian herring otolith carbonate indicates that these fish inhabit waters ranging in temperature from 15.3 to 17.7 ^{o}C, (excluding Spencer Gulf and Wilson Inlet) using the temperature relationship obtained for pilchards and pink snapper (Edmonds and Fletcher 1997; Edmonds *et al.* 1999).

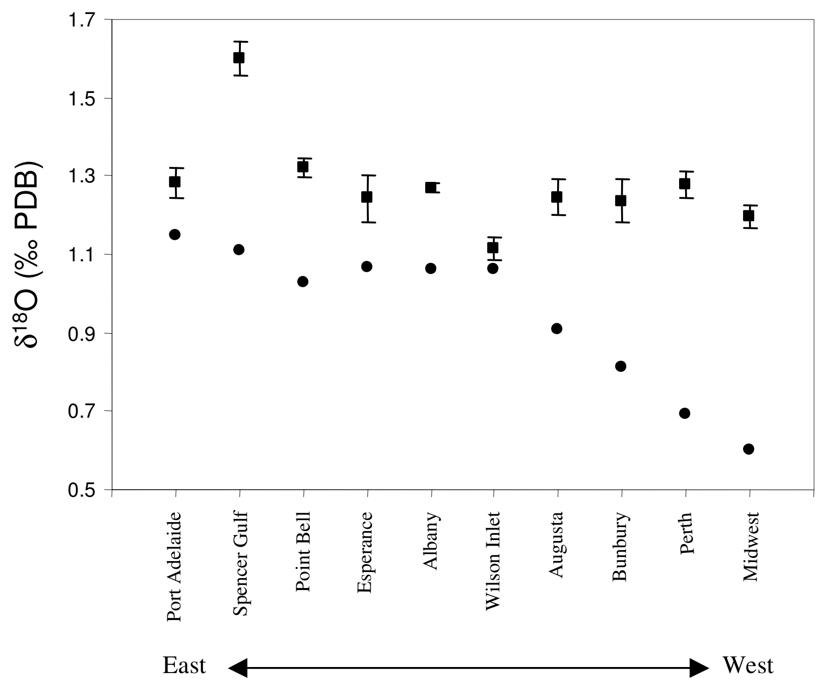


Figure 6.8 Mean $\delta^{18}O$ values ($\pm$ standard error) for Australian herring otolith carbonate (■) and calculated values (●) (based on the relationship of $\delta^{18}O$ with SST from Edmonds and Fletcher, 1997; Edmonds *et al*., 1999, for locations sampled in the present study).

Discussion

The results of the tagging, allozyme electrophoresis and otolith carbonate stable isotope analysis of Australian herring from throughout their geographic range demonstrates a consistent finding between these three techniques. Australian herring forms one biological stock between Victoria and Western Australia.

Movement patterns of 1+ and older Australian herring from the south coast of WA (Region 2) to both the southeast coast of WA (Region 3) and the west coast of WA (Region 1) provide the evidence for a single stock with a westward migration during the autumn and early winter seasons. A proportion of these fish then move northward along the west coast of WA. However, both the low proportion of tag recaptures from Regions 1 and 3 of fish originally tagged in Region 2 and the lack of movement of fish tagged in Geographe Bay (Region 1) indicate restricted movement. The low overall recapture rates of Australian herring for fish tagged during both 1997 and 1998 suggests that these results should be interpreted with caution.

There are several possible explanations for the low overall recapture rates for 1997 and 1998. There may not have been enough Australian herring originally tagged; two or three times as many fish might be tagged in subsequent operations to increase the number of fish available for recapture. Non-reporting of recaptured tagged fish may be greater than initially anticipated, by both the commercial and recreational sectors who are concerned that if too many fish are recaptured by their fishing sector it will lead to management changes; direct evidence includes the tags which were recovered from the south coast beach. Non-detection of the external T-bar spaghetti tags by the commercial factory processors resulted in fish with tags being boxed as bait. These tags were subsequently returned by the rock lobster fishers, the Melbourne Zoo and a Queensland Aquarium. Lastly, tag loss may have account for an unknown proportion of the tagged fish, as no fish were double tagged. Australian herring were tagged during their annual westward movement in March and April of both years to coincide with the beginning of the south coast commercial fishery trap net season and with the Easter school holiday. The increased fishing effort by both the commercial and recreational sectors along south coast and lower west coast beaches, at this time, would ensure equal fishing pressure along the coast and increase the likelihood of recaptures. By tagging fish at the eastern end of the fishery during the beginning of the fishing season the pattern of movement could be observed as fish moved to the west.

Similar results were found during nine tagging operations which released 6693 Australian herring in South Australia between 1952 and 1954 (WFRC 1973[6]). Australian herring were tagged with a white internal tag. The results overall tagging operations showed a low recovery rate (0.3%), with only 26 tagged and released fish later recaptured. There were 19 recaptures (0.28% of total released) in Western Australian waters and seven in South Australian waters. These recaptured Australian herring showed movement on the order of 600 to 1360 miles to the west and north. In the present study, the recaptured Australian herring also showed variation in distances moved, with fish being recaptured from the same or adjacent beaches to recoveries from approximately 1000 miles from the tag site.

Additional tagging was conducted in Western Australia between 1951 and 1955 to examine migration within the adult regions in WA. Internal and operculum clip-on tags were placed on 4784 fish during 16 tagging operations (WFRC 1973[7]). There was a recovery rate of 2.53% (121 recaptures). Of the

[6] This is based on information contained in a restricted publication 'Documents Relating to a Scientific Workshop on Salmon and Herring at Waterman on December 14 and 15, 1972' which was prepared to meet the need of the West Australian Research Committee, Department of Fisheries and Fauna, Western Australia, and issued in Perth 1973.

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recaptured fish, 101 were local recoveries and 20 (16.5%) showed migration to the west. Three tagging operations at Cheyne Beach, one at Bremer Bay and one at Rottnest Island produced Australian herring tag recoveries from locations along the lower southwest and north of Perth. Tag recoveries of the same magnitude (2.20% in 1997 and 1.15% in 1998) and the same pattern of movement was observed in the present study and supports the general conclusion that adult Australian herring move from South Australia along the south coast of Western Australia, with some proportion of these fish accessing the west coast. This annual movement represents their spawning migration into Western Australian waters.

Begg *et al.* (1997) examined the movement patterns and stock structure of tagged school (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) along the east coast of Australia. The two species displayed different movement patterns with school mackerel moving small distances from the original tag site which suggested separate stocks; and spotted mackerel, which behaved more like Australian herring, moving large distances seasonally which indicates the presence of one stock undertaking a season migration. Begg *et al.* (1997) had a low recovery rate during their study which they attributed to, in part, by non-reporting of recaptured fish by the commercial and recreational sectors. The importance of this factor to influence the results and conclusions of the study could not be measured.

The allozyme electrophoretic data suggests that Australian herring form one panmictic population throughout their range. The values of heterozygosity within fish has been estimated between 2 and 8% (Nei and Graur 1984, Raven and Johnson 1989). The level of heterozygosity for Australian herring was measured at 2%, and this value is seen as an overestimate as only loci demonstrating variation were used in the analysis. This emphasises the low level of variation within the 16 populations of Australian herring examined. By comparison, the mean heterozygosity for western Australian salmon, *A. truttaceus*, was 1%, falling at the low end of genetic variation expressed by Nei and Graur (1984). Genetic variation between presumptive stocks is the major interest of most genetic studies seeking to address fisheries management issues. Wright's F_{st} is a standardized measure of the amount of variation between populations relative to the genetic variation within the populations (Swofford and Selander 1981; Barker 1992). The Australian herring's F_{st} value of 0.0007 demonstrates a lack of genetic subdivision between regions. This low F_{st} value in conjunction with Nei's analysis of genetic distance indicates a single intermixed population, throughout the extensive spatial range examined, including marine and estuarine populations. This result concurs with the genetic analysis of the Australian salmon which shares a very similar life history with the Australian herring (McDonald 1980).

The values for the stable oxygen isotopes in the Australian herring otolith carbonate from populations throughout the geographic distribution indicates, in general, that these fish have not spent their life in the waters where they were captured and have values similar to fish which have spent a majority of their life in colder waters. This result suggests that this is a migratory species. Furthermore, the stable oxygen isotope values for Australian herring, measured in this study are similar to values expected for fish inhabiting the south eastern waters of Australia, suggesting that this species migrates from the south east to the south west of Australia. While the results of oxygen isotopes indicate that Australian herring are largely a migratory species, some oxygen isotope values also indicate that a proportion of these fish have spent a majority of their lives in the waters where they were caught. It is possible then to estimate the proportion of Australian herring resident to a region, such that the proportion of W.A. Australian herring captured in W.A. in this study could be estimated at 10%. This estimate is based on the distribution of the oxygen isotopes (Figure 6.4) for samples taken in South Australia having oxygen isotope values over 1.0, while values for samples taken from Western Australia have a significant number oxygen values under 1.0. The lower values for the oxygen isotopes for W.A. are due to the warmer waters of W.A., resulting in lower oxygen isotope values in the otolith carbonate, (based on the relationship of $\delta^{18}O$ with SST from Edmonds *et al*., 1999 and Edmonds and Fletcher, 1997). However, the oxygen isotope values for Australian herring resident to the southern region of the Western Australian coastline (Esperance to Peaceful Bay) are likely to have oxygen isotope values slightly greater than 1.0 and may not be fully taken into account in the W.A. population estimate.

Two locations sampled for this study, Spencer Gulf and Wilson Inlet, are influenced by evaporation and freshwater runoff respectively, which has affected the isotopic signature of the otolith carbonate of fish caught at these sites. A proportion of the fish from these sites spend a significant proportion of their life in these areas. Population estimates of Australian herring originating from Spencer Gulf may also be possible due to the location specific signature in the otolith carbonate produced by the hydrology of Spencer Gulf. From Figures 6.4 and 6.5, it is evident that a small proportion of Australian herring caught in the Western Australian fishery have a signature similar to otolith carbonate derived from Spencer Gulf. While other restricted bodies of water subject to low rainfall and high evaporation may exist along the southern Australian coastline, it is unlikely that these locations would be of the same magnitude such that Australian herring stocks would remain resident long enough to alter the isotopic signature of their otolith carbonate. Subsequently, there is also a possibility of estimating the proportion of Australian herring in the Western Australian fishery that are derived from Spencer Gulf. From this data, it is estimated that 9% of Australian herring captured in the Western Australian fishery are derived from Spencer Gulf (approximated from the proportion of Australian herring otoliths with oxygen isotope values between 1.8 and 1.9).

Other studies have used the analysis of stable isotopes of teleost otolith carbonate to distinguish mixing and non-mixing fisheries stocks (Nelson et al. 1989; Edmonds and Fletcher 1997; Edmonds et al. 1999). Numerous studies of the stable isotope ratios of teleost otolith carbonates have shown that oxygen isotopes are precipitated in equilibrium with the surrounding waters (Devereux 1967; Degens *et al*. 1969; Mulcahy *et al*. 1979; Kalish 1991a, b; Iacumin *et al*. 1992; Edmonds and Fletcher 1997; Edmonds *et al*. 1999). This has allowed differences in the average temperatures between locations of fisheries stocks to be reflected in the oxygen isotopes of teleost otolith carbonates. Assuming that oxygen isotope ratios are deposited in the otolith carbonate in equilibrium or close to equilibrium with ambient seawater there should be no difference between species that occupy the same location (Patterson *et al*. 1993).

While a statistically significant relationship between Australian herring $\delta^{18}O$ values and sea surface temperature was not found in this study; a significant relationship has been found for pink snapper (Edmonds *et al*. 1999) and pilchards (Edmonds and Fletcher, 1997) studied along the Western Australian coastline. Therefore, the isotopic signature of otolith carbonate for Australian herring does not relate to the temperature of the water where they were caught. This supports the migratory behaviour of this species.

Other studies have shown that variations in $\delta^{13}C$ values have been more attributable to otolith size rather than the location where the fish were caught (Edmonds and Fletcher 1997; Edmonds *et al*. 1999). This agrees with the hypothesis put forward by Kalish (1991b) that $\delta^{13}C$ is dependent mainly upon metabolic rate, with high metabolic rates having the greatest depletion in $\delta^{13}C$. The variation in $\delta^{13}C$ values in Australian herring were also more attributable to otolith weight than to location. However, a significant location effect was shown and may suggest that fish captured at these locations have experienced unique environmental conditions over their entire life history.

The three techniques used to discriminate potential stocks of Australian herring collected from Victoria to the west coast of Western Australia have shown a consistent result and corroborate the single stock hypothesis. Australian herring 1+ and older, make an annual migration from Victorian and South Australian waters into Western Australian waters during the autumn and winter which coincides with spawning. The otolith microchemistry and genetic analyses indicates a single biological stock. Results from tag recapture information showed a widespread westward movement with limited exchange between the south and west coasts of W.A. and no back movement from the west to south coast. Based on these results, the small degree of mixing between the west and south coast fish may constitute a 'self perpetuating population' (sensu Larkin, 1972) requiring separate management from fish is the other regions.

Acknowledgments

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CHAPTER 7. FISHERY-DEPENDENT AND INDEPENDENT FACTORS AFFECTING COMMERCIAL CATCHES OF AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*) IN SOUTHERN AUSTRALIAN WATERS

G. K. Jones and G..B. Nowara.

Objective 2. Determine whether fishing or factors independent of fishing (i.e. Leeuwin Current) have caused the decline in commercial catches currently being experienced across the range of this species.

The objective was achieved by collating the commercial catch, fishing effort and CPUE data from WA, SA and Victoria, and linking these parameters, (where available), with environmental factors, including the strength of the Leeuwin Current and pre-recruit index in eastern South Australia, as well as the relative demand for Australian herring as bait in the WA rock lobster fishery. In WA, the south coast trap net fishery, the dominant commercial fishery of that state, in terms of catch, has been characterised by large fluctuations in catch, effort and CPUE's over the past 10 years. Evidence is provided here to support the notion that in years of high Australian salmon catches, Australian herring catches were significantly lower, and fishing effort also declined with a decrease in demand, due to cheaper imported bait. Fishing effort (in terms of boat-days fished) in this fishery is believed to be valid indicator of effort, because Australian herring is the sole target species. Therefore, CPUE's are believed to be a valid indicator of relative abundance, and as such, the variation can be explained by the variation in recruitment strength entering the fishery, which was in turn, linked to variation in environmentally determined pre-recruit index as far away as eastern SA. In SA, the recent decline in catches was due mainly to decreased effort in both targeted and non-targeted effort in the hauling net fishery, through netting closures and lower number of netting licences. CPUE's varied according to the passage of strong or weak year classes passing through the fishery. In recent years, the one year difference in the timing of the peaks in the targeted CPUE's between Gulf St. Vincent (GSV) and Spencer Gulf was due to the increased targeting of fish of one year younger in GSV, due to the nearness of the main Adelaide market. In Victoria, catch fluctuations in recent years may also be due to the passage of strong year classes, as observed in eastern SA nursery areas.

Methods

Catch and effort

In Western Australia, all licenced commercial fishers are legally required to submit a monthly return giving details of their catch, fishing methods, effort and area fished. The data required are a monthly summary of days fished by method, area (1^0 latitude by 1^0 longitude block) and weight of species landed. The data are entered onto the CAES database at the WA Marine Research Laboratories. Data at this level of detail have been collected since July 1975. Data for Australian herring were analysed on a calendar year basis from 1976 to 1998.

For the west coast, CPUE's were calculated on a subset of fishing records where it could be reasonably assumed that the fisher was targeting Australian herring. Since there is no record of the targeted effort for Australian herring on the monthly return sheet, data were included if Australian herring catches made up 30% or more of the total catch by that gear in any one year. This analysis was carried out in two areas, Geographe Bay and Cockburn Sound.

On the WA south coast, fishing effort was calculated as number of days fished when Australian herring were caught. In the principal fishery for Australian herring in Western Australia, the south coast trap net fishery, CPUE's were calculated as tonnes / boat-day. CPUE's were not calculated for the smaller inshore coastal and estuarine fisheries as Australian herring is not a targeted species, and CPUE is not regarded to be a good measure of abundance in these fisheries.

For South Australia, all Marine Scalefish commercial fishers are required by legislation to provide data on monthly catch and effort for all species taken in the MSF fishery on a spatial scale (fishing block). They are required to indicate a target species for each method on each day of fishing. The data are collated at SARDI (Aquatic Sciences) using the GARFIS software. Data specific to Australian herring were summarised by calendar year, for the period 1977 – 98. Australian herring data were categorised as whether they were targeted or caught whilst other species were being targeted (i.e.as by-catch). Fishing effort for both targeted and non-targeted occasions was expressed as boat-days, and CPUE's were expressed as kg / boat-day.

For the Victorian fishery, only catch data were available and these were by financial year for the period 1951/52 – 97/98. The data were obtained from the Marine and Freshwater Research Institute's annual reports on commercial catches.

Effects of other fisheries (i.e. Australian salmon in WA) on the Australian herring catches in WA

Anecdotal information collected during the 1950's and 60's (Walker & Clarke 1987) concluded that variation in the Australian salmon catch influenced the Australian herring catch, especially along the south coast. As a result, it was believed that Australian herring catches were not considered a good indicator of abundance. This relationship has now been investigated by correlating the south coast Australian salmon catch with that of the Australian herring trap catch for the same year over the last 23 years. Both operations take place at about the same time of the year and on the same beaches, although different gear are used for the two species.

Economic data

To determine whether there was a relationship between catch, effort and average value of Australian herring caught in the WA commercial fishery, data on the average price and gross value of production for the period 1993/94 – 97/98 were obtained from ABARE reports (see Anon. 1996a, 1997, 1998).

Environmental data

Strength of the Leeuwin Current

Lenanton *et al.* (1991) found that Australian salmon catches along the south coast of WA were high in those years when the Leeuwin Current was weak; whereas catches were significantly lower in those years when the current was stronger and closer to the south coast shore. It was suspected that in these latter years, the stronger current forced the schools of Australian salmon further offshore and out of range of the beach seine nets. As the Australian herring trap net fishery takes place at almost the same time as the Australian salmon fishery, this relationship was also investigated for Australian herring. Information on average monthly sea level heights for the period March and April were used as an index of the strength of Leeuwin Current and these data, (supplied by the National Tidal Facility, Adelaide, South Australia), were correlated with the corresponding Australian herring south coast trap net fishery CPUE's.

Recruitment variability derived from eastern SA nursery areas

A relatively long time series (1981 – 95) of Australian herring pre-recruit index (PRI) data are available for the Barker Inlet, South Australia, and fluctuations in these indices appear to reflect inter-annual variability in the strength of the transport mechanism of eggs, larvae and juveniles from the WA spawning area to the eastern nursery areas of SA (Jones, Dimmlich and Partington unpublished data). An attempt is made to correlate these recruitment indices with the CPUE's observed in the WA and SA fisheries. For this comparison with the CPUE's the pre-recruit index was calculated as the natural log (x + 1) of the number of 0^+ fish per 100 m^2 sampled.

The age composition of Australian herring caught by the fishery along the south coast of WA are mainly in their third and fourth year and in SA their first and second years of life (Chapter 2), therefore the recruitment indices (1981 and 1995; Barker Inlet, "big net") and the 1996 index for Gulf St. Vincent (Chapter 4) were correlated with lags of three, 3 – 4 year moving averages against the CPUE's of the WA south coast trap net fishery, and for one and two years against the SA targeted CPUE's. Although there are no age composition data available for Victoria, the catch data are correlated with the eastern SA recruitment indices, using a one and two year lag.

Results

Western Australia

Commercial Catch, Effort and CPUE

Figure 7.1 shows the total commercial catch in WA between 1951/52 and 97/98. The data show large fluctuations with a general increase till 1991/92, followed by a dramatic drop during the mid 90's. Catches again increased in 1995/96 , but dropped again in 1997/98. In WA the catch and effort is divided geographically into two regions, the west and south coast.

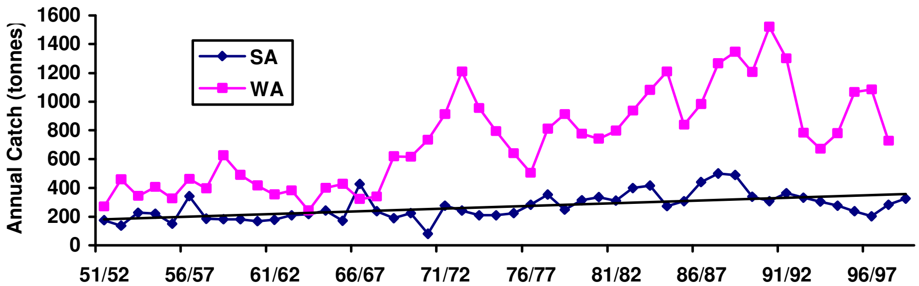


Figure 7.1 Annual commercial catch of Australian herring in WA and SA between 1951/52 and 1998/99.

West Coast fishery

The methods of capture are described in Chapter 1, and catch and effort between 1976 and 1998 are shown in Figure 7.2. The data includes all forms of net fishing along the west coast (estuary and ocean beach seine, gill net and hauling net) (see Chapter 1). Oceanic catches formed about 80 – 85 % of the total west coast catch in the 1970's, 85 – 100 % in the 1980's and between 94 and 99% in the 1990's. Annual catches generally increased to over 200 tonnes in 1988, and since then, have varied between 80 and 200 tonnes, with relatively low catches occurring in the last 2 years. Fishing effort (boat-days when herring were caught) was highest in 1982 (3745 boat-days), and since then have decreased to as low as 1925 boat-days in 1997.

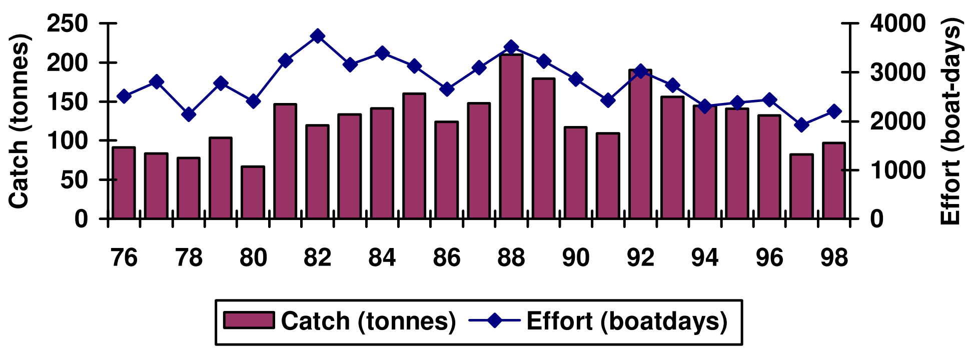


Figure 7.2 Annual commercial catch (tonnes) of Australian herring and fishing effort (boat-days when Australian herring caught) in the west coast region of WA, 1976 – 98.

South Coast fishery

In the south coast region, there are two fisheries – the estuary fishery which takes a relatively small proportion (3 – 12%) of the total south coast catch of Australian herring in each year, and the ocean fishery, which mainly comprises the trap net fishery. In the estuary fishery, annual catches fluctuated markedly between 20 and 80 tonnes in the period up to 1985, however, thereafter the catches steadily declined to about 25 tonnes in 1992 and have remained at about the same level since then. Fishing effort has shown a gradual increase till 1993, and thereafter a sudden drop by 30% in 1996 and have remained at about the same level since then (Figure 7.3). The decline in effort in these later years may be related to the decline in the number of netting licences, which have decreased from 66 in 1987 to 33 in 1998. In similarity with the west coast fishery, there is relatively little targeting of this species, especially with gill nets, therefore CPUE's have not been estimated because effort is not a reliable indicator of effective effort.

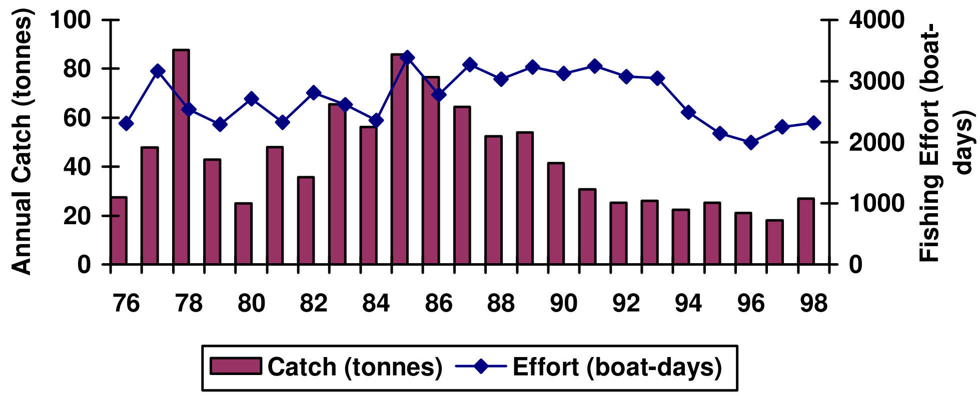


Figure 7.3 Annual commercial catch (tonnes) and fishing effort of Australian herring (boat-days when Australian herring caught) in the south coast estuary fishery of WA, 1976–1998.

The quantity of Australian herring taken in the trap net fishery amounts to between 60 and 90 % of the total commercial WA Australian herring catch. Figure 7.4 shows the catch and effort between 1976 and 1999 (the figures for 1999 which include the period January – May, are provisional).

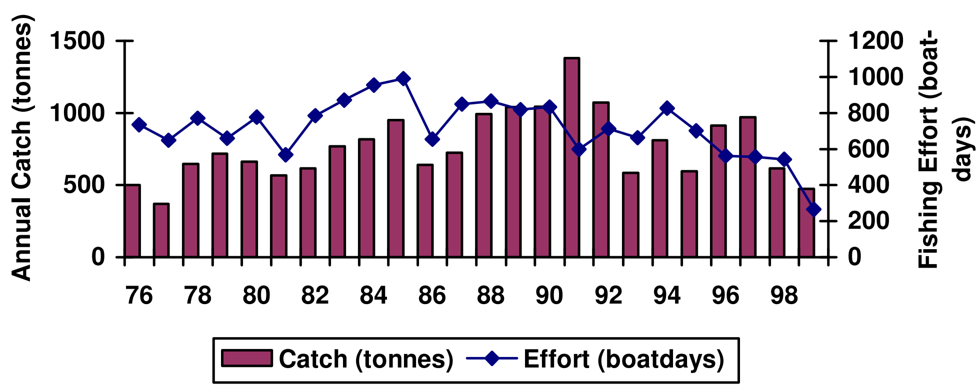


Figure 7.4 Annual commercial catch (tonnes) and fishing effort of Australian herring (boat-days) in the south coast of WA trap net fishery, 1976 – 1999.

Catches generally increased from over 400 tones in 1976 to 1383 tonnes in 1991, and thereafter have shown large fluctuations (584 – over 1,000 tonnes). Fishing effort has also fluctuated markedly throughout the period (560 – 990 boat-days); however, it has been relatively low (approx 550 boat-days) during the last three full years, 1996 – 1998.

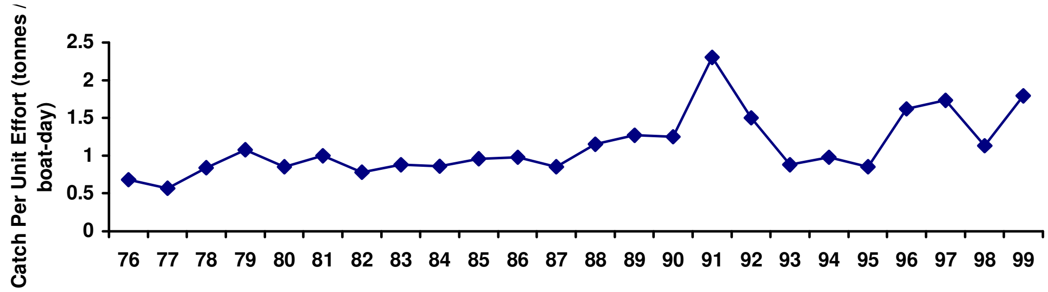


Figure 7.5 Annual catch per unit effort (CPUE, tonnes / boat-day) for the south coast trap net fishery, 1976 – 99.

The average CPUE has shown relatively little variation between 1976 and 1990; however, since that year, it has fluctuated widely, (0.85 - 2.3 tonnes per boat-day)(Figure 7.5).

Because CPUE's in the trap net fishery are regarded as better indicators of Australian herring abundance than for the other WA commercial fisheries, the data on the trap fishery have been used to investigate four factors which might influence the variation in catches, fishing effort and CPUE's in the fishery. These factors include those associated with fisher's behaviour, demand for Australian herring and environmentally driven influences.

Relationship between Australian salmon and Australian herring catches on the south coast

Figure 7.6 shows the fluctuations in the catches of Australian salmon and Australian herring (trap) along the south coast between 1976 and 1999.

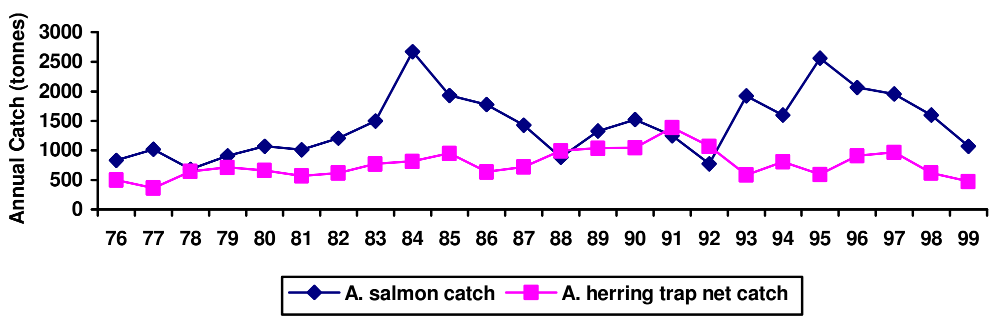


Figure 7.6 Fluctuations in annual commercial catches of Australian salmon and Australian herring along the south coast of WA, 1976 – 99.

Generally, there were two periods each of 4 – 5 yrs duration (in the early 1980's and early 1990's), when Australian salmon catches were relatively high and Australian herring catches low. For example, the second highest recorded Australian salmon catch of 2561 tonnes occurred in 1995, and this coincided with the second lowest Australian herring catch (594 tonnes) since 1977. The correlation was examined for two time periods: 1976 – 98 and 1983 – 98 (i.e. the period when beaches were assigned to Australian salmon/herring fishing teams), and annual catches were expressed as a percentage difference between the long-term mean catches. (Note: annual catches for 1999 were not included, as the catch data are incomplete for this year).

For the period between 1976 and 1998, the correlation in catches between the two species was not significant ($r = 0.09$, $P > 0.05$) however, for the 1983 – 98 period, in years when the Australian salmon catch was relatively high, the Australian herring catches were significantly low ($r = 0.497$, $p = 0.05$, 2 tailed).

Variation in value and demand for Australian herring

Over the last 5 years, there have been significant drops in the gross value and average price of Australian herring, mainly due to the decreased demand for Australian herring bait used in the rock lobster fishery, through the importation of cheaper North Sea herring (Table 7.1).

Table 7.1 WA herring production, gross value, average price and south coast trap fishing effort, 1993/94 – 1997/98 (Anon. 1996, 1997, 1998).

	1993/94	**1994/95**	**1995/96**	**1996/97**	**1997/98**
Annual catch (tonnes)	1001	788	1066	1083	725
Gross value ($ million)	1.201	1.181	1.439	0.487	0.326
Av. Price ($ / kg)	1.20	1.50	1.35	0.45	0.45
Annual Effort (calendar yr)	810 (1994)	720 (1995)	590 (1996)	585 (1997)	570 (1998)

For example, in 1995/96, the average price of Albany Australian herring used for rock lobster bait was 95 c / kg, and that for herring from the Netherlands was 88 c / kg (Jones and Gibson 1997). South coast Australian herring fishers may have chosen to decrease their effort due to the low value. It should be noted that the fishing effort in the south coast trap fishery during 1996 – 98 was relatively low (Figure 7.4); however, it was only in the last 2 years, that the average value has been low, thus indicating that the average value may not have influenced total catch, as much as fishing effort.

Effects of environmental conditions during the fishing season

The average monthly sea level height (cm) in March and April at Albany between 1976 and 1998 was correlated with the corresponding trap fishery catch rate (tonnes / boat-day). This correlation, although slightly negative, was not significant ($r = 0.3500$, $P > 0.05$, $DF = 20$) (Figure 7.7).

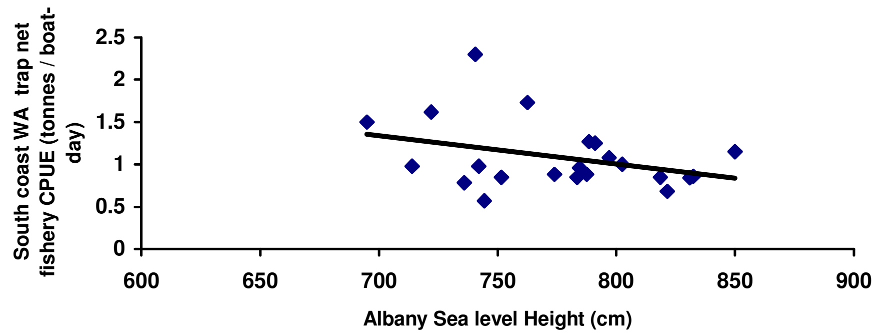


Figure 7.7 Correlation between Albany average sea level height (cm) in March - April and CPUE (tonnes / boat-day) in the south coast (WA) trap net fishery, 1976 – 98.

Effects of recruitment variation on catch rates

Figure 7.8 shows the variation in pre-recruit index of Australian herring from Barker Inlet (1981 – 95) and the present study (1996). Over the 16 year period that Australian herring PRI's have been monitored in Gulf St. Vincent, SA, there have been two strong year classes (1988 and 1996), and the high CPUE's three years later in the south coast trap fishery may reflect these strong year classes observed in Gulf St. Vincent (Figure 7.9). The relatively high CPUE's in the south coast trap net fishery in 1996 and 1997, may have been produced from strong year classes in other years (1993 and 1994) from other nursery areas to the west of Gulf St. Vincent, however, there are no data available in these areas prior to 1996 to confirm this hypothesis.

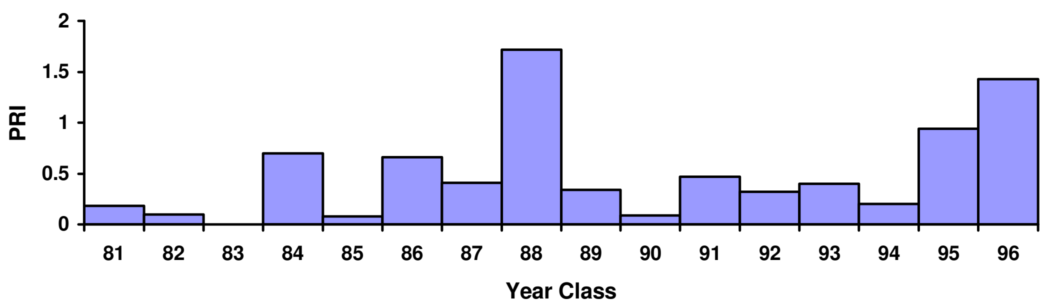


Figure 7.8 Pre-recruitment indices (Ln (x + 1) number of 0^+ fish per $100m^2$) for Australian herring year classes 1981 – 96, derived from Barker Inlet, SA (81 – 95 – "big" net, and Gulf St. Vincent, SA (1996 – "small" net) (Jones, Dimmlich and Partington unpublished data).

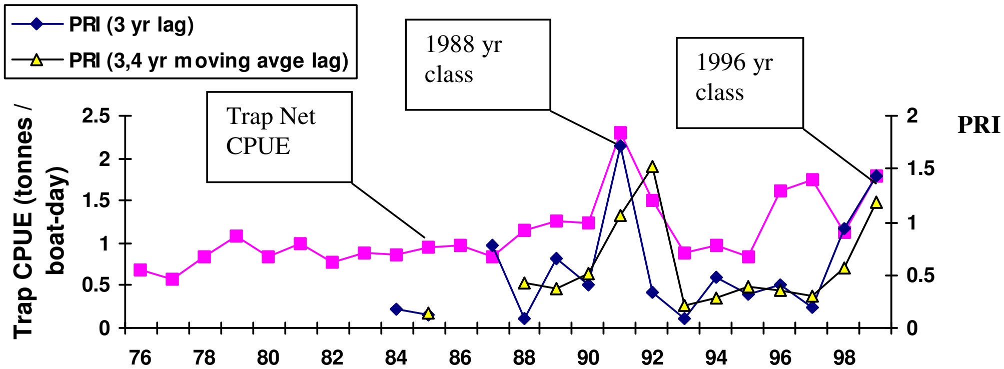


Figure 7.9 Relationship between south coast trap net fishery CPUE's (1976 – 99) and eastern South Australian pre-recruit indices (Ln (x+1) number of fish per 100m^2) with a 3 year lag.

South Australia

Commercial Catch, Effort and CPUE

The annual commercial catches between 1951/52 and 1997/98 are seen in Figure 7.1. The catches for most of the years are lower than those of WA, however, in similarity, they show a general increase till the late 1980's, and thereafter, a significant decline, so much so, that the annual catch in 1996/97 was the lowest since 1970/71. Figure 7.10 shows the state and regional catches between 1977 and 1998. The annual commercial catch of Australian herring throughout the state fluctuated between 212 and 472 tonnes with the catches in Spencer Gulf and Gulf St. Vincent being consistently higher than the west coast and south east of the state.

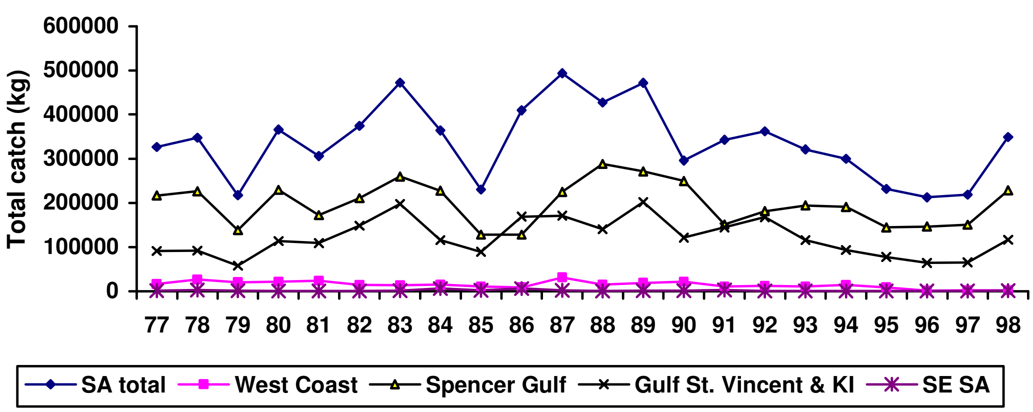


Figure 7.10 Total commercial catch of Australian herring in SA waters, 1977 – 1998 (all methods combined).

Both major gulfs showed highly significant timings in the fluctuations in their catches, with relatively low catches made in 1979, 85 and 1995 – 97, and relatively high catches in 1978, 80, 83, 89 and 98 (correlation coefficient, r = 0.6892, $P < 0.001$, ***). During this period, hauling nets were the method which took by far the greatest quantity (Figure 7.11), and the timings in the fluctuations in catches are almost identical to those for all methods of capture.

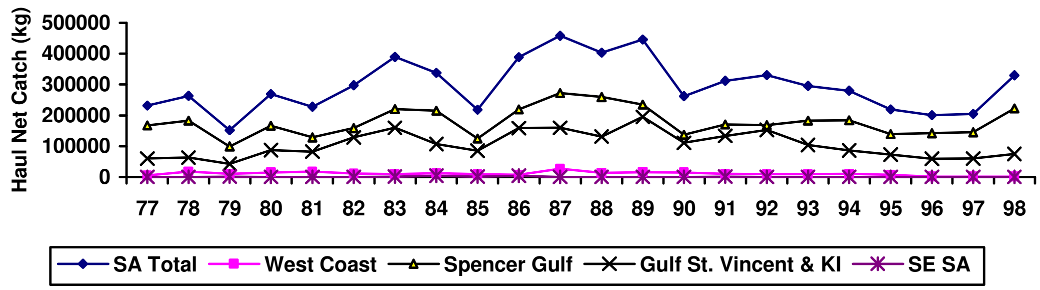
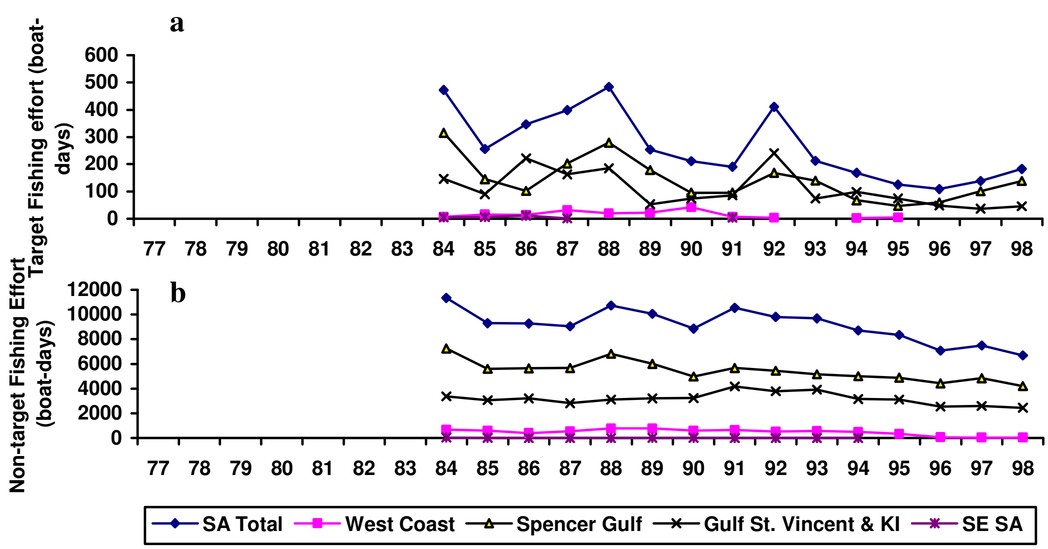


Figure 7.11 Annual commercial catch of Australian herring taken by hauling nets in SA waters, 1977 – 1998.

Although there is some targeting of Australian herring in the hauling nets, they are predominantly taken as by-catch to the more highly valued species. Fishing effort (boat-days) has been estimated for the period 1984 – 98, both on the occasions when herring are targeted, and also when the target species is another or "any" species (Figure 7.12 a and b, respectively). For both categories, and in all areas combined, fishing effort has declined over the period, with a decline of 61.3% of targeted and 40.9% of non-targeted effort.



Figures 7.12 a, b Fishing effort (a: target), (b: non-target) on Australian herring in the SA hauling net fishery, 1984 – 1998.

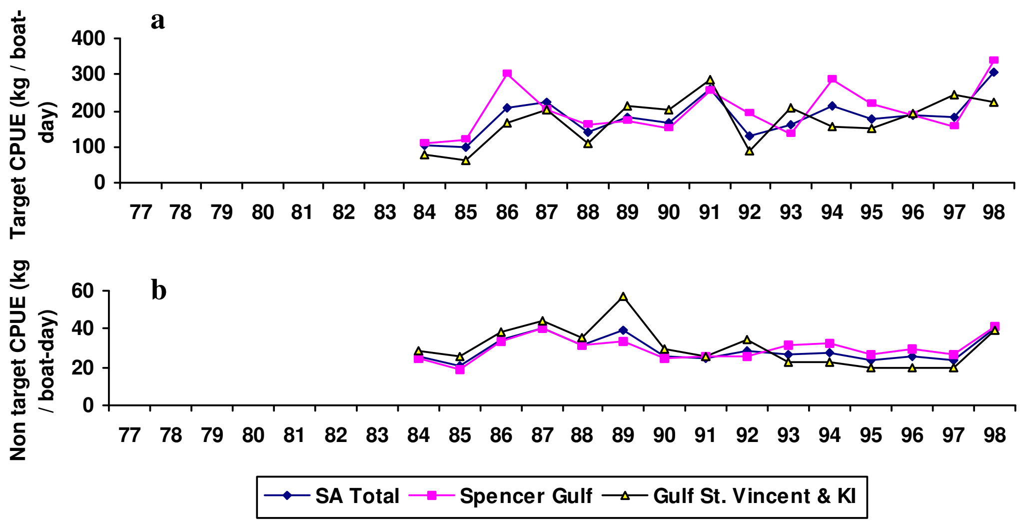


Figure 7.13 a, b (a: Target) and (b: non-target) catch rate (kg/boat-day) of Australian herring in the hauling net fishery for all SA waters, and Spencer Gulf and Gulf St. Vincent & KI, 1984 – 98.

The targeted and non-targeted CPUE's (kg / boat day) during the period 1984 and 1998 are seen in Figure 7.13 a and b, with average catch rates in the targeted fishery consistently higher by up to an order of magnitude than the non-targeted catch rates. For both categories and for both major fishing areas, the timings of the fluctuations showed consistency between 1984 and 1990, as well as in 1998. However, during the 1991 – 97 period, the same correlation did not occur. The non-targeted catch rates were consistently low, whereas the targeted catch rates continued to show strong fluctuations. Because of the relatively low price of herring compared with the other target species, it is suspected that some discarding of fish at the time of capture, has influenced the calculated non-targeted catch rates in these later years.

Fairclough *et al.* (Chapter 2) suggest that the main ages of Australian herring caught in the SA fishery are 1+ and 2+ yrs of age, and other size composition data prior to 1996 also suggests these ages (Chapter 1). With knowledge of the pre-recruit indices for Gulf St. Vincent (Barker Inlet) as far back as 1981 (Figure 7.8) and the relatively high CPUE's in both the non-target and target fishery, there is a suggested linkage between strong and poor year class strengths and CPUE's in the fishery 1 and 2 yrs later. For example, the strongest year class (1988) is manifested in the highest non-targeted CPUE of 1989 in Gulf St. Vincent, the strong 1992 yr class may be linked with the high targeted CPUE in GSV in 1993 and in Spencer Gulf in 1994, and the strong 1996 yr class with the high CPUE in GSV in 1997 and in 1998 in Spencer Gulf. Similarly, the poor year class strength of 1990 is manifested in relatively low CPUE's in GSV two years later in 1992. A possible reason for the CPUE's in GSV to be out of phase by one year with those of Spencer Gulf may be due the a greater demand for younger fish from GSV which are caught closer to the main Adelaide market. Thus, if this is so, a stronger year class would be noticed in the GSV fishery one year before the Spencer Gulf fishery.

Victoria

Commercial catches

Although the catches are much smaller than those in WA and SA, the reported commercial catch of Australian herring in Victorian waters between 1951/52 and 1997/98 has shown large fluctuations between almost 0 and 140 tonnes per year (Figure 7.14). In early years (1950's, 1960's), there may have been some misreporting of Australian herring catches, and the catches in these years may be over-estimates (Anon. 1996b); however, this situation may have been rectified by the 1970's. Even if this is the case, the catches have still fluctuated by an order of magnitude (0.4 – 60 tonnes) since the 1970's. In the past ten years, highest catches occurred in 1989/90, 1990/91 and 1997/98, and these relatively high catches may reflect the high 1988 and 1996 year class strengths observed in eastern SA (see Figure 7.8). Similarly, the poor 1990 and 1994 year class strengths are manifested 1.5 years later in very low catches in 1991/92 and 1995/96.

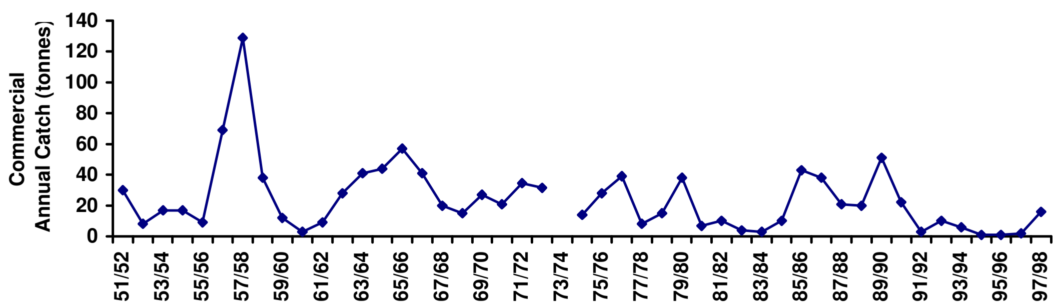


Figure 7.14 Reported annual commercial catch of Australian herring in Victorian waters, 1951/52 – 1997/98.

Summary

1. The WA commercial fisheries, take the largest proportion of all the commercial Australian herring fisheries in southern Australia, and are characterised by large fluctuations in the annual catch. The WA fisheries consist of both inshore coastal and estuarine fisheries. The estuary fisheries of the west coast and south coast have shown decreased catches in recent years. These declines are due partly to decreased effort, through the diminishing numbers of netting licences. However, as fishing effort is not regarded as indicative of effective effort, CPUE's are not available for these fisheries, and so it is not known whether the declines in catches are due to declining abundances.

2. In the main WA commercial fishery, the south coast trap net fishery, four possible factors were investigated to determine the reasons for the fluctuations in catches. There was evidence that since 1983, in years of high Australian salmon catches along the south coast, Australian herring catches remained significantly low. Therefore, decline in the Australian herring catches in the last 3 years,

may have been a consequence of the relatively high catches of Australian salmon between 1993 and 1997. Also, effort has declined in the last three years, possibly because of the relatively low demand for Australian herring as bait in the rock lobster fishery. It is therefore concluded that both catch and effort *per se* do not provide good indicators of relative abundance of Australian herring in this fishery.

3. The CPUE's in the WA south coast trap net fishery, however, were considered to be good indicators of relative abundance of Australian herring, as effort was targeted effort. The CPUE's were not significantly affected by the strength of the Leeuwin Current in the same year; however, the CPUE's in the trap net fishery were indicative of strong year classes observed in the Gulf St. Vincent (SA) nursery areas up to 4 years prior to them recruiting to the trap net fishery. Thus, the 1988, 1992 and 1996 year classes produced relatively high CPUE's in 1991, 1996 and 1999 respectively.

4. In the SA hauling net fishery, the decline in catches during the 1990's has been due mainly to a decline in targeted and non-targeted effort, through netting closures and a reduction in the number of netting licences. The CPUE data for SA is, however, more difficult to interpret because a significant proportion of the catch for this species is by-catch, and in some years, by-catch catch rates do not show the same trends as targeted CPUE's because of increased discarding of by-catch during the 1990's, especially in Spencer Gulf. The variation in targeted CPUE's reflect the inter-annual variation in pre-recruit index in Barker Inlet with a one year lag in GSV and 2 years for Spencer Gulf. In 1997 and 1998, CPUE's in SA were very high, possibly reflected by the relatively strong 1996 year class.

5. The fluctuations in the catches in Victoria also appear to reflect the inter-annual variation in pre-recruit index, as observed in eastern SA; however, age composition data are needed to confirm this hypothesis.

Acknowledgements

The authors wish to thank the S.A. Fisheries Statistic Unit for the extraction and summarising of S.A. catch and effort data, the commercial fishers in W.A. and S.A. for the use of catch and effort data, and the National Tidal Facility for providing the information of sea level heights.

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CHAPTER 8. STOCK ASSESSMENT OF AUSTRALIAN HERRING (*ARRIPIS GEORGIANA*)

B. S. Wise and N. G. Hall

Objective 4. Determine the movement patterns of Australian herring and their vulnerability to capture by Western Australian commercial and recreational fishers.

Objective 5. Develop an age-structured spatial model to assess the status of the Australian herring stock, using biological and tagging information gathered during this study.

An assessment of the Australian herring (*Arripis georgiana*) population was conducted utilising an age-structured spatial model. The model is based on the collation of all information known about the species, most of which has been presented in the preceding chapters. Occasionally the data needed to be reanalysed to be suitable for use in the model and these analyses are presented in this chapter. Information that was unknown was surmised from what was known. Separate assessment models were developed for Australian herring on the west coast of Western Australia and the southern coast of Australia. The latter assumes that the Australian herring stock is composed of a Western Australian and a South Australian component. Estimates of a number of population parameters of interest for the management of the stock and measures of variability associated with these parameters can be determined. The vulnerability of Australian herring to capture by commercial and recreational fishers (Objective 4) was addressed in the model through analysis of selectivity parameters.

Biological Information and Fisheries Statistics

Stock structure

Evidence presented in this report indicates that the Australian herring population is composed of a single genetic stock (Chapter 6). Unfortunately due to limited mark/recapture information it was not possible to develop a single stock assessment model. Consequently assessment of Australian herring assumes that the population is composed of two independent breeding stocks: a west coast stock including region 1 only, and a south coast stock including regions 2-6 (see Chapter 2 for detailed description of regions). This assumption is not too unrealistic as research shows that fish in breeding condition (stage VI-VIII) exist on both the west and south coasts (Chapter 2), and there is limited movement of tagged Australian herring between the west coast and south coast (Chapter 6). As the model considers breeding stocks in each location instead of a single larger breeding population, it enables the development of separate management plans for the recreational and commercial fisheries in each area.

During the breeding season (April-June), Australian herring in spawning condition are found throughout the distribution of the west coast stock while fish in spawning condition are found only in

the western portion of the distribution of the south coast stock (Chapter 2). Thus, the Western Australian south coast stock was assumed to be composed of a resident Western Australian component and South Australian component which migrates to Western Australia when mature. Australian herring east of South Australia were assumed not to form part of either breeding stock and consequently were not considered in the model. This assumption was based on the very low catches of Australian herring in Victoria (see this Chapter) compared to Western Australia and South Australia, suggesting a small population size in the state and the lack of information indicating that Australian herring from Victoria migrate to Western Australia to spawn.
Population parameters were estimated from data combined over all regions due to the inconsistent sampling caused by the differing fishing effort in each region. In addition, this avoids biases associated with the availability and vulnerability of fish to fishing resulting from the migration of larger/older Australian herring from South Australia to Western Australia.

Age and growth

Total length, age and sex information were available from the data collected during the 1996 to 1998 sampling program (Chapter 2). In Chapter 2 it was demonstrated that the mean monthly lengths of Australian herring during early life (late 0+ and 1+ fish) differ between the western and eastern distribution of the population, but by two years old they are similar sizes. It is impossible to determine at this time whether these differences result from differing growth rates or from the availability and vulnerability of fish to fishing and the subsequent inconsistent sampling. Consequently, for the purpose of the model, it was assumed that growth for fish in western and eastern distributions were similar. This assumption is reasonable as Australian herring mature at a length corresponding to late 1+ fish where the growth of fish in the western and eastern distribution have converged, thus the timing of migration is unaffected (see this Chapter).

Australian herring were assumed to grow to 15 years of age and growth in total length differed between sexes. These data comprised males, females and unsexed juveniles. These unsexed juveniles were randomly assigned to males and females assuming a 1:1 ratio. To assess the uncertainty associated with the treatment of the unsexed juveniles, the process of randomly assigning them to females and males was repeated to produce 100 length at age data sets for each sex.

Mean total lengths ($\overline{L}_a$) and standard deviations (σ_{L_a}) for each age were determined from the data collected during the 1996 to 1998 sampling program (Chapter 2) and are presented in Table 8.1.

To determine mean length at age matrices it was necessary to extrapolate the information for known ages to the unknown ages (*i.e.* ages 6-15, Table 8.1). Consequently mean lengths at age were determined from the von Bertalanffy growth curves and standard deviations were determined from linear interpolation between the standard deviation of the lengths at age.

Table 8.1 Mean length and standard deviations (standard errors) averaged over 100 randomly generated data sets in which unsexed juveniles were assigned to females and males assuming a 1:1 ratio.

Age	Females		Males	
	Mean length (TL mm)	Standard Deviation	Mean length (TL mm)	Standard Deviation
0	91.02 (0.33)	26.28 (0.24)	90.97 (0.33)	25.86 (0.26)
1	177.89 (0.36)	31.86 (0.23)	161.38 (0.51)	34.25 (0.18)
2	219.03 (0.02)	16.72 (0.02)	212.88 (0.04)	15.40 (0.02)
3	244.10 (0.017)	13.72 (0.01)	229.98 (0.06)	12.02 (0.04)
4	255.05 (0.086)	15.96 (0.07)	237.50 (0.10)	11.52 (0.05)
5	262.05 (0.033)	19.73 (0.02)	236.90 (0.08)	11.14 (0.01)
6	279.00 (NA)	28.66 (NA)	238.02 (NA)	10.19 (NA)
7	279.00 (NA)	31.46 (NA)	231.69 (NA)	7.70 (NA)
8	312.00 (NA)	29.18 (NA)	243.00 (NA)	NA
9	330.67 (NA)	5.86 (NA)	251.00 (NA)	NA
10	295.00 (NA)	NA		

A von Bertalanffy growth curve was calculated for the 100 randomly generated data sets and estimates of the parameters for each sex are presented in Table 8.2.

Table 8.2 Estimates of the von Bertalanffy growth curve parameters for 100 randomly generated data sets in which unsexed juveniles were assigned to females and males assuming a 1:1 ratio.

	Females			Males		
	Min	Average	Max	Min	Average	Max
L_∞ (TL mm)	275.45	275.60	275.86	251.53	251.79	252.05
K (per year)	0.619	0.622	0.623	0.685	0.688	0.693
a_0 (TL mm)	-0.119	-0.116	-0.114	-0.116	-0.114	-0.109

Mean lengths at age were calculated by:

$$L_a = L_\infty (1 - e^{-K\ (a+0.5-a_0)}),$$

and the resultant von Bertalanffy growth curve is presented in Figure 8.1.

It was assumed that the distribution of lengths at age are normally distributed with standard deviation sd_a, which is a linear function of mean length at age governed by

$$sd_a = \sigma_{L_1} + \left(\frac{L_a - \bar{L}_1}{\bar{L}_i - \bar{L}_1} \right) (\sigma_{L_i} - \sigma_{L_1}),$$

where *i*=5 was chosen because the sample size is greater than 50 fish (Table 8.1).

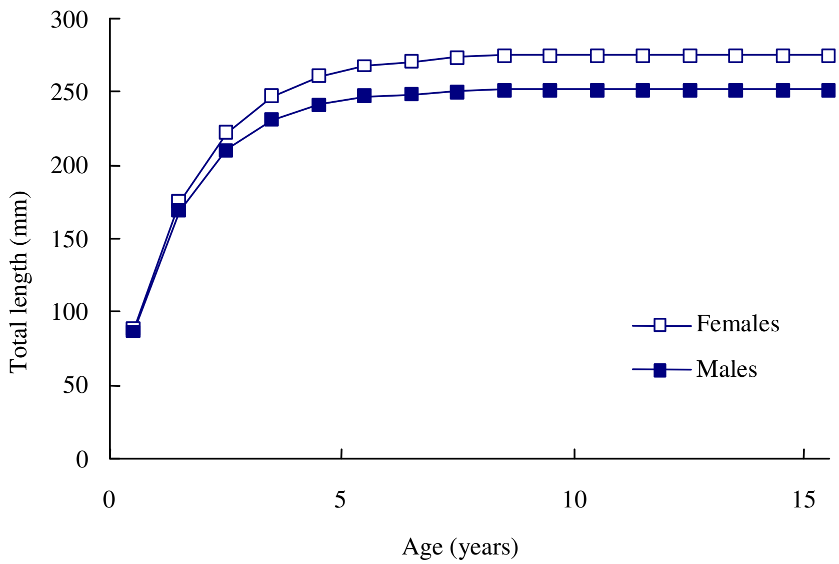

Figure 8.1 Total length at age determined from the average von Bertalanffy growth curve parameters in Table 8.2. Mean total lengths were calculated and plotted at the midpoint of each age class.

The mean length at age calculated from the von Bertalanffy growth curve and standard deviations determined from the linear interpolation between the standard deviation of lengths at the first and fifth age classes are presented in Table 8.3.

Table 8.3 Mid-year lengths for each age class calculated from the von Bertalanffy growth curve and standard deviations determined from the linear interpolation between the standard deviation of the mean length at the first and fifth age classes.

Age class	Females		Males	
	L_a	sd_a	L_a	sd_a
0	87.72	26.41	86.75	26.29
1	174.73	23.07	168.85	18.01
2	221.45	21.29	210.10	13.84
3	246.53	20.32	230.84	11.75
4	259.99	19.81	241.26	10.70
5	267.22	19.53	246.50	10.17
6	271.10	19.38	249.13	9.91
7	273.19	19.30	250.45	9.77
8	274.30	19.26	251.12	9.71
9	274.90	19.24	251.45	9.67
10	275.23	19.23	251.62	9.66
11	275.40	19.22	251.70	9.65
12	275.49	19.22	251.75	9.64
13	275.54	19.21	251.77	9.64
14	275.57	19.21	251.78	9.64
15	275.58	19.21	251.79	9.64

The mean length proportions at age were approximated by

$$p_{l/a}(L_l, L_a, sd_a) = \frac{1}{\sqrt{2\pi}sd_a} e^{-\left(\frac{L_l - L_a}{2sd_a}\right)},$$

where L_l is the midpoint of the length class as a result of discretising the length distribution into n_l length classes. The length proportions were used to develop mean length at age matrices and are presented in Table 8.4 and Figure 8.2.

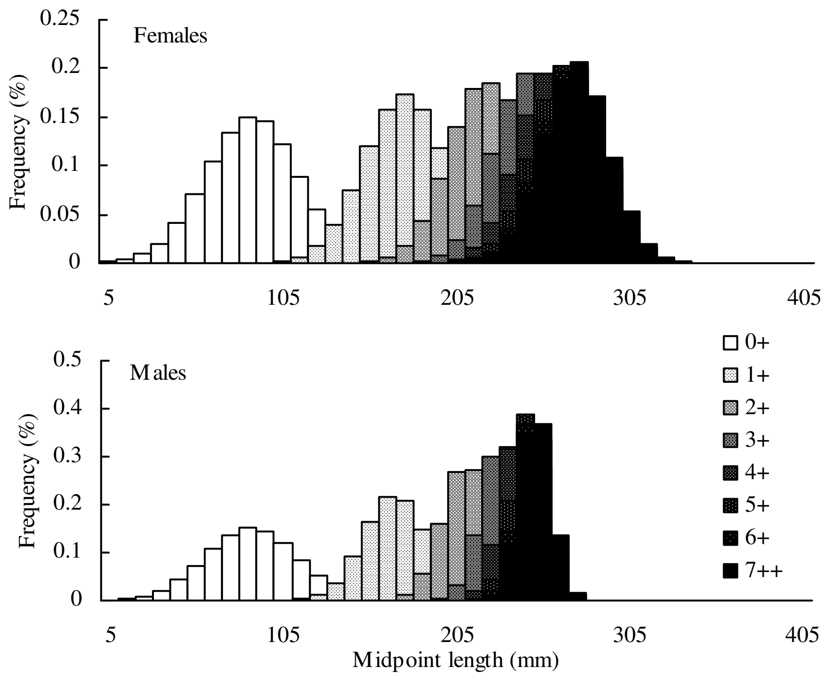

Figure 8.2 Mean length-frequencies at age for females and males from Table 8.4. The curves represent the proportion of mean total lengths within each age and do not reflect the actual proportions of mean length at age within the population.

Table 8.4 Proportions at mid-length (TL mm) at age for females and males.

Length (TL mm)	Age (years)							Females								
midpoint	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75	0.135	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
85	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95	0.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
105	0.122	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
115	0.089	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	0.056	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
135	0.030	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
145	0.014	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
155	0.006	0.120	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
165	0.002	0.158	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
175	0.001	0.173	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
185	0.000	0.157	0.043	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
195	0.000	0.118	0.087	0.008	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
205	0.000	0.073	0.139	0.024	0.004	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
215	0.000	0.038	0.179	0.059	0.015	0.006	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001
225	0.000	0.016	0.185	0.112	0.042	0.020	0.012	0.009	0.008	0.007	0.007	0.007	0.007	0.007	0.007	0.006
235	0.000	0.006	0.153	0.167	0.091	0.052	0.036	0.029	0.026	0.024	0.023	0.023	0.023	0.022	0.022	0.022
245	0.000	0.002	0.102	0.196	0.151	0.107	0.083	0.071	0.065	0.062	0.060	0.059	0.059	0.059	0.059	0.058
255	0.000	0.000	0.054	0.180	0.195	0.168	0.146	0.133	0.125	0.121	0.119	0.118	0.118	0.117	0.117	0.117
265	0.000	0.000	0.023	0.130	0.195	0.203	0.196	0.189	0.184	0.182	0.180	0.179	0.179	0.179	0.178	0.178
275	0.000	0.000	0.008	0.074	0.151	0.189	0.202	0.206	0.207	0.207	0.207	0.208	0.208	0.208	0.208	0.208
285	0.000	0.000	0.002	0.033	0.091	0.135	0.159	0.171	0.178	0.181	0.182	0.183	0.184	0.184	0.184	0.184
295	0.000	0.000	0.000	0.011	0.042	0.074	0.096	0.109	0.116	0.120	0.122	0.123	0.124	0.124	0.125	0.125
305	0.000	0.000	0.000	0.003	0.015	0.031	0.045	0.053	0.058	0.061	0.063	0.063	0.064	0.064	0.064	0.064
315	0.000	0.000	0.000	0.001	0.004	0.010	0.016	0.020	0.022	0.024	0.024	0.025	0.025	0.025	0.025	0.025
325	0.000	0.000	0.000	0.000	0.001	0.003	0.004	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0.008
335	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
345	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
355	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Length (TL mm)	Age (years)							Males								
midpoint	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	0.073	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	0.108	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75	0.137	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
85	0.151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95	0.144	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
105	0.119	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
115	0.085	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	0.053	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
135	0.028	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
145	0.013	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
155	0.005	0.165	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
165	0.002	0.217	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
175	0.001	0.209	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
185	0.000	0.148	0.056	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
195	0.000	0.077	0.159	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
205	0.000	0.030	0.269	0.030	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
215	0.000	0.008	0.271	0.137	0.018	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
225	0.000	0.002	0.162	0.300	0.118	0.042	0.021	0.014	0.011	0.010	0.009	0.009	0.009	0.009	0.009	0.009
235	0.000	0.000	0.057	0.319	0.314	0.207	0.146	0.117	0.104	0.097	0.094	0.092	0.092	0.091	0.091	0.091
245	0.000	0.000	0.012	0.164	0.351	0.388	0.369	0.349	0.337	0.330	0.327	0.325	0.324	0.323	0.323	0.323
255	0.000	0.000	0.001	0.041	0.163	0.277	0.338	0.366	0.379	0.386	0.389	0.390	0.391	0.391	0.391	0.391
265	0.000	0.000	0.000	0.005	0.032	0.075	0.112	0.135	0.148	0.155	0.158	0.160	0.161	0.161	0.162	0.162
275	0.000	0.000	0.000	0.000	0.003	0.008	0.013	0.017	0.020	0.021	0.022	0.022	0.023	0.023	0.023	0.023
285	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
295	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
305	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
315	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
325	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
335	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
345	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
355	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Length conversion

The conversion from LCF (length to the caudal fork, mm) to TL (total length, mm) was calculated using the length information which was available from the data collected during the 1996 to 1998 sampling program (Chapter 2), and governed by:

$$\mathrm{TL} = 1.174\mathrm{LCF} - 3.365 .$$

No significant difference (p>0.05) was found between the respective parameters calculated for females and males. The length conversions were utilised for converting catch at length information measured in LCF to TL.

Length-weight relationship

A single length-weight relationship (Figure 8.3) was calculated using the length (TL mm) and weight (gm) information which was available from the data collected during the 1996 to 1998 sampling program (Chapter 2), and governed by:

$$W_l = \phi_1 L^{\phi_2} ,$$

where parameters ϕ_1=1.02E-05 and ϕ_2=3.015. No significant difference (p>0.05) was found between the respective length-weight parameters calculated for females and males.

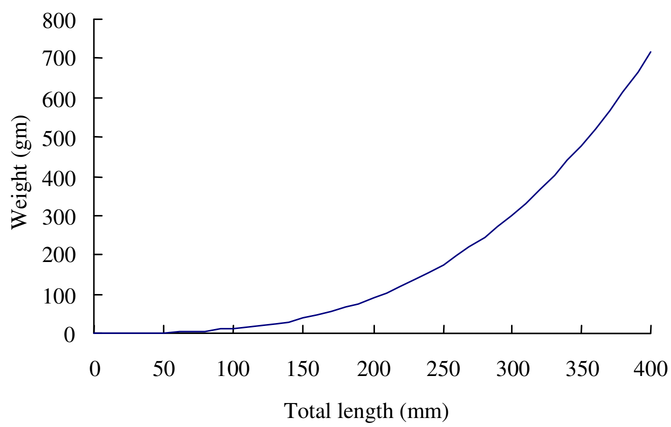

Figure 8.3 Length-weight relationship.

Maturity (migration)

Maturity (the proportion mature) was determined in Chapter 2 for females and males and governed by:

$$m_l = \frac{1}{1 + e^{(-\ln(19)(l - L_{50})/(L_{95} - L_{50}))}} ,$$

where parameter estimates for females are L_{50}=196.9, L_{95}=241.0 and males are L_{50}=179.0, L_{95}=203.9 (TL mm). It was assumed that Australian herring maturing in South Australia migrate to Western Australia. This assumption is considered realistic as no mature Australian herring were found in South Australia. The assumption was necessary because the tagging data set was incomplete for the calculation of migration rates.

Fecundity

Fecundity (number of eggs) was determined in Chapter 2 for females and related to total length (mm) by:

$$f_l = \phi_3 e^{\phi_4 L},$$

where ϕ_3=4619.3 eggs and ϕ_4=0.0114 mm^{-1}.

Natural mortality

Natural mortality was calculated to range between 0.3 and 0.5 based on the maximum age method:

$$M = \ln(100)/(\text{maximum age}).$$

Maximum ages investigated were 9 to 15 years. Consequently the natural mortality used was M=0.4 per year.

Commercial catch and recreational effort

The commercial catches by financial year in Western Australia, South Australia and Victoria are presented in Figure 8.4 (see also Chapters 1 and 7). As it is not known if Australian herring east of South Australia form part of the breeding stock, the information from Victoria was not considered in the model. This assumption is reasonable as the majority of the catch is taken in Western Australia and South Australia. The commercial catches in Western Australia and South Australia are presented by calendar year in Figure 8.5. The west coast (region 1) and the south coast (regions 2 and 3) catches in Western Australia have been separated.

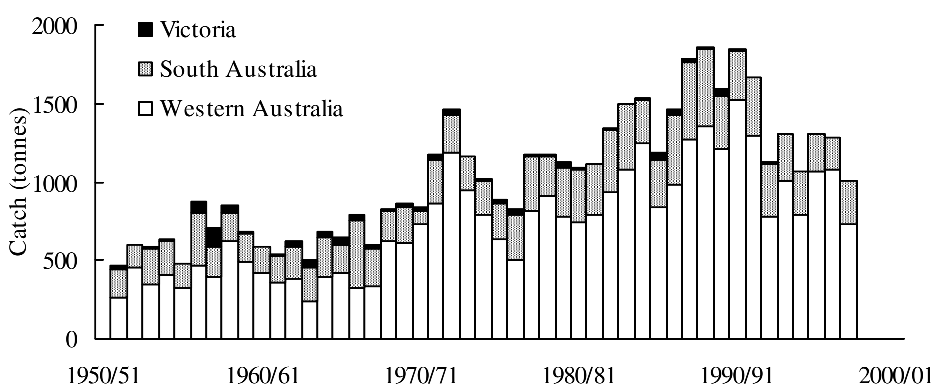

Figure 8.4 Commercial catches by financial year in Western Australia, South Australia and Victoria.

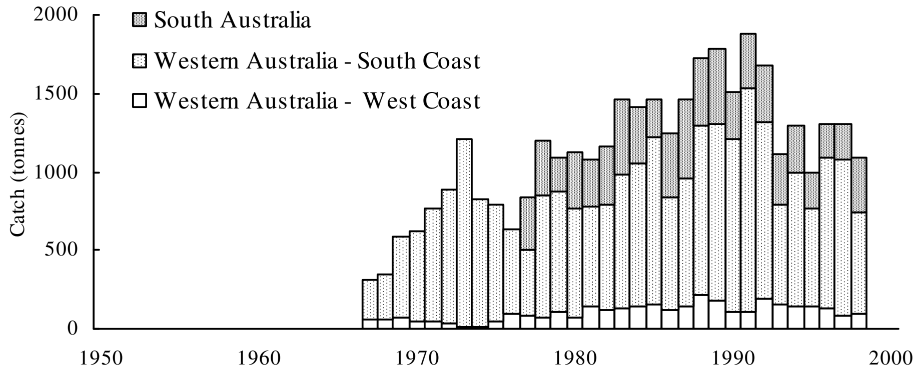

Figure 8.5 Commercial catches by calendar year in the west coast (region 1) and south coast (regions 2 and 3) of Western Australia and South Australia (regions 4-6).

The majority of the commercial catch in Western Australia is taken in the first part of the year while Australian herring are migrating. Thus the financial year catches (1951/52-1965/66) were substituted for missing catches in the respective calendar years 1952-1966 (Table 8.5). Furthermore the average south coast commercial catch was 88% (range 80-99%) of the total Western Australia commercial catch for the years 1967-1998. Consequently the financial year commercial catches in Western Australia in the years 1952-1966 were separated 88% and 12% into south coast and west coast catches respectively. South Australian financial year commercial catches (1951/52-1975/76) were substituted for missing catches in the calendar years 1952-1976 (Table 8.5).

The occasional creel surveys carried out in Western Australia and South Australia suggest that the number of recreational fishers lies between 25-30% and 20-35% of the population in the respective states since the early 1980s (pers. comm. Rod Lenanton, Fisheries Western Australia and Keith Jones, South Australia Research and Development Institute, also see Chapter 1). These creel surveys also suggest that the participation rates have increased over this period. Due to the lack of a recreational catch and effort time series the following assumption was made; the participation rate (Table 8.6) is 30% of the population size in each state and any change in the population size is reflected by a change in the participation rate. This assumption is highly conservative as it suggests that the participation rate has been relatively high, but due to the high uncertainty associated with the lack of suitable data this assumption is probably reasonable.

Table 8.5 Estimated commercial catches (tonnes) by calendar year for west coast and south coast Western Australia and South Australia. (* refers to the substitution of financial year catches for missing calendar year catches).

	Western Australia		South Australia		Western Australia		South Australia
Year	West Coast	South Coast		Year	West Coast	South Coast	
1952	*32	*236	*173	1976	91	540	*224
1953	*55	*403	*136	1977	83	425	327
1954	*41	*303	*227	1978	78	768	348
1955	*48	*355	*219	1979	104	766	217
1956	*39	*286	*151	1980	67	696	366
1957	*55	*406	*341	1981	146	629	306
1958	*47	*348	*186	1982	119	671	374
1959	*75	*550	*182	1983	134	853	472
1960	*59	*432	*182	1984	141	914	364
1961	*50	*367	*166	1985	160	1065	231
1962	*42	*311	*177	1986	124	710	410
1963	*46	*336	*209	1987	148	814	493
1964	*29	*212	*216	1988	210	1081	428
1965	*48	*352	*241	1989	180	1132	471
1966	*51	*373	*171	1990	112	1097	296
1967	56	257	*426	1991	109	1427	343
1968	57	288	*238	1992	190	1130	362
1969	67	524	*189	1993	156	633	321
1970	48	574	*225	1994	145	853	300
1971	48	714	*80	1995	141	626	231
1972	38	850	*278	1996	133	960	213
1973	8	1200	*241	1997	82	1001	219
1974	14	812	*209	1998	92	651	349
1975	53	738	*211				

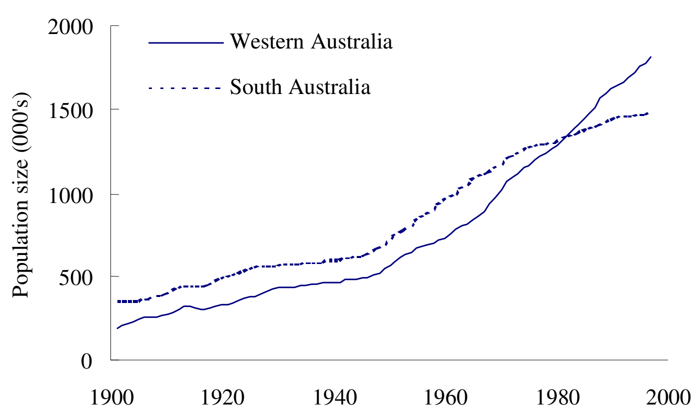

Figure 8.6 Population sizes of Western Australia and South Australia (Australian Bureau of Statistics).

Information on the recreational catch of Australia herring was determined from creel surveys conducted in 1994-1996 (see Chapter 1 for details of these creel surveys). During these creel surveys it was estimated that the shore and boat based Australia herring catch on the west coast of Western Australia in 1994 and 1995 was 158.5 and 132.7 tonnes respectively. The shore and boat based Australia herring catch on the south coast of Western Australia was estimated to be 88.4 and 44.5

tonnes in 1994 and 1995 respectively. The 1994-1996 average boat and jetty Australia herring catches in South Australia was estimated to be 35.6 tonnes.

The participation rate on the west coast was calculated from the total population size in Western Australia while the south coast participation rate was calculated from the population size excluding the Perth region (Table 8.6 and Figure 8.7). Again this assumption is highly conservative reflecting our uncertainty in the data. Indeed all calculated recreational participation rates (Table 8.6) are probably over estimates of the real participation rate as they account for all fishers and not just those that target and/or catch Australian herring.

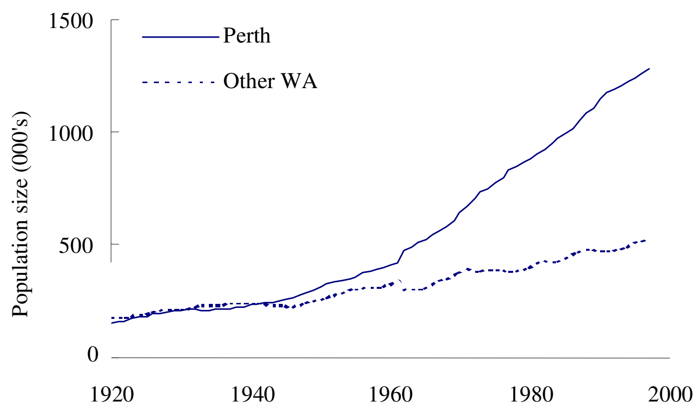

Figure 8.7 Population sizes of Perth and the remainder of Western Australia (Australian Bureau of Statistics).

Table 8.6 Estimated recreational participation (000's of anglers) by calendar year for the west coast and south coast of Western Australia and South Australia.

	Western Australia		South Australia		Western Australia		South Australia
Year	West Coast	South Coast		Year	West Coast	South Coast	
1952	184	101	231	1976	358	240	384
1953	190	104	236	1977	365	250	388
1954	195	105	242	1978	371	256	390
1955	201	108	250	1979	377	261	391
1956	204	112	259	1980	385	265	394
1957	209	115	266	1981	396	270	398
1958	212	117	272	1982	406	277	401
1959	216	120	280	1983	414	286	406
1960	219	123	287	1984	421	293	410
1961	227	126	294	1985	431	299	413
1962	233	143	299	1986	443	305	416
1963	240	147	307	1987	454	315	420
1964	245	153	316	1988	468	324	424
1965	251	158	325	1989	479	333	428
1966	259	162	331	1990	487	344	432
1967	269	168	335	1991	494	353	436
1968	281	175	340	1992	500	357	438
1969	293	184	345	1993	507	362	439
1970	304	193	351	1994	515	366	440
1971	321	202	363	1995	525	372	441
1972	328	214	367	1996	535	379	443
1973	334	220	371	1997	544	385	445
1974	344	226	378	1998	549	390	446
1975	350	233	381				

Indices of abundance

Standardised commercial catch rates were used as indices of abundance. Standardised catch rates were calculated only from Western Australian commercial fisheries. Changes in South Australian fishing effort were considered to be largely due to fishing practices and environmental effects, and as the magnitude of these impacts are unknown there is no means in which to standardise this effort.

Western Australian west coast catches were predominantly taken by beach haul fishing, while the south coast catches were predominantly taken by the trap net fishery (Figure 8.8). The fishing method referred to as beach haul includes the fishing techniques of beach seining and haul netting (described in Chapter 1).

The catch information for the south coast fisheries of Western Australia has been extensively checked for errors. The trap net fishery information has been recorded separately since 1990, though the method had been in use even before the commencement of the computerised catch and effort database in 1975. Utilising the services of the local Fisheries Officer (pers. comm. John Kelly, Fisheries Western Australia), Fisheries Research Technical Officer (pers. comm. Gabrielle Nowara, Fisheries Western Australia) and with reference to the actual monthly returns from fishers it was possible to assign catches to the method of capture (Figure 8.8). Effort in the trap net fishery was considered more reliable than the other fishing methods because in the former method fishers were more likely to be targeting Australian herring while in the latter it is unknown what species were targeted.

The Western Australian west coast Australian herring catches were classified into oceanic and estuarine catches (Figure 8.8). The oceanic catches formed the major component of the west coast catch where in the 1970s it was 80-85% of the total west coast catch, in the 1980s it was 85-100% of the total west coast catch, and in the 1990s it was 94-99% of the total west coast catch. Furthermore, of the oceanic fisheries, Cockburn Sound and Geographe Bay were considered to have a representative stable group of fishers. Catch and effort data have been recorded separately for Cockburn Sound and Geographe Bay from 1980-1998 and 1989-1998 respectively (Figure 8.9). During these years Cockburn Sound catches were 11-35% and Geographe Bay catches were 37-54% of the oceanic Australian herring catches. To ensure that the effort information was measuring actual effort only those fishers who were considered to be targeting Australian herring were included, that is, those whose catches consisted of more than 30% Australian herring. Annual effort was calculated for these fishers regardless of whether they caught Australian herring. It should be noted that this process has the potential to introduce bias since only fishers who are successful in catching Australian herring are selected, but in the absence of information on what fishers were targeting, was considered to be the most accurate information available.

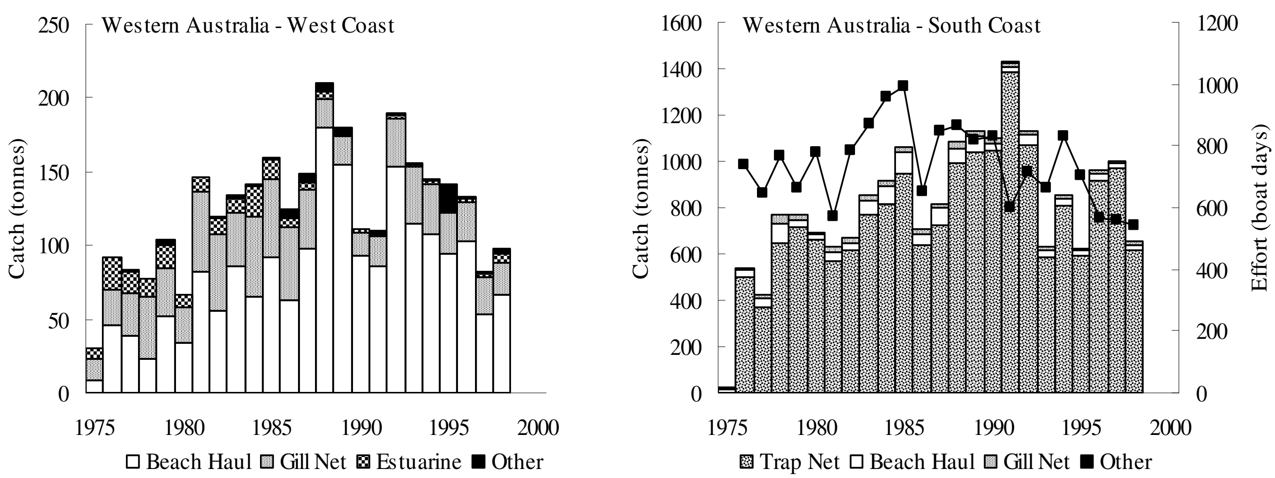

Figure 8.8 Commercial catches for the west coast and south coast Western Australia. The west coast was divided into ocean and estuarine fisheries. The gear types used in the ocean fisheries were beach haul, gill net and other. The south coast fisheries were divided into the gear types: trap net, beach haul, gill net and other. The trap net fishery effort (line) was calculated as boat days (refer to text for more details). In 1975 catch was recorded for the second half of the year only.

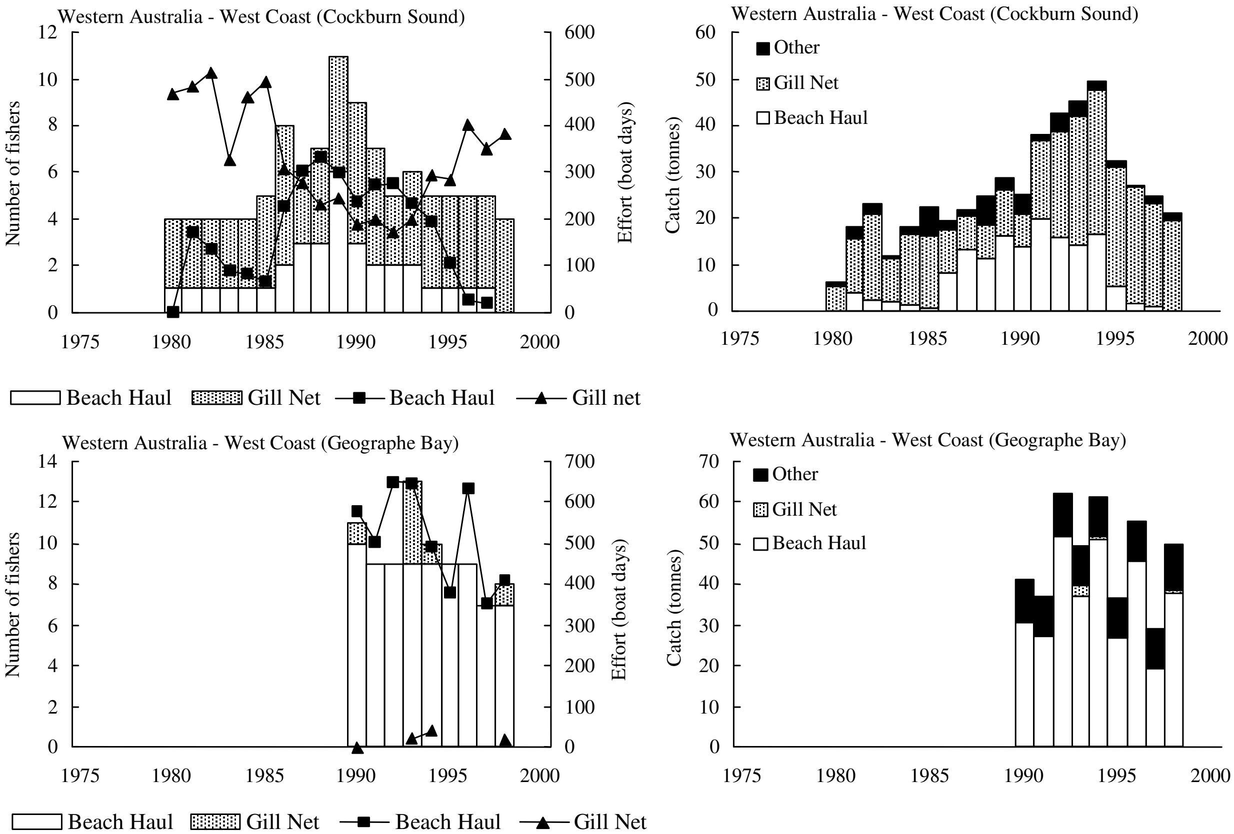

Figure 8.9 Catch and effort data for Cockburn Sound and Geographe Bay for fishers considered to be targeting Australian herring (refer to text for details of calculations).

Annual effort was calculated as boat days rather than net days as the former is considered more reliable. Boat days are the number of days in a month that a fisher has spent fishing, including days spent on the beach observing for Australian herring schools, consequently on some of these days they did not use their nets. Since net days effort is calculated as net length (average length of net used in a month) multiplied by number of boat days this will overestimate the annual number of net days. CPUE was calculated as the total annual catch of these fishers divided by the annual number of boats days fished (Figure 8.10 and Table 8.7). CPUEs were calculated for Cockburn Sound and Geographe Bay beach haul fisheries and the south coast trap net fishery. The CPUEs are considered standardised and therefore are relatively good indices of abundance.

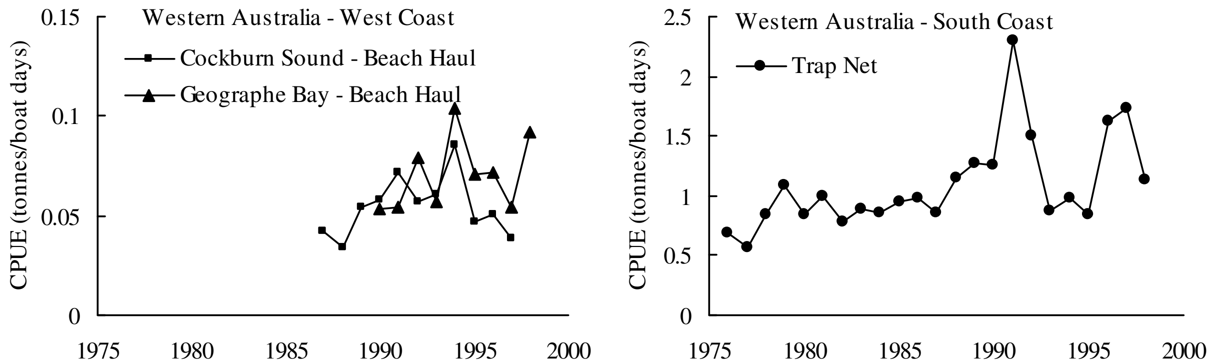

Figure 8.10 Standardised CPUEs calculated from catch and effort data from west coast and south coast Western Australia fisheries to be used as indices of abundance (refer to text for details of calculations).

Table 8.7 Standardised CPUEs calculated from catch and effort data from west coast and south coast Western Australia fisheries to be used as indices of abundance (refer to text for details of calculations).

	Western Australia CPUE (tonnes per boat-day)		
	West Coast Beach Haul Fisheries		South Coast
Year	Cockburn Sound	Geographe Bay	Trap Net Fishery
1975			
1976			0.6833
1977			0.5668
1978			0.8427
1979			1.0862
1980			0.8506
1981			0.9986
1982			0.7845
1983			0.8827
1984			0.8558
1985			0.9575
1986			0.9818
1987	0.0424		0.8547
1988	0.0336		1.1460
1989	0.0540		1.2717
1990	0.0582	0.0530	1.2544
1991	0.0716	0.0539	2.3045
1992	0.0567	0.0792	1.5037
1993	0.0609	0.0572	0.8811
1994	0.0860	0.1035	0.9794
1995	0.0474	0.0706	0.8471
1996	0.0510	0.0719	1.6215
1997	0.0386	0.0542	1.7392
1998		0.0922	1.1348

Recruitment Indices

Sampling in the Barker Inlet, South Australia, in the years 1981-1982,1984-1995 has provided an index of abundance of 0+ Australian herring (Chapter 7). Calculation of the index involves averaging the numbers of fish in the months inclusive of the month the 0+ fish first appear to the month of peak abundance of 0+ fish. The LSMEANS procedure in SAS was used to account for missing information and the indices are presented in Table 8.8.

Table 8.8 Barker Inlet 0+ recruitment indices.

	0+ Indices
1981	0.1831
1982	0.1364
1984	0.7798
1985	0.0779
1986	0.6603
1987	0.4145
1988	1.7183
1989	0.3395
1990	0.0931
1991	0.4704
1992	0.3195
1993	0.4023
1994	0.1991
1995	0.9441

The average monthly Fremantle sea level was plotted against the respective Barker Inlet indices and the month of October produced the highest correlation (Table 8.9 and Figure 8.11). It was assumed that through this correlation the Barker Inlet 0+ recruitment index could be extended back through time to 1952 using the following relationship,

$$I_{y,0} = 0.044 * FSL_y - 2.312$$ for y = 1975 to 1980, 1983.

where $I_{y,0}$ is the Barker Inlet 0+ recruitment index and *FSL* is the average monthly Fremantle sea level (cm) in October, in year y.

While the correlation of the Barker Inlet indices and the average monthly Fremantle sea level in October are significantly correlated, the extrapolation of this index was treated cautiously and is only used to provide a very approximate level of recruitment in earlier years (Table 8.10).

Table 8.9 Barker Inlet 0+ recruitment indices and Fremantle sea level (cm) correlation estimates.

	Correlation	Significance
January	-0.127	NS
February	-0.016	NS
March	0.216	NS
April	0.107	NS
May	0.459	p<0.1
June	0.484	p<0.1
July	0.365	NS
August	0.587	p<0.05
September	0.633	p<0.05
October	0.675	p<0.01
November	0.391	NS
December	0.508	p<0.1

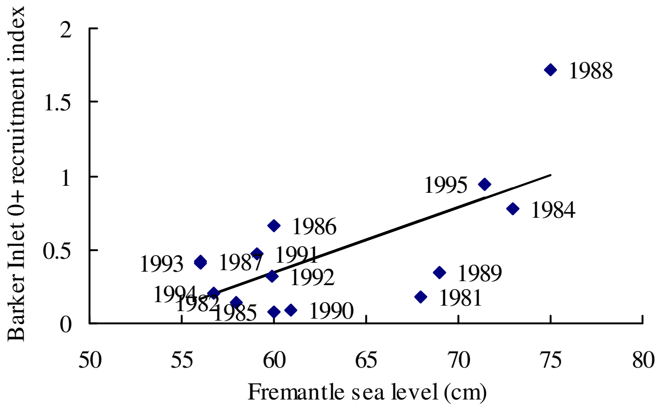

Figure 8.11 Barker Inlet 0+ recruitment against average monthly Fremantle sea level in October. The solid line represents the best fit relationship from Table 8.9.

Table 8.10 Estimated Barker Inlet 0+ recruitment index from the average monthly Fremantle sea level in October.

Year	Sea level	Index	Year	Sea level	Index	Year	Sea level	Index
1952	58	0.2567	1968	62	0.4339	1984	73	0.9211
1953	58	0.2567	1969	57	0.2124	1985	60	0.3453
1954	62	0.4339	1970	68	0.6996	1986	60	0.3453
1955	74	0.9654	1971	71	0.8325	1987	56	0.1681
1956	67	0.6553	1972	55	0.1238	1988	75	1.0097
1957	57	0.2124	1973	65	0.5667	1989	69	0.7439
1958	63	0.4782	1974	73	0.9211	1990	60.9	0.3851
1959	65	0.5667	1975	78	1.1426	1991	59.1	0.3054
1960	60	0.3453	1976	63	0.4782	1992	59.9	0.3408
1961	55	0.1238	1977	62	0.4339	1993	56	0.1681
1962	67	0.6553	1978	62	0.4339	1994	56.7	0.1991
1963	63	0.4782	1979	61	0.3896	1995	71.4	0.8502
1964	69	0.7439	1980	55	0.1238	1996	73.9	0.9610
1965	69	0.7439	1981	68	0.6996	1997	55.7	0.1548
1966	63	0.4782	1982	58	0.2567	1998	71.4	0.8502
1967	64	0.5224	1983	63	0.4782			

Recruitment indices were investigated for each of the six regions for the year 1996-1998 (Table 8.11). The indices, when combined over regions, show that the average annual recruitment does not vary between years. Conversely, the recruitment between regions varies considerably. This suggests that the average annual recruitment is relatively constant from year to year, and that the proportion of the recruits to each region may be dependent on some environmental factor such as the Leeuwin current. Assuming the average annual recruitment mirrors the absolute abundances, it was calculated that 49% of recruits remain in the south coast of Western Australia (regions 2-3) and 51% appear in South Australia (regions 4-6). As these indices have only been collected for three years these results should be treated with caution, but will become a valuable source of information for future stock assessments.

Table 8.11 Recruitment indices for 0+ Australian herring along the coastline of Western Australia and South Australia for the years 1996-1998.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Combined
1996	0.6348	0.9398	2.1973	2.4590	2.3023	1.4348	1.6613
1997	1.2739	1.8826	3.6698	1.0602	0.8641	1.0260	1.6294
1998	1.4921	2.2673	2.1671	2.6105	1.2143	0.8598	1.7685
Combined	1.1336	1.6965	2.6780	2.0432	1.4602	1.1069	

Catch at age and catch at length data

Catch at age and catch at length data from the recreational and commercial fisheries were collected during the 1996 to 1998 sampling program (Chapter 2). The recreational fishery consists of shore based fisheries and boat based fishers. As these sectors of the recreational fishery were not distinguished, the information was presented for the whole fishery for the west coast and south coast Western Australia and South Australia. The commercial fisheries consist of a number of gear types including; beach haul, gill net and trap nets. Information is only available for beach haul and trap net fisheries, so the information was presented for these fisheries where they exist on the west coast and south coast of Western Australia and South Australia. The catch at age and catch at length information have been summed over the 1996-1998 period (Figures 8 .12 and 8.13). Other sources of data collected include length samples collected during 1977-80 from the west coast and south coast of Western Australian and South Australian commercial fisheries (Figure 8.14). The information from the South Australian commercial fisheries was combined to create a single catch at length data set for 1978.

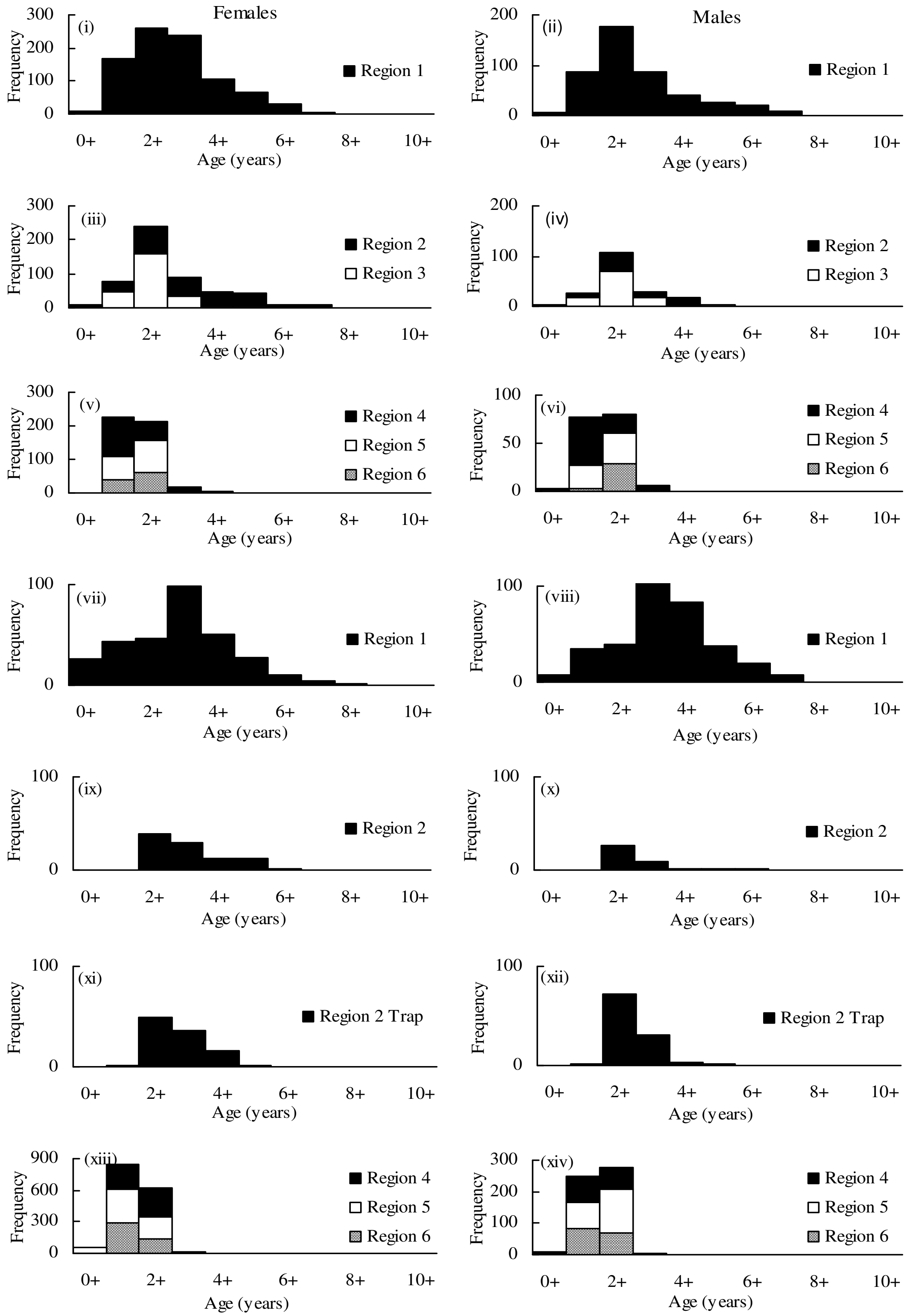

Figure 8.12 Catch at age data for commercial and recreational fisheries. (i)-(vi) are recreational data and (vii)-(xiv) are commercial data.

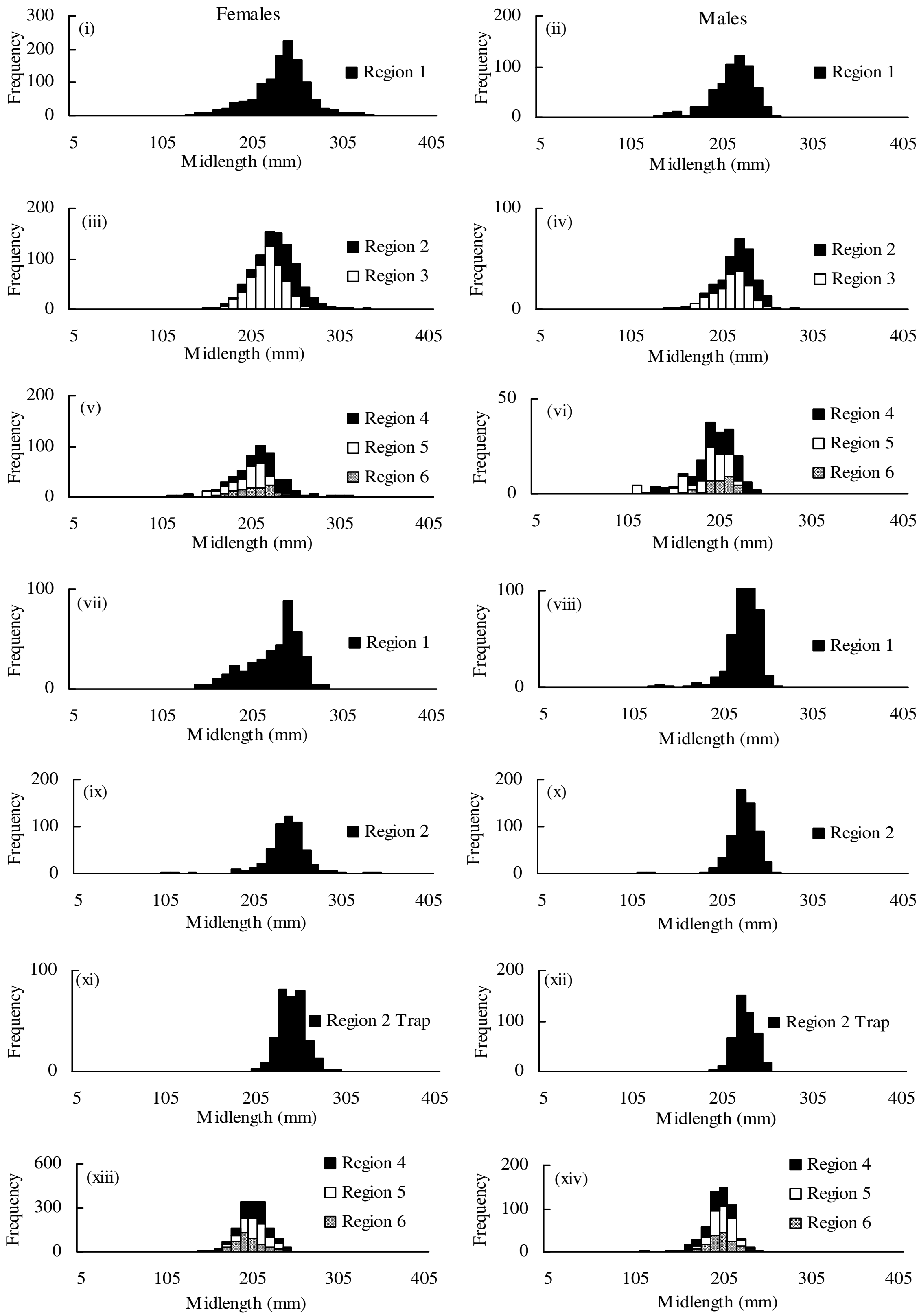

Figure 8.13 Catch at length data for commercial and recreational fisheries. (i)-(vi) are recreational data and (vii)-(xiv) are commercial data.

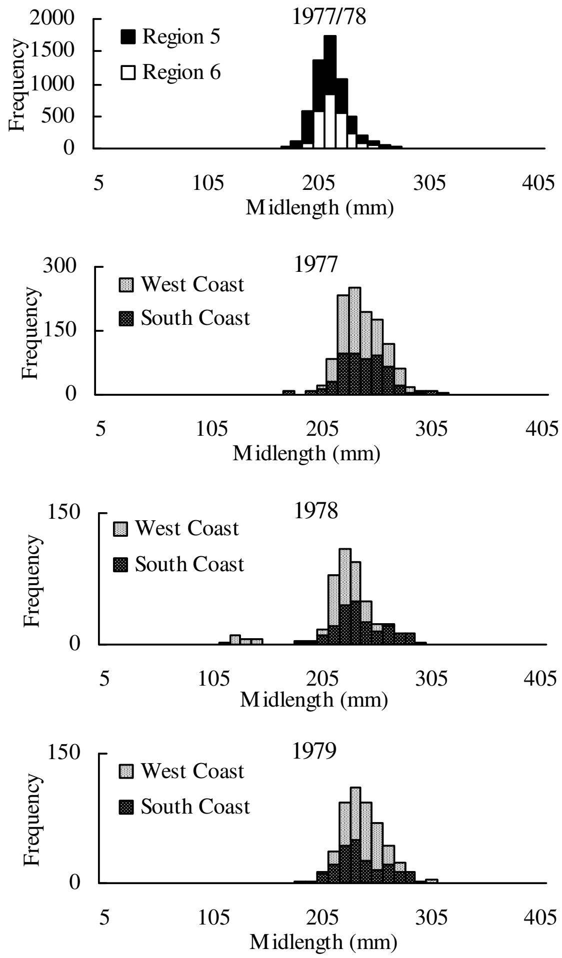

Figure 8.14 Catch at length data for commercial fisheries in Western Australia and South Australia. South Australian information is for region 5 in 1977/78 and region 6 in 1978. Western Australian information is for the west coast and south coast in 1977-1979.

Selectivity

Gear selectivity was calculated for the recreational and commercial fisheries in Western Australia and South Australia. Selectivity functions were calculated utilising the catch at age and catch at length data collected during the 1996 to 1998 sampling program (Chapter 2). No information was collected on Australian herring commercial or recreational bycatch, including fish discarded from the catch and either were returned alive or dead to the water. Consequently the calculated selectivity curves do not include this bycatch. The recreational fishery consists of shore based fisheries and boat based fishers. As these sectors of the recreational fishery were not distinguished, a single selectivity function was calculated for the west coast and south coasts of Western Australia and South Australia (Figure 8.12).

The commercial fisheries consist of a number of gears including beach haul, gill net, trap net and others (Chapter 1 and 7). Information is only available for beach haul and trap net fisheries, so selectivity functions are calculated for these fisheries where they exist on the west coast and south coast of

Western Australia and South Australia (Figure 8.13). It was assumed that the selectivity function for the beach haul gear is appropriate for other gear types where this information was not available. In Western Australia this assumption is probably reasonable as there is a legal minimum size of 180 mm (TL) and fishers target larger fish using appropriate sized mesh. In South Australia, 88-95% of the Australian herring catch is taken by haul net, and as there are no data available for the other gear types, it is probably reasonable to use the haul net selectivity function for the whole commercial fishery. Future research should be conducted to determine selectivity functions for all gear types in recreational and commercial fisheries.

The selectivity function was calculated for each gear type using a modified catch curve analysis. It was assumed that the recreational and commercial fisheries impact the Australian herring population independently, that is, the proportion of fish removed from the population by one fishery does not effect the proportion of fish removed from the other fisheries. In addition, the analysis for the Western Australian south coast population does not include fish migrating from South Australia. The reason for this simplicity was to avoid the need for data that are unavailable at this time, for example, the number or proportion of Australian herring that migrate from South Australia to Western Australia. Also, sampling of the recreational and commercial fisheries were not equivalent and consequently the catch curve analysis could not be undertaken on these fisheries simultaneously. It should be noted that these selectivity functions are only preliminary and more research is needed in the future to improve the estimates of the selectivity parameters.

The subscript *s* for sex is omitted for ease of presentation. The catch curve analysis involves the usual determination of the population size governed by,

$$N_a = \begin{cases} N_0 & \text{if } a=0 \\ (N_{a-1} - C_{a-1}) \sum_l p_{l/a-1} (1-m_l)\, e^{-M} & \text{if } 0<a<x \\ (N_{a-1} - C_{a-1}) \sum_l p_{l/a-1} (1-m_l)\, e^{-M} \;/ (1 - \sum_l p_{l/a} (1-m_l)\, e^{-M}) & \text{if } a=x \end{cases},$$

where N_0 is the estimated initial population size parameter,

C_a is the observed catch at age,

m_l is the maturity at length is zero if the fishery is in Western Australia,

$p_{l/a}$ is the mid-length at age matrix,

M is natural mortality.

The exploitation rate was calculated as:

$$U = \frac{\sum_a C_a}{\sum_a \sum_l p_{l/a} S_l N_a},$$

where S_l is the selectivity at length such that:

$$S_l = \frac{1}{1+e^{(-\ln(19)(l-selL_{50})/(selL_{95}-selL_{50}))}},$$

$selL_{50}$ and $selL_{95}$ are the estimated selectivity parameters.

Maturity at age is calculated so that in South Australia, fish that mature and migrate are removed from the population and consequently are no longer vulnerable to the fishing gear. In Western Australia the selectivity curves are calculated from Australian herring catch at age and catch at length data which already include South Australian migrants.
Predicated catches were calculated as:

$$\hat{C}_{l/a} = N_a p_{l/a} S_l U ,$$

such that:

$$\hat{C}_a = \sum_l \hat{C}_{l/a} \text{ and } \hat{C}_l = \sum_a \hat{C}_{l/a} .$$

Calibration of the model involved the calculation of the objective function: the negative of the logarithm of the likelihood function and includes two contributions. These relate to fitting the observed catch at age data and the observed catch at length data:

$$L = \sum_{i=1}^{2} L_i .$$

The contribution of the age composition information to the negative of the logarithm of the likelihood function is based on the assumption that the age-structure information is determined from a random sample (η_a is the sample size) of fish from the catch:

$$L_1 = \eta_a \sum_a (P_a \ln(\hat{P}_a)) ,$$

where:

$$P_a = C_a / \sum_a C_a \text{ and } \hat{P}_a = \hat{C}_a / \sum_a \hat{C}_a .$$

The contribution of the length composition information to the negative of the logarithm of the likelihood function is based on the assumption that the length structure information is determined from a random sample (η_l is the sample size) of fish from the catch:

$$L_2 = \eta_l \sum_l (P_l \ln(\hat{P}_l)) ,$$

where:

$$P_l = C_l / \sum_l C_l \text{ and } \hat{P}_l = \hat{C}_l / \sum_l \hat{C}_l .$$

The estimated selectivity parameters for the commercial and recreational fisheries are presented in Table 8.12 and the selectivity curves are presented in Figure 8.15. The choice of values for η_a and η_l was not important as the model was relatively robust to a range of sample sizes (10-10000).

These results indicate that the recreational sector are targeting similar size and sex fish in all locations and in general are catching slightly smaller fish than the commercial sector. The exceptions are the commercial catch of females on the west coast of Western Australia and to a lesser degree South Australia where the catch includes a relatively larger number of smaller fish. The difference between the lengths of females and males in the catch is probably due to the poor fit to the data. Indeed it can be seen from Table 8.12 that the low contrast in the data has resulted in high variability around the parameter estimates. An important consideration, in need of more research, is that these selectivity functions may explain the differences in the sex ratios reported by a number of researchers (Chapter 2).

Table 8.12 Estimated selectivity parameters (and standard errors) for commercial and recreational fisheries.

		Females			Males		
	Fisheries	N_0	$SelL_{50}$	$SelL_{95}$	N_0	$SelL_{50}$	$SelL_{95}$
Recreational	Western Australia	3471.8	215.6	278.8	1139.4	216.1	269.4
	West Coast	(1467.8)	(106.3)	(204.2)	(1569.1)	(214.2)	(330.4)
	Western Australia	2856.4	203.4	235.7	571.7	212.6	255.1
	South Coast	(1502.7)	(48.5)	(100.3)	(61.0)	(82.3)	(146.4)
	South Australia	63135.0	207.0	247.1	5031.4	210.3	249.7
		(815530)	(61.5)	(106.4)	(2.0)	(36.3)	(55.5)
Commercial	Western Australia	1113.1	197.0	254.9	1341.5	216.5	255.7
	West Coast Haul	(128.5)	(31.9)	(64.6)	(95.1)	(16.6)	(30.7)
	Western Australia	364.0	225.9	263.7	119.4	206.5	234.5
	South Coast Haul	(26.2)	(14.1)	(26.6)	(22.1)	(15.6)	(20.9)
	Western Australia	810.6	226.0	246.2	413.1	214.8	234.9
	South Coast Trap Net	(92.9)	(9.4)	(20.9)	(47.1)	(11.2)	(20.2)
	South Coast Haul	11071.2	200.5	233.2	16300.0	209.9	235.6
		(24602.0)	(16.3)	(31.0)	(103820)	(15.6)	(23.4)

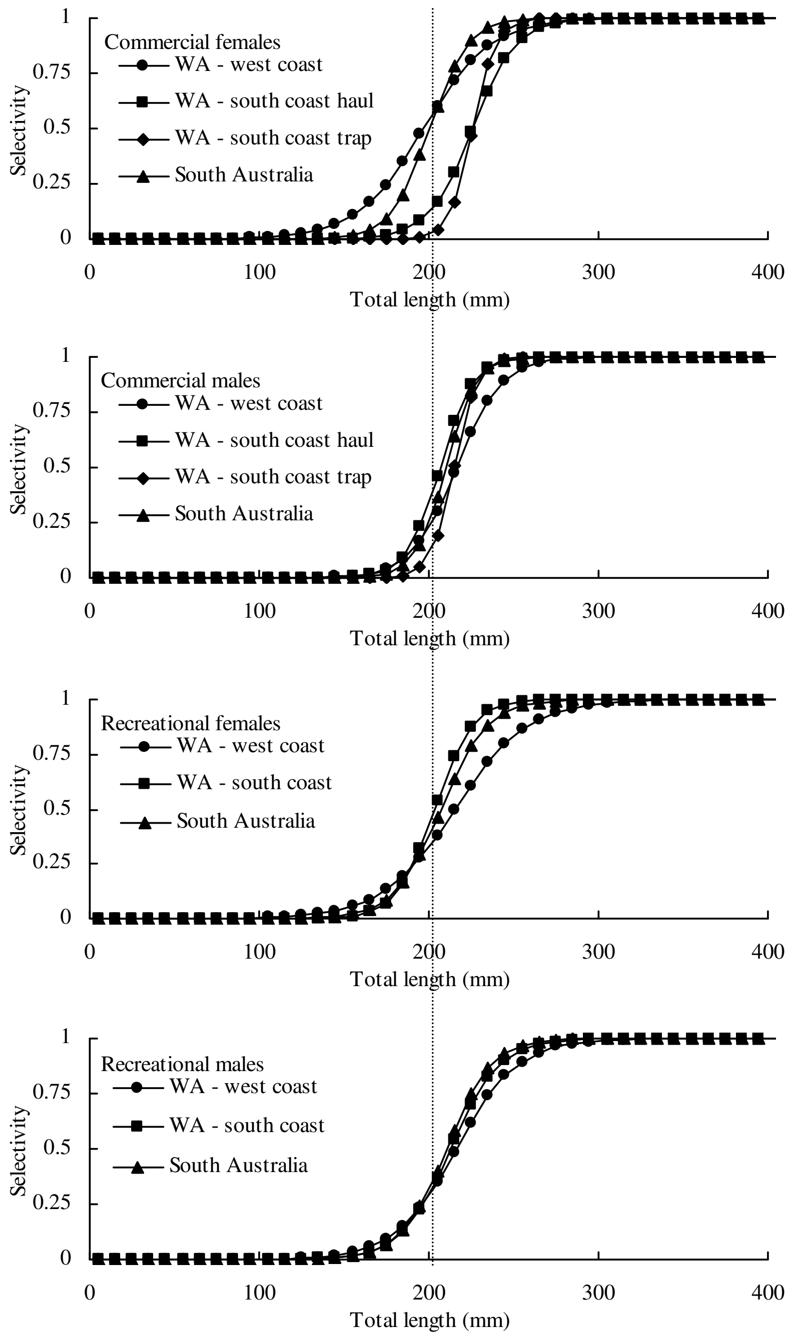

Figure 8.15 Selectivity curves for recreational and commercial fisheries. (Parameter estimates are presented in Table 8.12).

Regulations

In Western Australia there is a recreational bag limit of 40 Australian herring per day and a commercial legal minimum size of 180 mm (TL). In South Australia there was a legal minimum size of 150 mm (TL) in place for recreational and commercial fishers but after 1983 this was abolished. While in South Australia there is no legal minimum length, commercial fishers target larger fish as they attract a better price at the markets. There is no recreational bag limit in South Australia.

The model explores the following regulation changes:

1. Varying the recreational bag limit and commercial total allowable catch (TAC).
2. Varying the legal minimum size in the recreational and commercial fisheries.

The recreational catches for shore based and boat based anglers demonstrate the potential decrease in recreational catch by reducing the bag limit (Figures 8.16 and 8.17). Overall 50%, 75% and 95% of anglers kept 3 or less, 8 or less and 20 or less Australian herring respectively (Figure 8.16). Therefore reducing the bag limit from 40 to 20 in Western Australia has little impact on the number of Australian herring kept by each recreational fisher.

The effect of the recreational catch on the Australian herring population was investigated by calculating the number of fish kept by each fisher multiplied by the number of anglers catching that number of fish. Overall 50%, 75% and 90% of all fish kept by recreational fishers were caught by fishers who kept 11 or less, 20 or less and 30 or less Australian herring respectively (Figure 8.17). Assuming that recreational fishers who historically caught large numbers of fish subsequently catch only the proposed bag limit, reducing the bag limit from 40 to 30, 20 or 10 in Western Australia has the potential to reduce the total number of fish kept by anglers on average 1%, 6% or 22%.

Very little information has been collected on Australian herring commercial or recreational bycatch, which includes fish discarded from the catch, and which were returned either alive or dead to the water. Information on the survival of Australian herring returned to the water is unknown, consequently it was assumed that all fish not represented in the catch survived. This assumption is inadequate and future research should be considered to determine the commercial and recreational bycatch of Australian herring and their subsequent survival rates when returned to the water.

Other management regulations that may be considered are closed seasons and closed areas. The effectiveness of the compliance with and the enforcement of these regulations is unknown, as are the effectiveness of these regulations themselves. Consequently these measures have not been investigated.

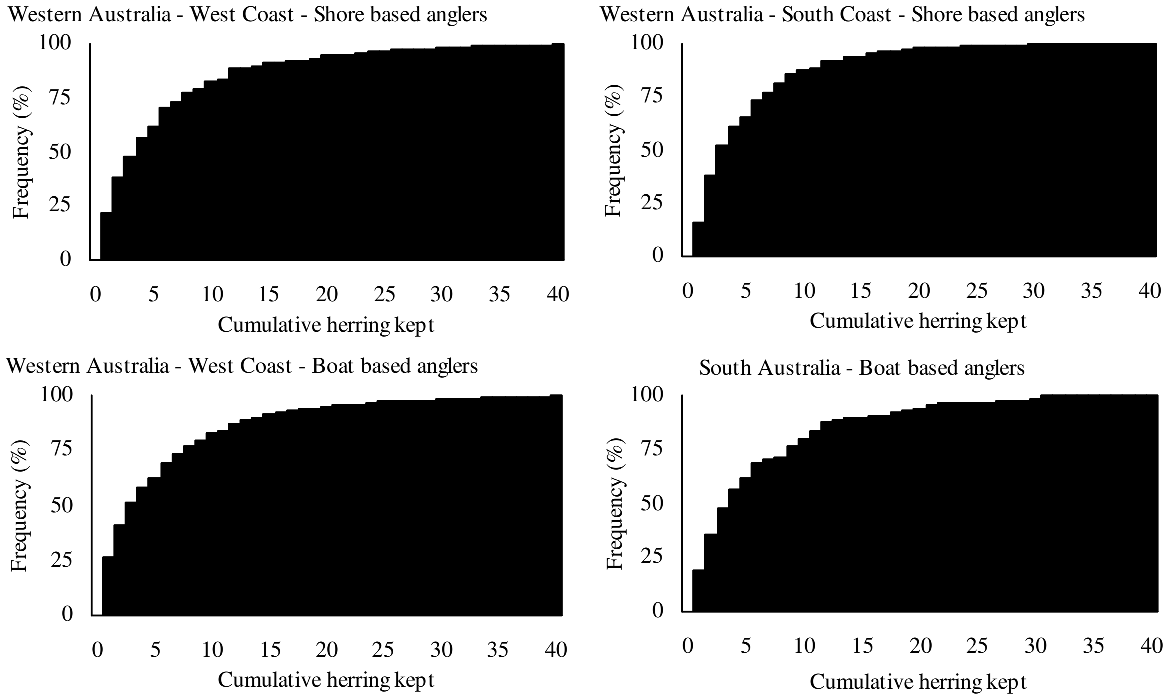

Figure 8.16 Cumulative number of Australian herring kept by recreational fishers.

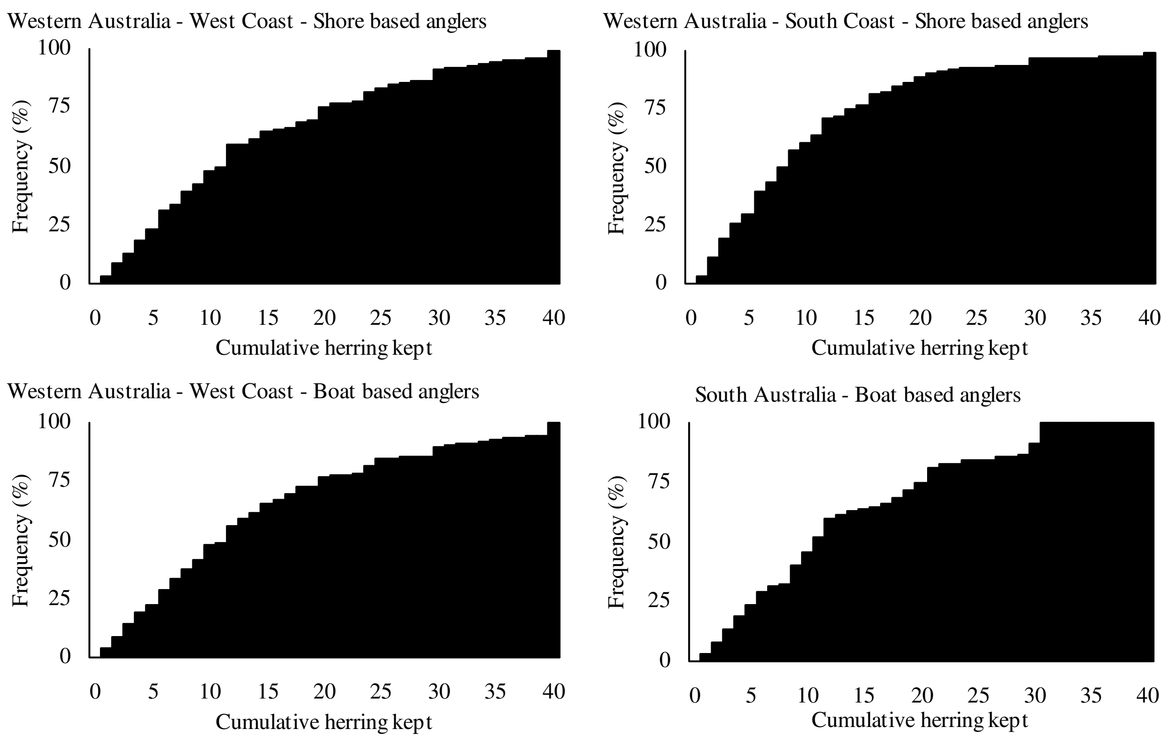

Figure 8.17 Cumulative total number of Australian herring kept by recreational fishers. The total number of Australian herring was calculated as number of Australian herring kept by each fisher multiplied by the number of anglers catching that number.

Population Dynamics Model

Introduction

The assessment of Australian herring is based on an age- and sex-structured population dynamics model that explicitly recognises exploitation is by both recreational (*rec*) and commercial (*com*) fisheries. Separate assessment models were developed for Australian herring on the west coast of Western Australia (region 1) and the southern coast of Australia (regions 2-7). The latter assumes that the Australian herring stock is composed of both a Western Australia (*WA*) component and a South Australia (*SA*) component. A mean length at age matrix is utilised to allow the incorporation of catch at length information.

The model deals firstly with migrating fish (only applicable in the model for Australian herring on the southern coast of Australia). The fish are subjected to exploitation, and for simplicity commercial fishing is assumed to occur prior to recreational fishing which in turn is assumed to occur to prior to natural mortality. Fish migrating (only applicable in the model for Australian herring on the southern coast of Australia) are subjected to exploitation in both Western Australia and South Australia. Spawning is assumed to occur prior to exploitation in Western Australia. An annual time step is used, consequently Australian herring surviving fishing and natural mortality are aged by one year.

Sources of information used in the model are the biological and fishing data described previously (Table 8.13). A maximum-likelihood model was used to estimate quantities (and their uncertainty) of interest to the management of the Australian herring stock and were determined using the AD Model Builder package.

Model for Australian herring on the west coast of Western Australia

The number of Australian herring (region 1) of sex *s* aged a (where $0 \le a \le x$) were calculated by:

$$N^s_{y,a} = \begin{cases} R^s_y & \text{if } a=0 \\ N^s_{y-1,a-1} \sum_l p^s_{l/a-1} U^s_{y-1,l} e^{-M} & \text{if } 0<a<x \\ N^s_{y-1,a-1} \sum_l p^s_{l/a-1} U^s_{y-1,l} e^{-M} + N^s_{y-1,a} \sum_l p^s_{l/a} U^s_{y-1,l} e^{-M} & \text{if } a=x \end{cases}$$

where $N^s_{y,a}$ is the number of Australian herring of sex s and age *a* in the stock at the start of year *y*,

R^s_y is the number of age 0 fish of sex s recruiting to the fishery in year *y*,

M is the natural mortality (year^{-1}),

$U^s_{y,l}$ is the annual survival from exploitation such that:

$$U^s_{y,l} = (1 - S^{s,rec}_l H^{rec}_y)(1 - S^{s,com}_l H^{com}_y),$$

$S^{s,f}_l$ is the selectivity for recreational and commercial fisheries (*f*=*rec* and *com*) for fish of sex *s* in the mean length class with mid-length *l*,

$p^s_{l/a}$ is the proportion of fish of sex *s* and age *a* in the mean length class with mid-length *l*,

H^{com}_y is the commercial harvest rate which is assumed to be taken prior to the recreational harvest rate such that:

$$H^{com}_y = C^{com}_y / Be^{com}_y ,$$

H^{rec}_y is the recreational harvest rate such that:

$$H^{rec}_y = qE^{rec}_y .$$

C^{com}_y and E^{rec}_y are the observed annual commercial catch and annual recreational effort respectively.

Be^f_y is the exploitable biomass available to fishing sector f (*f*=*rec* and *com*) calculated as:

$$Be^f_y = \sum_s \sum_a \sum_l S^{s,f}_l N^s_{y,a} p^s_{l/a} w_l ,$$

where: w_l is the weight of fish.

The number of 0 year olds at the start of each year was determined by the Beverton-Holt spawner-recruit curve such that:

$$R_y = \frac{E_y}{\alpha + \beta E_y} \text{ and } R^s_y = p_s R_y ,$$

where p_s is the proportion of recruits that are sex *s* and was set as a constant such that the ratio of females to males was 1:1. ie $p_s = 0.5$,

E_y is the total number of eggs produced by females (*s*=females) each year such that:

$$E_y = \sum_a \sum_l N^s_{y,a} p^s_{l/a} m^s_l f^s_l ,$$

m^s_l and f^s_l are the maturity and fecundity at length of female fish respectively,

α and β are the parameters of the stock recruitment relationship determined from the virgin recruitment (R_0) and the steepness (*h*) of the stock recruitment relationship. The steepness parameter was assumed to be 0.9 indicating a stable population.

α was calculated as:

$$\alpha = \frac{(1-h)}{4h} \frac{E_0}{R_0} ,$$

and β was calculated as:

$$\beta = \frac{(5h-1)}{4hR_0} ,$$

The initial population was considered in pre-exploited equilibrium such that:

$$N_{0,a}^{s} = \begin{cases} p_s R_0 & \text{if } a=0 \\ N_{0,a-1}^{s} e^{-M} & \text{if } 0<a<x \\ N_{0,a-1}^{s} e^{-M} \;/(1-e^{-M}) & \text{if } a=x \end{cases},$$

The virgin egg production for females (*s*=females) was calculated as:

$$E_0 = \sum_a \sum_l N_{0,a}^{s} p_{l/a}^{s} m_l^{s} f_l^{s} \; .$$

The virgin exploitable biomass was calculated as:

$$Be_0^{f} = \sum_s \sum_a \sum_l S_l^{s,f} N_{0,a}^{s} p_{l/a}^{s} w_l \; .$$

Predicated recreational catches were calculated as:

$$\hat{C}_{y,a,l}^{s,rec} = S_l^{s,rec} H_y^{rec} N_{y,a}^{s} p_{l/a}^{s} (1 - S_l^{s,com} H_y^{com}) \, ,$$

such that the total number of fish of each age or of each length that are caught are determined by:

$$\hat{C}_{y,a}^{s,f} = \sum_l \hat{C}_{y,a,l}^{s,f} \;\text{ and }\; \hat{C}_{y,l}^{s,f} = \sum_a \hat{C}_{y,a,l}^{s,f} \;\text{ respectively,}$$

and the total mass of the catch is:

$$\hat{C}_y^{f} = \sum_s \sum_a \sum_l \hat{C}_{y,a,l}^{s,f} w_l \; .$$

The objective function was the negative of the logarithm of the likelihood and includes four contributions. These relate to fitting the observed catch and catch rate information, observed catch age and length composition:

$$L = \sum_{i=1}^{4} L_i$$

The contribution of the observed annual recreational catch (in weight) information (f = *rec*) of the logarithm of the likelihood function is based on the assumption that the errors in measuring the catch in mass are log-normally distributed with a CV of σ_c:

$$L_1 = \frac{1}{2\sigma_c^2} \sum_y (\ln(C_y^{rec}) - \ln(\hat{C}_y^{rec}))^2 \; .$$

The observations of commercial catch were used in estimating the harvest rate for the commercial fishery, and thus can not be used in fitting the model.

The contribution of the Western Australian west coast haul catch rate data for Cockburn Sound (k=1) and Geographe Bay (k=2) to the negative of the logarithm of the likelihood function is based on the assumption that fluctuations in catchability are log-normally distributed with a CV of σ_q:

$$L_2 = \frac{1}{2\sigma_q^2} \sum_k \sum_y (\ln(CPUE_y) - \ln(q^k Be_y^{com}))^2 \; .$$

The contribution of the age composition information to the negative of the logarithm of the likelihood function is based on the assumption that the age-structure information is determined from a random sample (η_a is the sample size) of fish from the catch:

$$L_3 = \eta_a \sum_s \sum_f (\sum_y \sum_a (P_{y,a}^{s,f} \ln(\hat{P}_{y,a}^{s,f}))),$$

where:

$$P_{y,a}^{s,f} = C_{y,a}^{s,f} / \sum_a C_{y,a}^{s,f} \text{ and } \hat{P}_{y,a}^{s,f} = \hat{C}_{y,a}^{s,f} / \sum_a \hat{C}_{y,a}^{s,f} .$$

The contribution of the length composition information to the negative of the logarithm of the likelihood function is based on the assumption that the length-structure information is determined from a random sample (η_l is the sample size) of fish from the catch:

$$L_4 = \eta_l \sum_s \sum_f (\sum_y \sum_l (P_{y,l}^{s,f} \ln(\hat{P}_{y,l}^{s,f}))),$$

where:

$$P_{y,l}^{s,f} = C_{y,l}^{s,f} / \sum_l C_{y,l}^{s,f} \text{ and } \hat{P}_{y,l}^{s,f} = \hat{C}_{y,l}^{s,f} / \sum_l \hat{C}_{y,l}^{s,f} .$$

Model for Australian herring on the southern coast of Australia

Australian herring are considered to be members of the South Australian assemblage (regions 4-6) of fish until they migrate to Western Australia, when they join the Western Australia assemblage (regions 2-3). Migration is assumed to be determined by maturation. Thus, the proportion of fish that will migrate from South Australia to Western Australia is determined as the proportion of the immature fish remaining in South Australia that will attain maturity during the past year. In determining the proportions that will mature, and hence migrate, calculations have been based on the mean length at age.

For fish of age *a* and sex *s*, the proportion that are mature was determined by:

$$m_{l_a}^s = \frac{1}{1 + e^{(-\ln(19)(l_a^s - L_{50}^s)/(L_{95}^s - L_{50}^s))}},$$

where the mean length at age *a* was calculated as:

$$l_a^s = L_\infty^s (1 - e^{-K^s (a + 0.5 - a_0^s)}).$$

The proportion that mature at age *a*+1 was given by:

$$m_{l_{a+1}}^s = \frac{1}{1 + e^{(-\ln(19)(l_{a+1}^s - L_{50}^s)/(L_{95}^s - L_{50}^s))}}$$

where the mean length at age *a*+1 was calculated as:

$$l_{a+1}^s = L_\infty^s (1 - e^{-K^s}) + l_a^s e^{-K^s} .$$

The proportion of the immature fish at age a that become mature by age a+1 was determined by:

$$\gamma_a^s = \frac{m_{l_{a+1}}^s - m_{l_a}^s}{1 - m_{l_a}^s},$$

and represents the proportion of fish of age a and sex s in South Australian that will migrate to Western Australia.

The number of fish in the Western Australia assemblage of Australian herring (regions 2-3) of sex *s* and age *a* (where 0≤*a*≤*x*) was calculated by:

$$N_{y,a}^{s,WA} = \begin{cases} p_r R_y^s & \text{if } a=0 \\ N_{y-1,a-1}^{s,WA} \sum_l p_{l/a-1}^s U_{y-1,l}^{s,WA} e^{-M} + N_{y-1,a-1}^{s,SA} \sum_l p_{l/a-1}^s U_{y-1,l}^{s,SA} U_{y-1,l}^{s,WA} \gamma_{a-1}^s e^{-M} & \text{if } 0<a<x \\ N_{y-1,a-1}^{s,WA} \sum_l p_{l/a-1}^s U_{y-1,l}^{s,WA} e^{-M} + N_{y-1,a}^{s,WA} \sum_l p_{l/a}^s U_{y-1,l}^{s,WA} e^{-M} + & \text{if } a=x \\ \quad N_{y-1,a-1}^{s,SA} \sum_l p_{l/a-1}^s U_{y-1,l}^{s,SA} U_{y-1,l}^{s,WA} \gamma_{a-1}^s e^{-M} + N_{y-1,a}^{s,SA} \sum_l p_{l/a}^s U_{y-1,l}^{s,SA} U_{y-1,l}^{s,WA} \gamma_a^s e^{-M} & \end{cases}$$

and the number in the South Australia assemblage of Australian herring (regions 4-6) of sex *s* and age *a* (where 0≤*a*≤*x*) was calculated by:

$$N_{y,a}^{s,SA} = \begin{cases} (1-p_r) R_y^s & \text{if } a=0 \\ N_{y-1,a-1}^{s,SA} \sum_l p_{l/a-1}^s U_{y-1,l}^{s,SA} (1-\gamma_{a-1}^s) e^{-M} & \text{if } 0<a<x \\ N_{y-1,a-1}^{s,SA} \sum_l p_{l/a-1}^s U_{y-1,l}^{s,SA} (1-\gamma_{a-1}^s) e^{-M} + N_{y-1,a}^{s,SA} \sum_l p_{l/a}^s U_{y-1,l}^{s,SA} (1-\gamma_a^s) e^{-M} & \text{if } a=x \end{cases}$$

where $N_{y,a}^{s,i}$ is the number of Australian herring of sex s and age *a* in the *i* assemblage (*i* = *WA* or *SA*) at the start of year *y*,

R_y^s is the number of age 0 fish of sex s recruiting to the fishery in year *y*,

M is the natural mortality (year^{-1}),

p_r is the proportion of recruits remaining in Western Australia waters,

$p_{l/a}^s$ is the proportion of fish of sex *s* and age *a* with the mean length in the mid-length class *l*

$U_{y,l}^{s,i}$ is the annual survival from exploitation for states *i*=*WA* or *SA* such that:

$$U_{y,l}^{s,i} = (1 - S_l^{s,i,rec} H_y^{i,rec})(1 - S_l^{s,i,com} H_y^{i,com}),$$

$H_y^{i,com}$ is the commercial harvest rate for fisheries:

$$H_y^{i,com} = C_y^{i,com} / Be_y^i,$$

$H_y^{i,rec}$ is the recreational harvest rate such that:

$$H_y^{i,rec} = q^i E_y^{i,rec},$$

$S_l^{s,i,f}$ is the selectivity for recreational and commercial fisheries (*f=rec* and *com*) in the states *i=WA* or *SA* for fish of sex *s* with mean length in the mid-length class *l*.

$C_y^{i,com}$ and $E_y^{i,rec}$ are the observed annual commercial catch and annual recreational effort in the states *i=WA* or *SA* respectively. $Be_y^{i,f}$ is the exploitable biomass available to fishing sector f (*f=rec* and *com*) in the states *i=WA* or *SA* calculated such that:

$$Be_y^{i,f} = \begin{cases} \sum_s \sum_a \sum_l S_l^{s,WA,f} N_{y,a}^{s,WA} p_{l/a}^s w_l + S_l^{s,WA,f} N_{y,a}^{s,SA} p_{l/a}^s U_{y,l}^{s,SA} \gamma_a^s w_l & \text{if state } i = WA \\ \sum_s \sum_a \sum_l S_l^{s,SA,f} N_{y,a}^{s,SA} p_{l/a}^s w_l & \text{if state } i = SA \end{cases},$$

where: w_l is the weight of fish.

The numbers of catch at age and catch at length samples collected during 1996-1998 from the haul fishery on the south coast of Western Australia were not adequate for separation into their respective years for use in the model. Since the selectivity functions of the haul net and trap net fisheries were similar (see this Chapter) and the majority of the commercial catch is taken by trap net, the total commercial catch on the south coast was treated at trap net catches.

The number of 0 year olds at the start of each year was determined the Beverton-Holt spawner-recruit curve:

$$R_y = \frac{E_y}{\alpha + \beta E_y} \text{ and } R_y^s = p_s R_y,$$

where p_s is the proportion of recruits that are of sex s and was set as a constant such that the ratio of females to males was 1:1. ie $p_s = 0.5$,

E_y is the total number of eggs produced by female (*s=females*) each year such that:

$$E_y = \sum_a \sum_l N_{y,a}^{s,WA} p_{l/a}^s m_l^s f_l^s + N_{y,a}^{s,SA} p_{l/a}^s U_{y,l}^{s,SA} \gamma_a^s f_l^s,$$

m_l^s and f_l^s are the maturity and fecundity at mean length of female fish respectively,

α and β are the parameters of the stock recruitment relationship determined from the virgin recruitment (R_0) and the steepness (*h*) of the stock recruitment relationship. The steepness parameter was assumed to be 0.9 indicating a stable population.

α was calculated as:

$$\alpha = \frac{(1-h)}{4h} \frac{E_0}{R_0},$$

and β was calculated as:

$$\beta = \frac{(5h-1)}{4hR_0},$$

The initial population was considered in pre-exploited equilibrium such that:

$$N_{0,a}^{s,WA} = \begin{cases} p_s p_r R_0 & \text{if } a=0 \\ N_{0,a-1}^{s,WA} e^{-M} + N_{0,a-1}^{s,SA} \gamma_{a-1}^{s} e^{-M} & \text{if } 0<a<x \\ N_{0,a-1}^{s,WA} e^{-M} /(1-e^{-M}) + N_{0,a-1}^{s,SA} \gamma_{a-1}^{s} e^{-M} + N_{0,a}^{s,SA} \gamma_{a}^{s} e^{-M} /(1-\gamma_{a}^{s} e^{-M}) & \text{if } a=x \end{cases},$$

and

$$N_{0,a}^{s,SA} = \begin{cases} p_s (1-p_r) R_0 & \text{if } a=0 \\ N_{0,a-1}^{s,SA} (1-\gamma_{a-1}^{s}) e^{-M} & \text{if } 0<a<x \\ N_{0,a-1}^{s,SA} (1-\gamma_{a-1}^{s}) e^{-M} /(1-(1-\gamma_{a}^{s}) e^{-M}) & \text{if } a=x \end{cases},$$

The virgin egg production for females (s=*females*) was calculated as:

$$E_0 = \sum_a \sum_l N_{0,a}^{s,WA} p_{l/a}^{s} m_l^{s} f_l^{s} + N_{0,a}^{s,SA} p_{l/a}^{s} \gamma_a^{s} f_l^{s}.$$

The virgin exploitable biomass was calculated as:

$$Be_0^{i,f} = \begin{cases} \sum_s \sum_a \sum_l S_l^{s,WA,f} N_{0,a}^{s,WA} p_{l/a}^{s} w_l + S_l^{s,WA,f} N_{0,a}^{s,SA} p_{l/a}^{s} \gamma_a^{s} w_l & \text{if state } i = WA \\ \sum_s \sum_a \sum_l S_l^{s,SA,f} N_{0,a}^{s,SA} p_{l/a}^{s} w_l & \text{if state } i = SA \end{cases}.$$

Predicated catches were calculated as:

$$\hat{C}_{y,a,l}^{s,rec,f} = \begin{cases} S_l^{s,WA,rec} H_y^{WA,rec} (N_{y,a}^{s,WA} p_{l/a}^{s} (1-S_l^{s,WA,com} H_y^{WA,com}) + \\ \quad N_{y,a}^{s,SA} p_{l/a}^{s} U_{y,l}^{s,SA} \gamma_a^{s} (1-S_1^{s,WA,com} H_y^{WA,com})) & \text{if state } i = WA \\ S_1^{s,SA,rec} H_y^{SA,rec} N_{y,a}^{s,SA} p_{l/a}^{s} (1-S_l^{s,SA,com} H_y^{SA,com}) & \text{if state } i = SA \end{cases}$$

such that the total number of fish of each age or of each length that are caught are determined by:

$$\hat{C}_{y,a}^{s,i,f} = \sum_l \hat{C}_{y,a,l}^{s,i,f} \text{ and } \hat{C}_{y,l}^{s,i,f} = \sum_a \hat{C}_{y,a,l}^{s,i,f} \text{ respectively.}$$

and the total mass of the catch is:

$$\hat{C}_y^{i,f} = \sum_s \sum_a \sum_l \hat{C}_{y,a,l}^{s,i,f} w_l .$$

The objective function was the negative of the logarithm of the likelihood and includes five contributions. These relate to fitting the observed catch and catch rate information, observed catch age and length composition and Barker Inlet recruitment index:

$$L = \sum_{j=1}^{5} L_j$$

The contribution of the observed recreational catch (in weight) information of the logarithm of the likelihood function is based on the assumption that the errors in measuring the catch in mass are log-normally distributed with a CV of σ_c:

$$L_1 = \frac{1}{2\sigma_c^2} \sum_i \sum_f (\sum_y (\ln(C_y^{rec,f}) - \ln(\hat{C}_y^{rec,f}))^2).$$

The observations of commercial catch were used in estimating the harvest rate for the commercial fishery, and thus can not be used in fitting the model.

The contribution of the Western Australian south coast trap net catch rate data ($i = WA$) to the negative of the logarithm of the likelihood function is based on the assumption that fluctuations in catchability are log-normally distributed with a CV of σ_q:

$$L_2 = \frac{1}{2\sigma_q^2}\sum_y (\ln(CPUE_y) - \ln(qBe_y^i))^2 .$$

The contribution of the age composition information to the negative of the logarithm of the likelihood function is based on the assumption that the age-structure information is determined from a random sample (η_a is the sample size) of fish from the catch:

$$L_3 = \eta_a \sum_i \sum_f \sum_s (\sum_y \sum_a (P_{y,a}^{s,i,f} \ \ln(\hat{P}_{y,a}^{s,i,f}))) ,$$

where:

$$P_{y,a}^{s,i,f} = C_{y,a}^{s,i,j} / \sum_a C_{y,a}^{s,i,f} \text{ and } \hat{P}_{y,a}^{s,i,f} = \hat{C}_{y,a}^{s,i,j} / \sum_a \hat{C}_{y,a}^{s,i,f} .$$

The contribution of the length composition information to the negative of the logarithm of the likelihood function is based on the assumption that the length-structure information is determined from a random sample (η_l is the sample size) of fish from the catch:

$$L_4 = \eta_l \sum_i \sum_f \sum_s (\sum_y \sum_l (P_{y,l}^{s,i,f} \ \ln(\hat{P}_{y,l}^{s,i,f}))) ,$$

where:

$$P_{y,l}^{s,i,f} = C_{y,l}^{s,i,f} / \sum_l C_{y,l}^{s,i,f} \text{ and } \hat{P}_{y,l}^{s,i,f} = \hat{C}_{y,l}^{s,i,f} / \sum_l \hat{C}_{y,l}^{s,i,f} .$$

The contribution of the Barker Inlet recruitment index to the negative of the logarithm of the likelihood function is given by:

$$L_5 = \frac{1}{2\sigma_I^2}\sum_y (I_{y,0} - \lambda R_y)^2 .$$

Model data and parameters

The maximum age (x) was taken to be 15 years, the sex ratio was assumed 1:1 (p_s=0.5), natural mortality (M) was assumed to be 0.4 and the steepness (h) was assumed to be 0.9 which indicates that the population is stable. The proportion of recruits was fixed at 0.49 remaining in Western Australia and 0.51 distributed to South Australia (see this Chapter). The other data used in the model are presented in Table 8.13 and has been described previous (see this Chapter).

The parameters estimated were R_0, q^{rec}, $q^{Cockburn\ Sound}$, $q^{Geographe\ Bay}$ in the assessment model developed for Australian herring on the west coast of Western Australia and were R_0, $q^{WA,\ rec}$, $q^{SA,\ rec}$, $q^{com\ (trap\ net)}$, λ in the assessment model developed for Australian herring on the southern coast of Australia. The factors $\frac{1}{2\sigma_c^2}$, $\frac{1}{2\sigma_q^2}$, $\frac{1}{2\sigma_I^2}$, η_a, η_l, used in the likelihood which reflect the uncertainty in each data source were set to one. Parameters of interest to management that were determined from the models include the virgin biomass, virgin exploitable biomass, exploitable biomass in 1978, 1988 and 1998 and the ratio of exploitable biomass in 1978, 1988 and 1998 to the virgin exploitable biomass.

Table 8.13 Data used in the models.

Data description		Data summary
Age-length matrix for each sex	$p_{l/a}^{s}$	
Length-weight relationship parameters for sexes combined	W_l	ϕ_1, ϕ_2
Maturity (migration) parameters for each sex	m_l^s	L_{50}^s, L_{95}^s
Fecundity parameters for females	f_l^s	ϕ_3, ϕ_4
Commercial catches for west coast and south coast of Western Australia and South Australia. Catches for the south coast of Western Australia were distinguished into trap net catch and other Recreational catches for west coast and south coast of Western Australia and South Australia	$C_y^{i,f}$	1952-1998 (Trap net fisheries distinguished since 1975) 1994-1996
Recreational fishing participation (effort) for west coast and south coast of Western Australia and South Australia	$E_y^{i,f}$	1952-1998
Catch at age samples for each sex from recreational and commercial fishing in the west coast and south coast of Western Australia and South Australia. Catch at age data were available for trap net and haul net fisheries respectively.	$C_{y,a}^{s,i,f}$	1996-1998
Catch at length samples for each sex from recreational and commercial fishing in the west coast and south coast of Western Australia and South Australia. Catch at length data were available for trap net and haul net fisheries respectively.	$C_{y,l}^{s,i,f}$	1996-1998 1977-1978
Selectivity parameters for each sex by recreational and commercial fishing in the west coast and south coast of Western Australia and South Australia. Selectivity parameters were available for trap net and haul net fisheries respectively.	$S_l^{s,i,f}$	$selL_{50}^{s,i,f}$, $selL_{95}^{s,i,f}$
CPUE from Cockburn Sound (1986-1997) and Geographe Bay (1989-1998) haul net fisheries and Trap net fishery (1976-1998) on the south coast of Western Australia	$CPUE_y^{i,f}$	Various years
Recruitment indices for Barker Inlet. Data from Barker Inlet is only available for 1981,1982,1984-1995 but extrapolated for other years using the correlation with the Fremantle sea level	$I_{y,0}$	1952-1998

Discussion

The stock assessment models for the west coast of Western Australia and southern coast of Australia were implemented in the AD Model Builder package and fitted to the available data. However, following the inconclusive results of fitting and detailed examination of the model structure, it was recognised that further enhancement of the model structure was necessary. The latter has been undertaken, and the modified versions of the models have been presented in this report. Fisheries WA aims to undertake the subsequent fitting of the data to these new models in the near future.

Future modelling of the Australia herring population will also need to consider the different measures of uncertainty. The sensitivity of the model parameter estimates to the likelihood factors $\frac{1}{2\sigma_c^2}$, $\frac{1}{2\sigma_q^2}$, $\frac{1}{2\sigma_I^2}$, η_a, η_l, should be carried out to determine the importance of each of the data sources. A sensitivity analyses could be used to determine whether catch at length data are adequate or if there is a need to continue collecting catch at age data. In addition, the sensitivity analysis could be used to determine the importance of continuing to collect an index of annual recruitment abundance. Another area of future modelling is to investigate the assumptions used in the model. One of the most important assumptions needing further investigation is the assumption in the model that the Australian herring population is composed of two stocks. This will involve future research to determine the movement of eggs/larvae, juvenile and adult Australian herring between the west coast of Western Australia and the southern coast of Australia. Another area requiring further research is determining the level of recreational catch and effort.

Various management measures were highlighted in this chapter. The possible outcome of these management measures could be investigated using harvest strategy evaluation and risk assessment. Harvest strategies and risk assessment were not undertaken as part of this research project, though these analyses will be carried out in the future. The importance of these analyses becomes apparent when considering the issues of resource allocation between the recreational and commercial sectors, and potential increases in exploitation by each fishing sector.

DIRECT BENEFITS AND BENFICIARIES

The beneficiaries of this project are the commercial and recreational fishing community, fisheries managers and the general community. The ultimate goals of the program are to conserve the Australian herring stock while optimising exploitation at sustainable levels by both the commercial and recreational sectors. The wider community will benefit by the increased understanding of the biology of this important resource.

At the conclusion of this project, the beneficiaries of this research remain the commercial and recreational fishing community, fisheries managers and the general community in Western Australia and South Australia. This popular species is still the focus of resource sharing issues in both states and the information collected during this project will assist with resolving management issues. It is also clear that a management strategy which involves both Western Australia and South Australia should be developed as this fishery straddles both states and comprises one biological stock.

FURTHER DEVELOPMENT

There are several aspects to the stock assessment Australian herring research project which warrant further investigation and development.

The biological parameters of age and length, discussed in chapter 2, could be used to generate an age at length key. This key could be valuable to Fisheries Research., Fisheries WA, for the purpose of streamlining the monitoring of the commercial catches of the Australian herring trap net fishery. Further examination of the inter-annual variation in age composition data for each of the fisheries in 1996-98 would assist in the correlation between recruitment indices and CPUE's in this trap fishery.

Several aspects of the recruitment monitoring for the Western Australian herring fishery are being further investigated as part of FRDC Project 99/153. This project is only examining the W.A.` component of the Australian herring population.

FRDC Project 99/153 aims to develop a standard, statistically rigorous methodology for juvenile recruitment at key sampling sites; extend the 3 year timeframe for Australian herring data; extend this process to six other commercially and recreationally valuable species; and improve the precision of recruitment estimates by investigating the diel and lunar influences on fish catches.

The age-structured stock assessment model will be further developed to test the consequences of various harvest strategies on the annual catch levels.

CONCLUSIONS

Objective 1. Objective 1 was met with the following outcomes: Australian herring demonstrated a peak in spawning during May as determined from the hatching dates and the GSI data. Spawning is restricted to south-western Australia. Sexual maturity is reached at the end of the second or third year of life, when females are *ca* 197 and males *ca* 179 mm in length. Australian herring are multiple spawners during a limited spawning season. The age of the Australian herring sampled in south-western Australia contained fish between 0^+ - 10 years of age, however the 0^+ - 5^+ age classes dominated. In contrast, fish sampled in the eastern part of Western Australia and South Australia were mainly 0^+ - 2^+.

Daily rings were assessed for their use in ageing juvenile Australian herring. the otolith microstructure made it possible to count the rings until the fish was approximately 190 days old, after which time it was very difficult to read the growth increments. Hatching dates for the years 1996-98 occurred over 12 weeks from April to June. The growth rates for these juvenile fish were twice as great in Western Australia as South Australia.

Objective 2. Objective 2 was met with the following outcomes. The historic catch data from Western Australia, South Australia and Victoria was correlated with environmental factors (strength of Leeuwin Current), the recruitment index in eastern South Australia and market values, to explore the variation in commercial catch levels during the past decade for WA, SA and Victoria. The estuarine fisheries of the west and south coasts of WA have shown decreased catches in recent years, due in part to a diminished number of netting licences. However, it is not possible to determine whether the decrease in catches is a result of declining abundance as CPUE is not a reliable measure from this fishery. The commercial catch from the main WA commercial fishery, the south coast trap net fishery, has shown a decline in Australian herring catches corresponding with relatively high catches of Australian salmon and the low market demand for Australian herring as bait in the rock lobster industry.

The impact of these non-fishing factors on the annual Australian herring catch suggests that neither catch nor effort provide a good indicator of relative abundance. However, the CPUE was considered an indicator of relative abundance. The CPUE's were not significantly affected by the strength of the Leeuwin Current in the same year; however they were indicative of the strong year classes observed in the Gulf St Vincent (SA) nursery up to 4 years prior to them recruiting to the trap fishery.

During the 1990's, the decline in catches in the SA hauling net fishery was due mainly to a decline in targeted and non-targeted effort. This resulted from netting closures and a reduction in the number of netting licences. While the CPUE data are difficult to interpret, the variation in targeted CPUE's reflect the interannual variation in recruitment index in Barker Inlet with a on year lag in Gulf St Vincent and two years for Spencer Gulf.

Objective 3. Objective 3 was met with the following outcomes: A model of juvenile transport from Western Australia spawning grounds to coastal nursery habitats was developed, using indices of recruitment of young of the year fish, in order to explain the factors involved in recruitment success. Oceanic and wind induced currents and the fishes ability to swim were factors in the model. Interannual variation in recruitment success could be explained by variation in the strength of any of these factors. During years of strong transport the recruitment indices were stronger in eastern regions than western regions; while in years of weak transport the indices were stronger in western regions than eastern regions. Recruitment indices are being prepared for other coastal species, such as Australian salmon.

Maximising the effectiveness of the sampling program for Australian herring involved initial exploration of sampling sites and examination of historic records. Routine sampling occurred at a suite of sites in both Western Australia and South Australia. Day and night samples were collected during the spring of 1998 in WA and SA. This short experiment indicated that the 0^+ Australian herring are more abundant during the day than the evening in Western Australia, while the 1^+ and older fish were more abundant at night in South Australia. These results have been used to develop a new sampling regime in each state to maximise our catches of the young of the year Australian herring.

Objective 4. Objective 4 was met with the following outcomes: Movement and stock discrimination were examined using three techniques; tagging, allozyme electrophoresis and stable isotope analysis of otolith carbonate. The tagging study of the movement patterns of Australian herring showed that while many of the recaptures were local to the tag site, a small proportion moved from the south coast to the west coast, north of Perth. All of the tag recoveries from fish originally tagged in Geographe Bay, on the west coast, were local. The results of the tagging experiment are similar to those of an earlier tagging operation in the 1950's. The degree of movement suggests that fish move from south-eastern to south-western Australia with a small proportion of tagged fish moving on to the west coast of WA. These results complement the allozyme electrophoresis and stable isotope analysis of otolith carbonate studies and together suggest that Australian herring form one biological stock across their geographic range.

The vulnerability of Australian herring to capture was examined through gear selectivity functions (Chapter 8). The results indicated that the recreational sector are targeting similar size and sex fish in all locations and are generally catching smaller fish than the commercial sector.

Objective 5. Objective 5 was met with the following outcomes: Two age structured stock assessment models have been developed, one for the west coast of Western Australia and one for the southern coast of Australia, using data collected during this project and historic information. It was recognised that further enhancement of the stock assessment models was necessary as the results from testing the model with data were inconclusive. Continued testing and development of the models will be undertaken by Fisheries Western Australia. The stock assessment models will be used by Fisheries

Western Australia and South Australian Research and Development Institute on an annual basis to assess the status of Australian herring.

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APPENDIX 1: INTELLECTUAL PROPERTY

not applicable

APPENDIX 2: STAFF

Fisheries Western Australia

Ian Keay - Technical Officer

SARDI

Dr Keith Jones - Program Leader, Marine Scalefish.

Mr Wetjens Dimmlich - Project Leader (SA), Herring Research

Mr David Fleer - Technical Officer, Herring Research.

Murdoch Univeristy

Margaret Platell

Dave Fairclough - Honours Student

PEOPLE ASSISTING

FISHERIES WESTERN AUSTRALIA

Rick Allison

Suzy Ayvazian

Sally O'Connor

Joshua Brown

Gabrielle Nowara

Chris Dibden

Recreational Fishers

Jim Rowett - Esperance

Kevin Nickols - Esperance

Laurie Birchall - Perth

Terry Anderson - Albany

Rick Allison - Perth

Ian Keay - Perth

Dave Fairclough - Perth

Commerical Fishers

Barry and Shane Smith - Denmark

Dick Lear - Busselton

SARDI

Casual Staff

Keith Evans

Paul Jennings

Graham Hooper

Andrea Browne

Angela Lines

Scott Davids

Volunteer Staff

Mary Lawrence

Brendon Whitehorn

Recreational Fishers

Ken Atkins - Venus Bay

Clay Marshall - Elliston

Bill Klavey - President, Pt Lincoln Angling Club

Paul Williams - Adelaide

Commercial Fishers

Alan Suter - Professional Fisher, Ceduna

Sam Starkey - Professional Fisher, Steaky Bay

Des and Michael Slattery - Professional Fisher and Fish Processor, Pt Pirie

Craig Aitcheson - Professional Fisher, Pt Pirie

Bill Smith - Professional Fisher, Pt Pirie

Len Famazos - Fish Processor, Adelaide

Ern and Wendy Hendry - Professional Fisher and Fish Processor, Warooka

Tim Hill - Professional Fisher, Pt Vincent

Robert Butson - Professional Fisher, Pt Wakefield

Jeff Wait - Professional Fisher, Adelaide